SEISMIC MICROZONATION STUDY BY COMPARING MEASURED MICROTREMORS WITH OBSERVED EARTHQUAKE MOTIONS

-A Case Study in the Damaged Area during the 2007 Noto Hanto Earthquake, Japan-

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ABSTRACT

The influence of local geology and soil conditions on the intensity of ground shaking and earthquake damage has been known for many years. Therefore, a significant part of damage observed in destructive earthquakes around the world is associated with seismic wave amplification due to local site effects. Microtremor measurements were carried out for 55 sites in Monzen-machi, Wajima city, where the damage had been concentrated during the 2007 Noto Hanto Earthquake. The site response (transfer functions) had been calculated by using individual site to reference spectral ratio of microtremors as well as horizontal to vertical spectral ratio. These resulted transfer functions are then compared with the transfer functions obtained from aftershock records for 7 sites where we have aftershock observation points. Also, the dynamic characteristics of two public reinforced concrete buildings have been estimated by using microtremors and then compared with dynamic characteristics which were calculated from aftershock records inside these buildings. The results show high amplification factors in the heavily damaged area due to site effects which can be estimated by microtremors as well as by aftershock records. The comparison between microtremors and observed earthquake motions demonstrate that microtremors can be considered as a powerful tool for estimating the earthquake site response as well as for evaluating the dynamic characteristics of building.

Keywords: Microzonation, Microtremors, Site Effect, Transfer Function, Dynamic Characteristics of Buildings

INTRODUCTION

A significant part of damage observed in destructive earthquakes around the world is associated with seismic wave amplification due to local site effects. Local site effect is generally summarized as the amplification factors of strong ground motions resulting from responses of local soils relative to incident seismic wave in the bedrock. Site transfer function, which has been extensively used to evaluate the local site effects, is defined as the ratios of Fourier amplitude spectra of earthquake recorded on soft soil to Fourier amplitude spectra of incident earthquake waves in the bedrock. Since deep borehole records (input motions at bed rock) are not so easy to be obtained, a reference stiff site which is supposed to be free of site effects or with minimum site effects is used as an alternative of in put motion at bed rock. Using earthquake data to calculate site transfer function gives very reliable results, but earthquake data are not often available. Site transfer function also can be estimated by boring exploration method that gives very accurate results. But, boring exploration method demands considerable manpower and substantial time as well as very high cost. On the other hand, using microtremors to evaluate the seismic site response becomes very popular in seismic microzonation studies due to its easiness and inexpensive application of

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microtremors. In 25th of March 2007, an earthquake with magnitude 6.9 according to JMA (Japanese Meteorological Agency) shook the offshore Noto peninsula, Ishikawa Prefecture, Japan. Intensity 6+ on JMA scale with maximum PGA 1.3g was observed at the seismic station in the Monzen Branch office in Monzenmachi, Wajima city during the main shock (National Earthquake for Land and Infrastructure Management and Building Research Institute, 2007). The aftershock observation had been carried out by Tokyo Institute of Technology (TIT_{ech}) by installing 11 seismic observation stations in the heavily damaged area (Yamanaka et. al. 2007). Also, aftershock records were collected from Building Research Institute (BRI) seismic stations which had been installed in the buildings of Wajima City Hall Office and Monzen Branch Office. Regarding the geological settings of Wajima city and the damage distribution, microtremor measurements had been carried out in Hashiride and Touge areas. Also, microtremor measurements have been carried out for Wajima City Hall Office and Monzen Branch Office, where we obtained aftershock records, in Wajima city.

The main goals of this study are:

- Earthquake site response estimation by using microtremors.
- Estimation of dynamic characteristics of building by using microtremors.
- Verifying the accuracy and the applicability of microtremors in microzonation studies by comparing them with observed earthquake motions.

