STUDY ON SITE EFFECTS USING STRONG MOTION DATA OF BYT-NET ARRAY IN TURKEY

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ABSTRACT

Simultaneous separation of source, propagation path, and local site effects from observed strong motion records is carried out by an inversion method in the frequency range from 0.5 to 20 Hz for the purpose of empirical evaluation of the local site effects in different geological conditions. The analyzed data are S-wave portions of 74 accelerograms from 18 events observed at 14 sites in northwestern part of Turkey. These events are shallow earthquakes with magnitude from 3.0 to 5.2 and hypocentral distance from 10 to 90 km. A linear inversion method is applied to the logarithm of the observed spectra, and solutions for source spectra, inelasticity factor of propagation path for S-waves (Q_s-value), and factor of site amplification at each site are obtained in least squares sense. In the inversion, we assumed the factor of site amplification at the reference site 1101 is the same as that of theoretical amplification of S-waves to the soil model whose bottom layer has an S-wave velocity (V_s) around 2100 m/s. The factors of site amplification G_j(f) obtained in the present study at each site are verified by comparisons with the theoretical transfer functions. The estimated Q_s-value of the propagation path is modeled as $Q_s(f)=49.28f^{0.86}$. Furthermore, we compare the amplifications with average V_s in top 30 meters of the S-wave profiles (V_s30) and proposed linear empirical formula between them at each frequency.

Keywords: Accelerometer, Q_s-value, Site amplification, Average S-wave velocity

1. INTRODUCTION

There has been a great progress in the last decade in the study of strong ground motions and its engineering applications. Strong motion instrument arrays have been established for providing the basis for the estimation of strong ground motion in future earthquakes. Many numerical techniques for estimating the wave propagation in an irregular ground structure such as a sedimentary basin have been developed to explain the local amplification of seismic waves. The separation method using inversion technique was first proposed by Andrews (1982) to separate the source and propagation spectra from strong ground motion records. Iwata and Irikura (1986; 1988) extended the method in order to consider both S-wave attenuation through the propagation path and local site effect at each site.

Since the cities of Bursa and Yalova are located at the southern zone of the western extensions of the North Anatolian Fault (NAF) zone, importance of the seismic risk in the Bursa region appeared to be progressively more crucial. The improvement of seismic hazard knowledge and the last two large earthquakes near these cities, 17 August 1999, Golcuk-Kocaeli (Mw = 7.4) and 12 November 1999, Duzce earthquakes (Mw = 7.2), led us to carry out this study.

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2. DATA and DATA PROCESSING

The analyzed data are the S-wave portions of 74 accelerograms from 18 events observed at 14 sites. The maximum values of observed acceleration are from 0.067 to 95 gal. Figure 1 shows the observation sites and the locations of epicenters determined by Earthquake Research Department (ERD), These events are shallow earthquakes ranging in magnitude from 3.0 to 5.2 and in hypocentral distance from 10 to 90 km. Table 1 shows the geological period, geology and average shear-wave velocity V_s of the surface layer for 30 m. at each site.

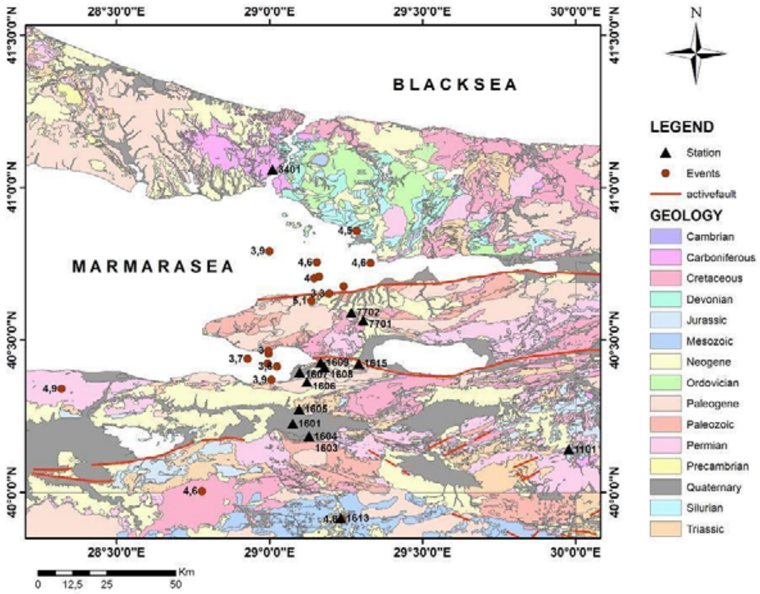

Figure 1. Locations of observation sites (triangles) and epicenters (circles) on the geology map.

