ESTIMATION OF GROUND MOTION CHARACTERISTICS AND DAMAGE DISTRIBUTION IN GOLCUK, TURKEY, BASED ON MICROTREMOR MEASUREMENTS

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ABSTRACT

Microtremor measurement using one sensor was conducted at five sites in Golcuk, Turkey, across the damaged area due to the 1999 Kocaeli earthquake, and the horizontal-to-vertical (H/V) spectral ratios of microtremor for the sites were determined. The inverse analyses of the H/V data successfully resulted in the two-dimensional shear wave velocity (V_S) profile down to the bedrock. With this profile, ground motions during the main shock were simulated using two-dimensional response analysis, and then strength demands of the ground motions were computed for a simplified building system. The evaluated ground and building responses are consistent with the damage distribution in the area. This indicates that the estimated V_S profile and ground motions are reasonable and that the microtremor H/V method is reliable evaluating site effects.

Introduction

The Kocaeli earthquake of August 17, 1999 destroyed over 60,000 masonry houses, and residential and office buildings in the northwest area of Turkey. In Golcuk, Kocaeli Province, in particular, a large number of medium-rise buildings sustained either partial or complete collapse typically of a soft first story. Figure 1 shows spatial distribution of collapsed building ratios in Golcuk, which is based on the results of the reconnaissance survey performed by Architectural Institute of Japan (AIJ) team (AIJ Reconnaissance Team, 1999). The damage to buildings was concentrated at several areas in the north of Ataturk street, which is the main street running in the east-west direction. The concentration of the building damage could be due to the effects of surface geology on ground motions, i.e., so-called "site effects." In fact, most of the northern area of the main street is located on a plain while the south is on a hill, where the building damage was slight.

In order to evaluate the site effects quantitatively, two- or three-dimensional shear wave velocity (V_S) profiles down to the bedrock should be properly determined. It is, however, difficult to estimate multi-dimensional deep V_S profiles using conventional geophysical methods with boreholes. For this purpose, the microtremor horizontal-to-vertical (H/V) spectrum method

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originally proposed by Nakamura (1989) has been developing for two- or three-dimensional soil profiling. Recent studies, for example, have indicated that the H/V spectrum of microtremor at a site reveals that of Rayleigh or surface waves (e.g., Tokimatsu, 1995; Arai and Tokimatsu, 2000) and that V_S profile at a site can be estimated by inverse analysis of microtremor H/V data (Arai and Tokimatsu, 1998). Based on the improved H/V method, microtremor measurement was performed in Golcuk and the two-dimensional V_S structure across the damaged area was estimated. With this V_S structure, in this paper, ground motions during the main shock were simulated by two-dimensional dynamic response analysis, and then strength demands of the ground motions were computed for a simplified building system.

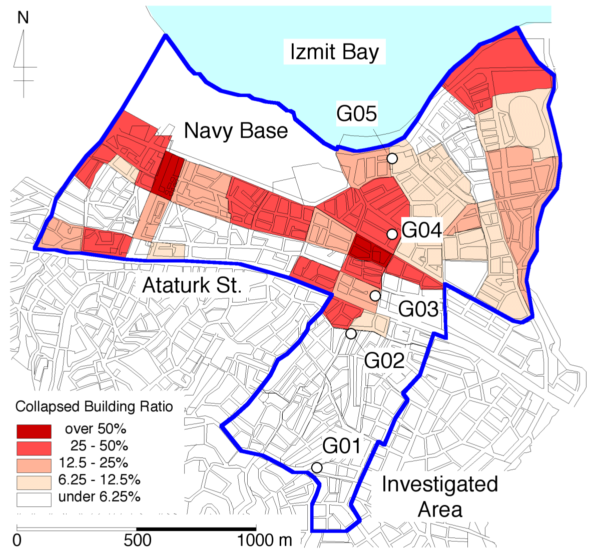

Figure 1. Map showing microtremor observation sites and distribution of damage to buildings in Golcuk (AIJ Reconnaissance Team, 1999).