BACKGROUND THEORY

Site transfer function has been extensively used to evaluate the local site effects (Borcherdt 1970). Earthquake data as well as microtremors have been widely used to estimate site effects. Since earthquake data are not often available, using microtremors to estimate local amplification has attracted many researchers for a long time ago. Microtremors are the background vibration of the earth from artificial sources such as traffic, industrial machines and so on. The period of Microtremors ranges from 0.05 sec to 2 sec and their amplitude is less than several microns (Kanai 1961). Kobayashi et al. (1985) compared the acceleration response spectra (for 5% damping) of the main shock of Mexico City earthquake with the Fourier velocity spectra of the microtremors. The comparison showed good agreements in spectral shape. They considered empirically that the Fourier velocity spectra of microtremors reflect the transfer function of S-wave in layered soil ground. They considered that spectral ratio of acceleration response spectrum of the main shock and Fourier velocity spectrum of microtremors would be equivalent to the acceleration response spectrum of the incident waves from seismic bedrock during the main shock. Then the product of this spectral ratio with Fourier spectrum of microtremors will indicate the inferred acceleration response spectrum at the ground surface during the main shock. This method had been used in Mexico City to predict strong ground motions due to the Michoacan, Mexico earthquake of Sep. 19th, 1985. On the other hand, Nakamura (1989) popularized the method of recording microtremors with a three-component seismometer and producing an estimation of site geological conditions from horizontal-over-vertical spectral ratio. He assumed that H-over-V spectral ratio is similar to transfer function for horizontal motion of surface layer with no need for any time restriction on microtremor measurements.

OBSERVATIONS

Aftershock Observation

Aftershock observation was conducted in the heavily damaged areas (Hashiride, Touge and Kuroshima) by installing 11 seismic accelerometers. The heavily damaged areas are located in a narrow valley along Hakka River with a width of 1 to 2 km. The three seismic observation stations (L1, L2 and L3) as well as the five stations (L4, L5, L6, L7 and D1) were installed in Hashiride and Touge areas, respectively. Hashiride and Touge areas are sandwiched by the mountains in the northern and southern sides of the valley along Hakka River where the Quaternary alluvial layers deposited over Tertiary rock. The thickness of Quaternary alluvial deposits becomes less towards the mountains where the Tertiary rocks become closer to the surface. L1 and L4 stations are located near the mountain foot where Tertiary tuff and Tertiary sandstone are placed, respectively. L2, L3, L5, L6 and L7 stations are located in the Quaternary alluvial layers, while D1 station is located on the Terrace deposits which is classified into different geological conditions from the others in Touge area. K1, K2 and K3 seismic observation stations were installed in Kuroshima area which is characterized by its steep slope from the coast. Figure 1 shows the surface geological map (Editing Committee of Engineering Geological Map in Hokuriku District, 1990) with the location of aftershock observation stations. Three hundreds and twelve aftershocks were recorded by these stations. Also, 9 aftershocks in Wajima City Hall Office and 34 aftershocks in Monzen Branch Office building were recorded by Building Research Institute (BRI) seismic observation stations.

Copyright problem

Figure1. Surface geological maps of Monzenmachi town (after, Editing Committee of Engineering Geological Map in Hokuriku District, 1990) with the location of aftershock observation stations

Microtremors Observation

Microtremor measurements were carried out using very high sensitive seismometers with servo system. The sensor can observe ground motion for the period ranging from 0.1 Hz to 100 Hz. The resolution is 1.5 * 10^{-6} m/sec.

Regarding the geological settings of Wajima city and the damage distribution during 2007 Noto Hanto earthquake, 55 microtremor measurements were carried out in Monzenmachi town where the heavy damage was observed including the sites of aftershock observation stations. Twenty-eight microtremor measurements were carried out in Hashiride area (including L1, L2 and L3) and 27 microtremor measurements in Touge area (including L4, L5, L6, L7 and D1). In order to obtain simultaneous microtremor records, continues measurements were carried out in L3 and L6 sites for Hashiride area and Touge area, respectively. While other microtremor measurements have a length of 300 sec. Figure 2 shows the locations of microtremor measurements in Monzenmachi town. Also, microtremor measurements were carried out for Wajima City Hall Office and Monzen Branch Office where we have aftershock records (recorded by BRI seismic stations). Three horizontal sensors have been used to measure microtremors on the building in order to obtain the natural period for normal and torsion modes, while damping factors of the building were calculated neither from microtremors nor from aftershocks.