Data processing is carried out by the following procedures. The S-wave portions of two horizontal components (NS and EW) of seismic ground motions are analyzed.

The data length for the analysis is from 2.5 to 25 s after onset of the S-waves, which is determined by considering the duration time of faulting at the source estimated from the earthquake magnitude by an empirical relation.

Fourier acceleration amplitude spectra of two horizontal components are computed by the method of the finite Fourier transformation and are summed vectorially. Before using the inversion scheme, the spectra were smoothed with a 91 point moving average method.

Table 1. Surface geology of the sites.

Station province	Station city town	Code	Gological Period	Geology	Vs30 (m/sec)
Bilecik	Merkez	1101	Lower Jurassic	Sandstone	901
Bursa	Merkez	1601	Quaternary	Silty sand - Clayey sand	251
Bursa	Merkez	1603	Quaternary	Talus	459
Bursa	Merkez	1604	Quaternary	Talus	459
Bursa	Demirtas	1605	Triassic	Metaclastic rock	497
Bursa	Gemlik	1606	Lutetian	Limestone covered by fine filling	303
Bursa	Gemlik	1607	Quaternary	Alluvial	370
Bursa	Gemlik	1608	Pliocene	Alluvial	366
Bursa	Gemlik	1609	Quaternary	Alluvial	228
Bursa	Keles	1613	Lower Pliocene	Conglomerate-Sandstone-Mudstone	412
Bursa	Orhangazi	1615	Pliocene	Pliocene sediments	348
Istanbul	Merkez	3401	Visean	Claystone-Siltstone	600
Yalova	Merkez	7701	Miocene	Claystone sediments	375
Yalova	Merkez	7702	Pliocene	Silty-clay stone and sandstone	359

Subsurface structures were investigated by MASW (Multi Channel Analysis of Surface Waves), and provide us with opportunities to calculate theoretical transfer functions. The transfer functions are calculated by one-dimensional multiple reflection theory of SH-waves (Haskell, 1960) with incident angle of 0 degree, and superposed in Figure 2.

3. METHOD OF ANALYSIS

3.1. Spectral Inversion

Several authors have tried to analyze observed seismograms to separate source, and path effects. Iwata and Irikura (1986; 1988) extend Andrew's equation to consider both S-wave attenuation throughout the propagation path and the local site effect at each site. They assume the quality factor of the wave attenuation is independent from the path and only depends on frequency (i.e., $Q_s = Q_s(f)$). Then the observed value of the S-wave Fourier amplitude spectra is expressed by

$$O_{ij}(f) = S_i(f)G_j(f)R_{ij}^{-1}\exp\left(-\pi R_{ij} f \big/ Q_s(f)Vs\right), \qquad (1)$$

where, $O_{ij}(f)$, observed S-wave Fourier amplitude spectrum of *i*-th event at *j*-th site; $S_i(f)$, source amplitude spectrum of i-th event; $G_j(f)$, factor of site amplification at *j*-th site; R_{ij}, hypocentral distance between i-th event and j-th site; $Q_s(f)$, average Q_s-value along the wave propagation path; V_s, average S-wave velocity along the wave propagation path (=3.7 km/s).