The objectives of this paper are to introduce the use of microtremor H/V inversion method for two-dimensional V_S profiling and to examine the effects of the V_S structure on the ground motion characteristics and the building damages during the 1999 Kocaeli earthquake.

Microtremor Measurement

Microtremor measurement with a three-component sensor was conducted at five sites in Golcuk, hereinafter called Sites G01-G05. These sites are fallen on the line crossing the damaged area and extend from the southern hill northward to the shore of Izmit bay as shown in Figure 1. Sites G03-G05 are located in the heavily damaged area while Sites G01 and G02 are on the southern hill, where the building damage was slight.

The measurement system used consists of amplifiers, 16-bit A/D converters and a note-type computer, which are built in a portable case, with a three-component velocity sensor unit whose natural period is 1s. At each site, microtremor motions were measured for 5 minutes, and digitized with equi-interval of 0.01s. Ten sets of data with 2048 points each were selected from the digitized motions excluding traffic-induced vibrations, and used for the following analyses.

H/V Spectrum of Microtremor

The microtremor H/V spectral ratio, $(H/V)_m$, used in this study is defined as:

$$(H/V)_m = (S_{NS} S_{EW})^{1/2} / S_{UD} \tag{1}$$

in which S_{UD} is Fourier amplitude of vertical motion, and S_{NS} and S_{EW} are those of two orthogonal horizontal motions. In this definition, $(H/V)_m$ could correspond to the H/V spectral ratio of Rayleigh waves at a site (Tokimatsu, 1995; Arai and Tokimatsu, 2000).

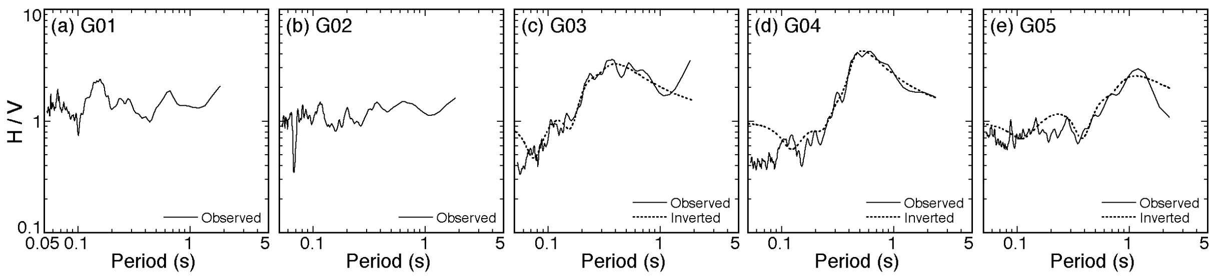

Figure 2. H/V spectra of microtremors compared with those of Rayleigh waves theoretically computed for the inverted soil layer models at Sites G01-G05.

The microtremor H/V spectra at Sites G01-G05 are shown in Figure 2 by solid lines. At Sites G01 and G02 located on the hill, the observed H/V spectra have no significant peaks. This suggests that the bedrock could outcrop at these sites. At Sites G03-G05 located on the plain, on the other hand, the observed H/V spectra have significant peaks. The H/V peak period increases northward, i.e., from 0.4s at Site G03 to 1.2s at Site G05. The variation of H/V peak period suggests that the V_S profile varies drastically along the line passing through Sites G01-G05.

V_S Profiling Using H/V Spectrum of Microtremor

According to the inverse analysis proposed by Arai and Tokimatsu (1998), the V_S profiles at Sites G01-G05 are estimated using the observed H/V data shown in Figure 2. In the inverse analyses, the following assumptions are made: (1) soil model at Sites G01 and G02 is represented by a half-space while that at the other sites a four-layered half-space; (2) soil models at these sites have a common bedrock; and (3) V_S values of the soil layers are those from the results of microtremor array measurement near Navy Base (Kudo *et al.*, AIJ Reconnaissance Team, 1999). The above assumption leaves only the thickness of the top three layers at Sites G03-G05 unknown, thus, which were sought so that the misfits between the H/V ratios of observed microtremor and theoretical Rayleigh waves be minimized.