Copyright problem

Figure 2. Points of Microtremor measurements in Monzen-machi area, circles refer to microtremor measurements in the site of aftershock observation, red and blue rectangular show Hashiride and Touge regions, respectively

COMPARISON OF MICROTREMORS & EARTHQUAKE SITE RESPONSE

Earthquake site to reference spectral ratios (L4 was defined as a reference site) have been calculated and the average spectrum has considered as a site transfer function. Regarding Nakamura's method, microtremor H/V spectral ratios represent earthquake transfer function for horizontal motion of surface layers. Therefore, microtremor H/V spectral ratios have been calculated and compared with earthquake site transfer functions obtained from aftershocks as shown in figure 3. Regarding microtremor site to reference method, horizontal spectral ratios of rover mobile site to reference site ($H_{rov.}/H_{ref.}$) represent the relative transfer function between these two sites. Then, the product of this ratio with observed spectra of earthquake motion in the reference site ($E_{ref.}$) represents the estimated spectra of earthquake motion in the rover site. Figure 4 shows the comparison of estimated earthquake motions (based on microtremor site to reference spectral ratios) with observed earthquake motions.

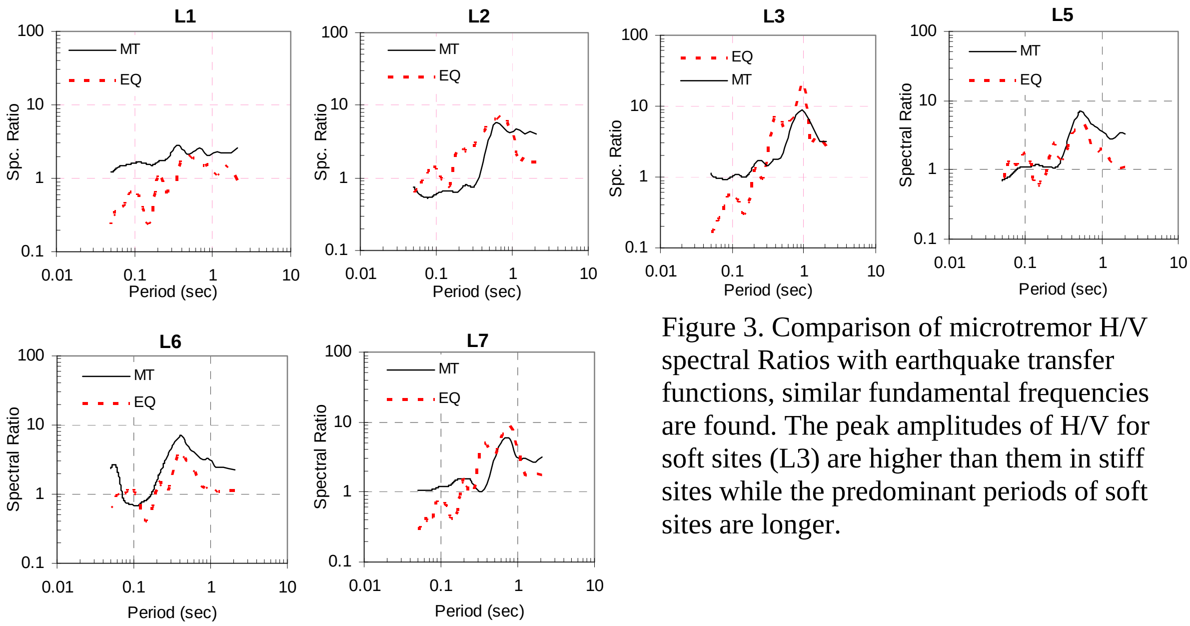
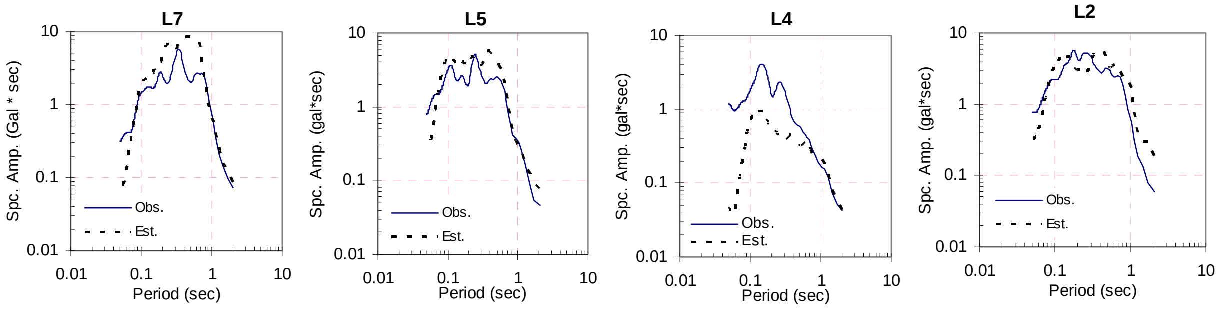


Figure 3. Comparison of microtremor H/V spectral Ratios with earthquake transfer functions, similar fundamental frequencies are found. The peak amplitudes of H/V for soft sites (L3) are higher than them in stiff sites while the predominant periods of soft sites are longer.