By taking logarithm, Eq. (1) is modified as follows,

$$\log \bar{O}_{ij}(f) = -\log R_{ref} + \log S_i(f) + \log G_i(f) - \log e(\pi R_{ij} f / Q_s(f)V_s), \qquad (2)$$

where e is Napier number, $\bar{O}_{ij}(f) = (R_{ij} / R_{ref})O_{ij}(f)$, and R_{ref} is the arbitrary normalized distance. With regard to $S_i(f)$, the effect of directivity due to the radiation pattern coefficient is neglected, since the observed waves in high frequency range are usually less influenced by the radiation pattern coefficient (e.g., Iwata and Irikura, 1986; 1988). For each frequency, *I* (source amplitude spectrum) + *J* (factor of site amplification) + 1 (Q_s-value) parameters from *I* x *J* data sets are determined in least squares sense.

The above inversion procedure allows us to separate the source spectrum, the Q_s values of propagation media, and the local site effect.

3.2. Choice of Reference Site

The site 1101 is located on the rock with V_s around 2100 m/s. For inversion, we assumed the factor of site amplification at a reference site 1101 is the same as that of theoretical amplification of S-waves to the soil model whose bottom layer has V_s around 2100 m/s.

4. RESULTS AND DISCUSSION

4.1. Local Site Effect

In the present study, we adopt the inversion scheme by Iwata and Irikura (1986; 1988). The inversion is executed by the least squares method with linear equality constraint by the singular value decomposition method.

Figure 2 shows the characteristics of site responses at the sites 1603, 1604 and 1606. $G_j(f)$ at the site 1101 was calculated by one-dimensional multiple reflection theory of SH-waves (Haskell, 1960) as the constrained condition for solving the inversion problem.

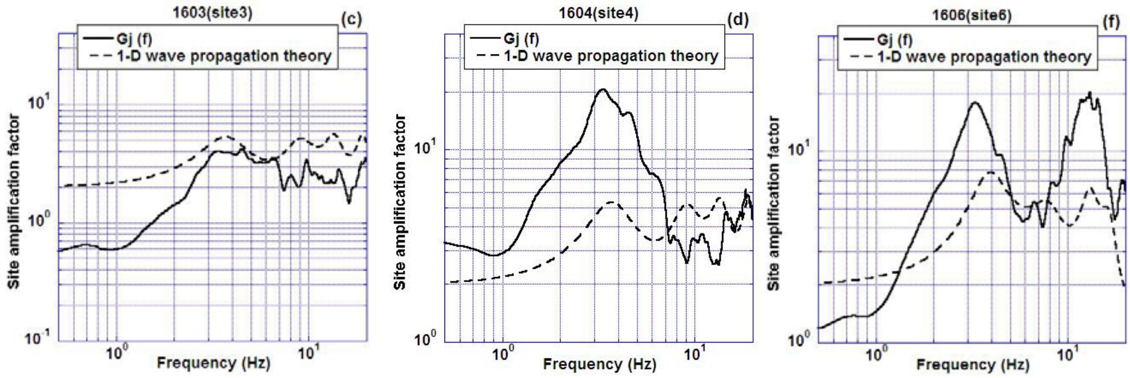

Figure 2. Example of the characteristics of site responses for the sites 1603, 1604 and 1606.

4.2. Source Spectra's and Q_s value

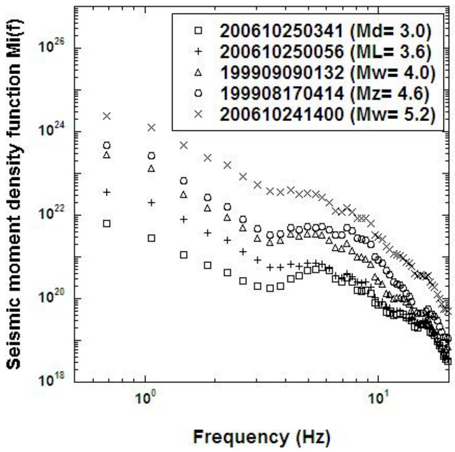

Figure 3. Examples of seismic moment density functions.