Figure 3 shows the inverted V_S profiles with standard errors (e.g., Matu'ura and Hirata, 1982) of layer thickness at Sites G03-G05. The dashed-lines in Figure 2 indicate the theoretical H/V spectra for the inverted profiles at the sites. The theoretical H/V spectra are in good agreement with the observed ones. Besides, the evaluated errors of layer thickness at the sites are sufficiently insignificant. These results indicate that the estimated V_S profiles could be reliably reasonable.

The determination of the V_S profiles can result in a geophysical cross section along the line passing through Sites G01-G05 as shown in Figure 4. On the south of the main street, the bedrock with V_S over 1300m/s outcrops. The bedrock, however, dips on the immediate north of the main street creating a vertical gap of about 100m and then slopes gently northward.

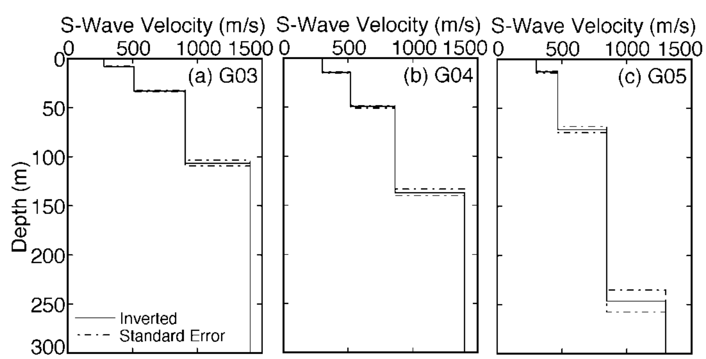

Figure 3. Inverted V_S profiles with standard errors of layer thickness at Sites G03-G05.

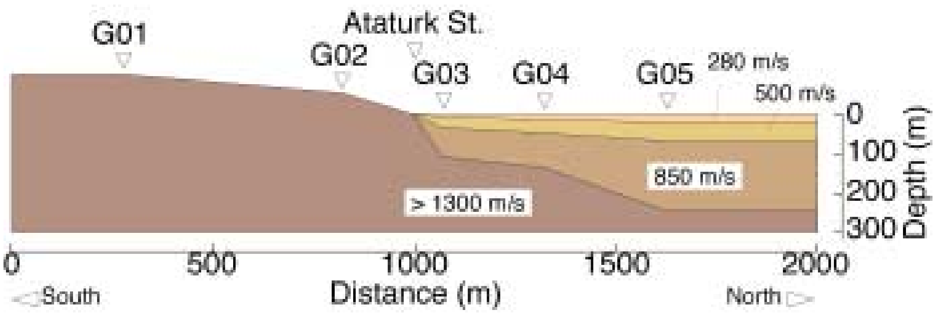

Figure 4. Estimated two-dimensional V_S profile along the line passing through Sites G01-G05.

Ground Motion Characteristics During The 1999 Kocaeli Earthquake

With the inverted V_S structure shown in Figure 4, two-dimensional equivalent-linear dynamic response analysis was performed using the finite element method (Lysmer *et al.*, 1975). In the analysis, transmitting and viscous boundaries were used on both sides and at the bottom of the soil model, respectively. The stronger NS horizontal motions recorded at Yarimca (YPT) station during the main shock, which is located about 10km northwest of Golcuk, was used as the input motion; thus, which is the vertically incident S-waves with in-plain particle motions. Peak acceleration and velocity of the input motion are 322cm/s^2 and 73cm/s, respectively.

Figure 5 shows the variation of peak ground accelerations (PGA) and velocities (PGV) of the simulated horizontal motions along the observation line. The simulated PGV are almost constant with locations and their values are 90-100cm/s. On the other hand, the PGA varies considerably along the line and their values lie in the range of 250-600cm/s^2. Figure 6 shows the variation of the collapse ratios of medium-rise reinforced concrete (R/C) buildings along the line (AIJ Reconnaissance Team, 1999). Comparing Figure 5 with Figure 6, the PGA values in the heavily damaged zone near Sites G03 and G04 exceed 500cm/s^2, and are larger than those in the other zone. This suggests that the PGA could have a significant effect on the damage to buildings in the area.