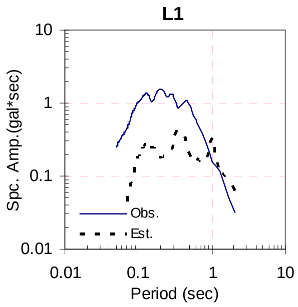


Figure 4. Comparison of estimated earthquake motions (based on microtremors) with observed earthquake motions, a good agreement has been observed especially when both sites (reference & rover) are located on soft deposit layers in the same basin, while the agreement becomes less for stiffer sites located out of the basin or at the basin edge (L1&L4). The less agreement for these sites is due to the quite big difference in the excitation of microtremors in these sites compared with soft sites.

COMPARISON OF MICROTREMORS & EARTHQUAKE BUILDING RESPONSE

Using aftershock records, Fourier spectra are calculated for Monzen Branch Office and Wajima City Hall Office in both directions and for top and first floors. Building transfer function, which is the spectral ratio of top floor to first floor, is calculated for each building in both directions. By using microtremors, Fourier spectra are calculated for Wajima City Hall office and Monzen Branch Office in both directions.

By comparing the Fourier spectra obtained from microtremors with building transfer function obtained from aftershock records, a good agreement in fundamental frequencies was observed as shown in figure 5.

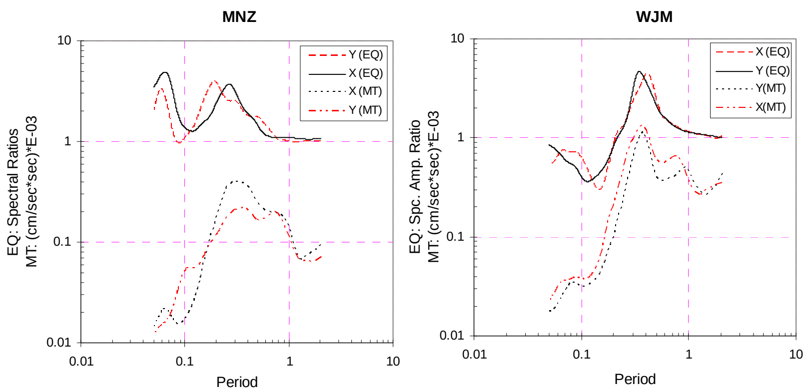


Figure 5. Microtremor Fourier spectra with earthquake transfer function of Monzen Branch Office (left) and Wajima City Hall Office

CONCLUSIONS AND RECOMMENDATIONS

The site transfer functions as well as building transfer functions had been estimated by using microtremors. Then compared with earthquake transfer functions and good agreements were found that confirmed the validity of microtremors in microzonation studies. As a result, following conclusions have been drawn:

Microtremor H/V spectral ratio, which is a simple technique and easy to be applied, gives reliable results for predominant period estimation while for amplification factors, we don't obtain a good agreement with earthquake amplification factor for all sites. But, it was remarkable that the peak amplitude of H/V ratios increased when the site effect appeared very clearly, which means the peak amplitude of H/V ratios gives a good indicator to identify significant site effects.

Microtremor site to reference spectral ratio, which requires simultaneous measurements in reference and rover sites, gives good agreements with observed earthquake records. But, a great attention must be paid for selecting the reference site which is supposed to have similar microtremor excitation conditions and located on soft sediments in the same basin. That means this method can not be applied to estimate the ground motions in stiff sites. But such stiff sites don't have significant site effects and we need not to worry about their site effects.

By comparing the microtremor transfer functions of two public RC buildings with earthquake transfer functions; we can verify the reliability of microtremors as a tool for evaluating building transfer functions.

More than one technique is recommended to estimate site response in order to obtain more reliable results. Comparison and complementation of different techniques are more probable to provide more accurate and adequate results.

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