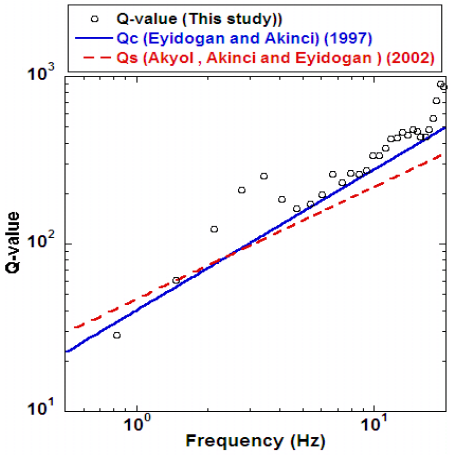

Figure 4. Q_s-values as a function of frequency. Circles indicates the Q_s-value evaluated in this study. Blue dash line show the results by Eyidogan and Akinci (1997) and red dash line by Akyol, Akinci and Eyidogan (2002) for the same region.

Source spectra $M_i(f)$ of 18 events are obtained by inversion analysis. Figure 3 shows examples of the source spectra for events with magnitude from 3 to 5.2. The source spectrum $M_i(f)$ is redefined from $S_i(f)$ so that the dimension is identical with that of seismic moment. $M_i(f)$ is called effective seismic moment. When $M_i(f)$ is converted from $S_i(f)$, we assume the shear-wave velocity of 4.0 km/s, density of 3.0 g/cm^3, and the average point-source radiation coefficient of 0.6, respectively. Q_s-value obtained by the inversion as a function of frequency and a formula of $Q_s(f) = 49.28f^{0.86}$ fits the result. The value of Q_s obtained in this study is very similar to the value of coda Q_c function $Q_c = 40f^{0.84}$ obtained by Eyidogan and Akinci (1997) using the single-scattering model and $Q_s = 46.59f^{0.67}$ obtained by Akyol et al. (2002) using nonparametric inversion method for the same region (Figure 4).

4.3 Average s-wave velocity and site amplification

In this study, we compared the site amplifications with average S-wave velocity in top 30 meters of the S-wave profiles (V_s30) and proposed linear relationships between them at each frequency (Figure 5). These relationships illustrate that V_s30 can be considered as a good indicator to estimate site amplification for lower frequencies. On the other hand, V_s30 is not good for estimating site effect for higher frequencies.

Furthermore, we also compared the amplifications with average S-wave velocity for different top meters of the S-wave profiles (V_s2, V_s5 and V_s10) and proposed linear relationships between them at 12 Hz (Figure 6). These relationships show that for higher frequencies V_s2, V_s5, V_s10 can be considered as a good indicator to estimate site amplification.

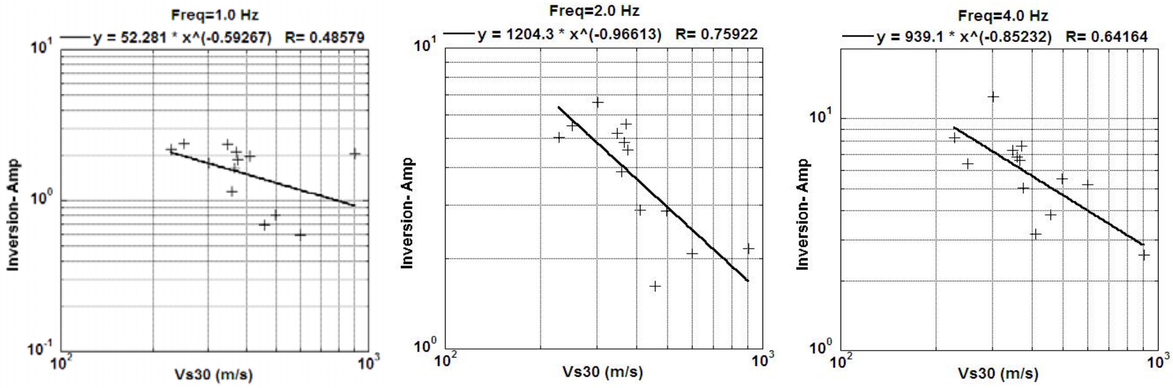

Figure 5. Relationship between site amplifications obtained from spectral inversion and V_s30 calculated for S-wave profiles at earthquake observation sites for different frequencies. Solid lines are linear regression lines of observed data shown by crosses and R is correlation coefficients.