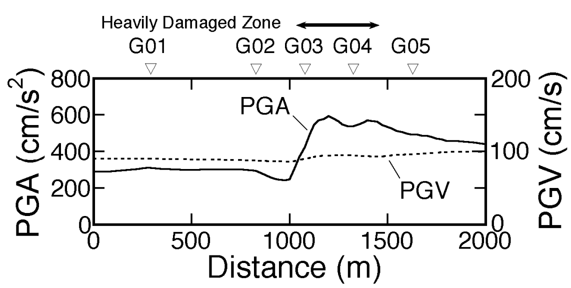

Figure 5. Variation of PGA and PGV of the simulated motions along the observation line.

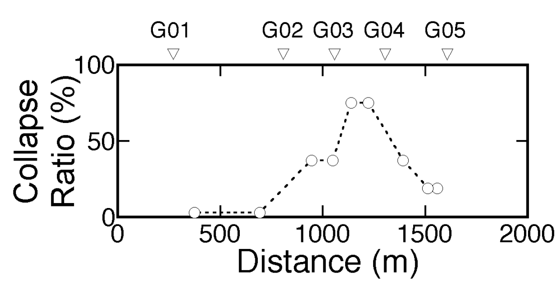

Figure 6. Variation of the collapse ratios of medium-rise R/C buildings along the observation line (AIJ Reconnaissance Team, 1999).

To investigate the possible reason why the PGA values in the heavily damaged zone near Sites G03 and G04 are largely amplified, amplitude ratios between the Fourier spectra of the simulated ground motions and those of the input motions, i.e., amplification factors were computed at Sites G01-G05 and are shown in Figure 7. The amplification factors at Sites G01 and G02 are almost unity for all periods, while those at Sites G03-G05 are larger than unity, and their peak periods are 0.2, 0.5, and 0.8s, respectively. These values are equal to or slightly less than the natural site periods of the vertically incident S-waves computed for the inferred soil profiles shown in Figure 3. This indicates that the large amplification of the PGA in the heavily damaged zone near Sites G03 and G04 could be due mainly to those for vertically propagating S-waves with periods less than 1s, i.e., so-called "site effects."

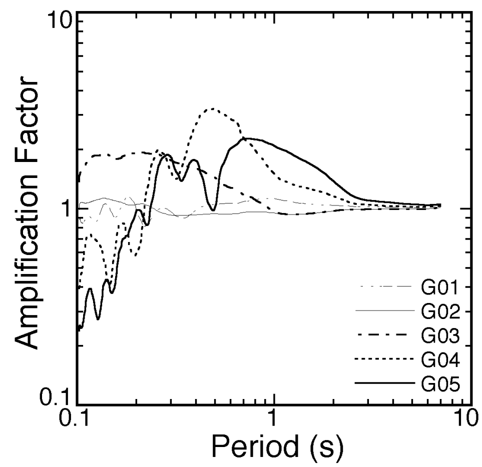

Figure 7. Amplification factors between Sites G01-G05 and the bedrock for vertically incident S-waves.

Evaluation of Building Damage

In order to examine the effects of the PGA on the building damage, strength demands of the simulated ground motions were computed for simplified single-degree-of-freedom (SDOF) building systems with elasto-plastic force-displacement relations. To determine displacement ductility demands and damping factors of the systems required in the analyses, microtremor measurement was performed at two R/C buildings near the observation line. These buildings are five-storied and have a similar structural system, but one is no damaged and the other heavily damaged. Figure 8 shows the amplification factors between the top and ground floors of these buildings estimated from spectral analyses of the microtremor data. Fundamental periods of the non-damaged building could be 0.3s, while that of the damaged one be almost 0.7s. This indicates that the maximum response ductility of medium-rise R/C buildings might be about/over 4 during the 1999 Kocaeli earthquake. Damping factor of the non-damaged building was also estimated from the observed amplification factors shown in Figure 8, and the estimated value is 0.06.

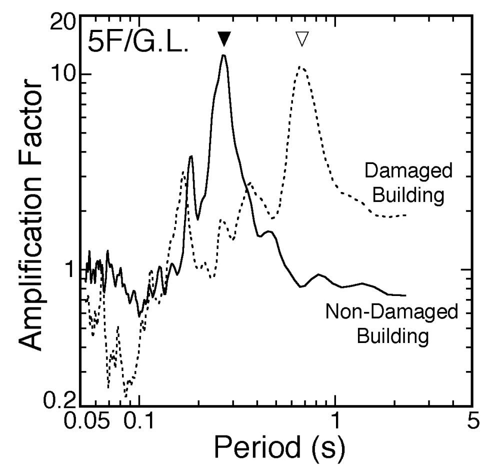

Figure 8. Amplification factors between the top and ground floors of the damaged and non-damaged buildings.

Based on the above results, displacement ductility demands μ used in the strength demand analyses are assumed to be equal to 2, 4, and 6, and damping factor of the SDOF system is taken equal to 0.06. Figure 9(a) shows spatial variations of the computed strength demand spectra along the line using the gradations shown in the legend, in which μ is taken equal to 4. Strength demand spectra in the heavily damaged zone have a significant peak at a period of 0.3s. This peak period is consistent with the observed natural period of the medium-rise R/C building shown in Figure 8. Then, spatial variations of the strength demands computed for the SDOF system with a natural period of 0.3s are shown in Figure 9(b), in which μ are taken equal to 2, 4, and 6. In each ductility demand, the spatial variation of the computed strength demands is in fairly good agreement with both that of the collapse ratios of medium-rise R/C buildings shown in Figure 6 and that of the PGA shown in Figure 5. This reveals the fact that the estimated V_S profiles and ground motions are reliably reasonable and that the damage distributions of the medium-rise R/C building in Golcuk could be mainly controlled by the PGA during the earthquake, in other words, by the site effects as discussed previously.

Conclusions

The two-dimensional V_S profile in Golcuk across the damaged area due to the 1999 Kocaeli earthquake was evaluated using the microtremor H/V inversion method. With this profile, ground motions during the earthquake were simulated by a two-dimensional response analysis, and then strength demands of the ground motions were computed for simplified SDOF building systems. The evaluated ground and building responses are consistent with the observed damage distribution in the area. This result indicates that the estimated V_S profile and ground motions are reasonable and reliable, and that the microtremor H/V method employed in this study could be reliable means for estimating the effects of surface geology on ground motion characteristics and building damages during earthquakes.

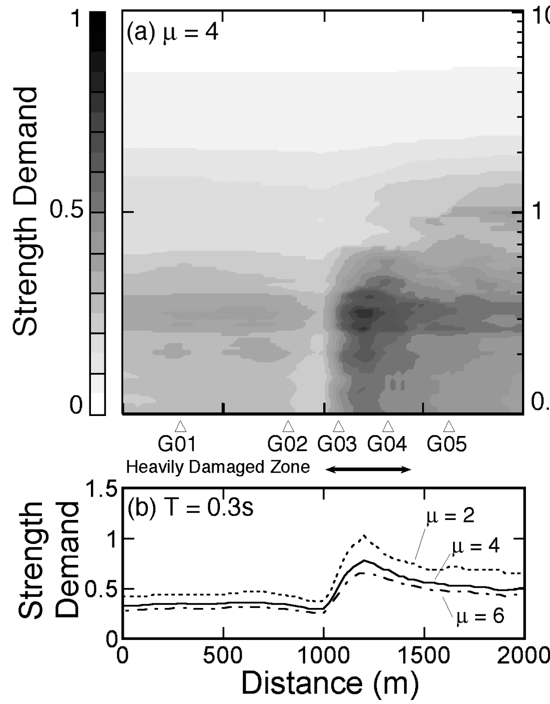

Figure 9. Variation of strength demand spectra computed for the simplified SDOF building systems along the observation line.

Acknowledgments

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