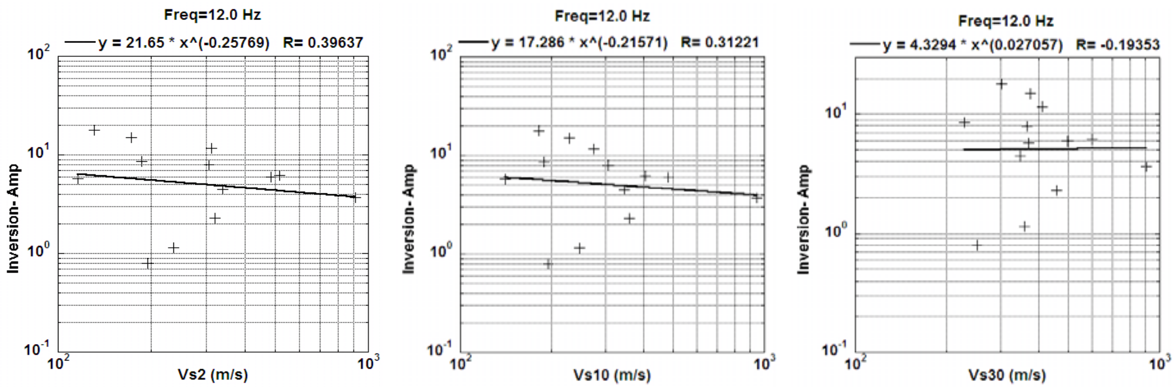

Figure 6. Relationship between site amplifications obtained from spectral inversion and different average S-wave velocities (V_s2, V_s5 and V_s30) calculated for S-wave profiles at earthquake observation sites for high frequency (12 Hz). Solid lines are linear regression lines of observed data shown by crosses and R is correlation coefficients.

5. CONCLUSIONS

The site amplification factors for S-waves were evaluated from strong motion records at 14 acceleration meter sites, one of which is located in Istanbul, 1 in Bilecik, and 12 in Bursa-Yalova Provinces, in the Northwestern region of Turkey and operated by Earthquake Research Department (ERD). The relation between local site effects and surface geology and also V_s30 are obtained from the site amplification factor for these sites. These results show that:

The value of Q_s obtained in this study is very similar to the value of coda Q_c function obtained by Eyidogan and Akinci (1997) and Q_s obtained by Akyol et al. (2002) for the same region.

Almost we obtained same fundamental frequencies (2 – 5 Hz) but different amplification values due to different surface geology effect.

Different $G_j(f)$ values in sites 1603 and 1604 are observed which means assumption of V_s profile for 1604 is not appropriate so more investigations for this site are recommended.

We obtained high amplification value for the site 1606. This high amplification can be explained by the fine filling cover around 9 – 13 m over the bedrock.

By comparing amplification functions with theoretical transfer functions, it is possible to say that they are generally in harmony, some differences are investigated, it is possible to foresee that sufficient depth is not obtained in the theoretical transfer functions calculated for these sites. In addition, difference in amplification values obtained with both methods may be related with insufficiency of selected constraint conditions, as mentioned before.

Considering the NHERP classification, the value of $G_j(f)$ is increased when V_s30 decreased in the frequency range 1-10 Hz.

Considering surface geology, our sites classified into three groups which are consistent with our results except site 1604 as mentioned before.

Relationship between site amplifications obtained from spectral inversion and V_s30 demonstrate that V_s30 a good tool to estimate site effect for lower frequencies. While for higher frequencies V_s2, V_s5, V_s10 are more recommended to estimate site effect.

These results show that earthquake waves approaching from different directions scatter under the local ground conditions and reach the site from more than one direction and also these results shown in this study may strongly influence the definition of seismic hazard around Bursa and Yalova cities. New studies are necessary for the understanding of seismic wave attenuation and amplification as consequences of travelling through poorly consolidated soils in Northwestern Anatolia.

AKNOWLEDGEMENT

I am really indebted to Dr. Toshiaki YOKOI - Building Research Institute - who sincerely advised and guided me during this work and I would like to express my deepest gratitude to my colleagues in my institute –Earthquake Research Department- and Mr. Hussam Eldein ZANIEH -Tokyo Institute of Technology- for their highly intensive efforts during this research.

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