MICROZONATION OF ADAPAZARI USING MICROTREMORS

by

Murat Ergenokon SELÇUK
B.S. in Civil Engineering, Yıldız Technical University, 1999

Submitted to the Kandilli Observatory and

Earthquake Research Institute in partial fulfillment of

the requirements for the degree of

Master of Science

in

Earthquake Engineering

Boğaziçi University

2004

MICROZONATION OF ADAPAZARI USING MICROTREMORS

APPROVED BY:

Assoc. Prof. Dr. Bilge SİYAHİ ....
(Thesis Supervisor)

Prof. Dr. Mustafa Ö. ERDİK ....

Assoc. Prof. Dr. Hayrullah KARABULUT ....

DATE OF APPROVAL ..27 JAN 2004..................

ACKNOWLEDGEMENTS

I want to express my deepest gratitude to my thesis supervisor Assoc.Prof.Dr. Bilge Siyahi, Assoc.Prof.Dr. Hayrullah Karabulut and Assoc.Prof.Dr. Eser Durukal for their guidance and Prof.Dr. Mustafa Erdik for his encouragement and providing the opportunity of participating in site work with the Japanese Group in Adapazarı. I would also like to thank Prof.Dr. Nuray Aydınoğlu and Prof.Dr. Özal Yüzügüllü for their valuable discussion during the courses.

Not to mention that, I am indebted to my parents and for their care, help and support throughout my life, so the thesis is dedicated to them. I also thank my brother Fatih for his precious guides.

I would like to sincerely thank Hüseyin Afşin Beker for his guidance and his cooperation that is very important for my success in this project.

Moreover, I thank Ali Yalçın Salkın for his guidance and help, not only as a friend but also as a member of my family.

I appreciate Mine Demircioğlu, Feyza Nur, Ayşegül Köseoğlu, Gökçe Tönük, Yeliz Çatalyürekli for their assistance to improve the thesis.

Also my thanks go to the following people for their many helpful comments and positive suggestions; Dr. Kemal Beyen, Hakan Akman, Yavuz Kaya, Muammer Özbek, Yavuz Güneş from seismology laboratory.

This thesis was supported by Bogazici University Research Found Grant No: 03T101.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Adapazarı, the provincial capital of Sakarya, is a city where strong earthquakes occurred and many buildings were completely destroyed during these earthquakes. Altough It is located at the most hazardous region in Turkey, on the North Anatolian Fault Zone (NAFZ) it did not prevent the development of the city particularly as a center of industry.

In this study, microtremor measurements of Adapazarı are used for classification, prediction of H/V ratios and evaluation of predominant periods of the soil. Thus, firstly properties and usages of microtremors are shown and the techniques used in microtremor analysis are studied in the first three chapters.

Furthermore, techniques used in microtremor data analysis to obtain H/V ratios are studied by means of a Matlab code. Then, site characteristics of Adapazarı such as, location, seismicity, damage recorded in the last earthquake (17 August 1999, M_w = 7.4), geological condition and soil properties are given in the following chapters.

Afterwards, according to the results of data analyses, the fundamental frequencies/periods are found for different zones of Adapazarı. Then different soil formations, which are Akveren and alluvial formations, are clearly distinguished after these data analyses.

Finally, microzonation for soil types, according to fundamental periods of the soils, is obtained as a result of more than 200 measurements conducted at Adapazarı.

ÖZET

Sakarya'nın merkez ilçesi Adapazarı birçok kuvvetli depreme maaruz kalmış ve bu depremler neticesinde yine birçok yapı tamamen yıkılmıştır. Kuzey Anadolu Fay Hattının yakınında, depremsellik açısından Türkiye'nin en riskli bölgesinde konumlanmış olması bile onun endüstrinin merkez ilçesi şeklinde büyümesini engelleyememiştir.

Bu çalışmada, Adapazarı'nın zemin sınıflaması, H/V oranının belirlenmesinde ve de zeminin hakim peryodlarının tayininde mikrotremor ölçümlerinden faydalanılmıştır. Bunun için ilk üç bölümde, öncelikli olarak mikrotremorların özellikleri, kullanım alanları ve de mikrotremor teknikleri hakkında detaylı bilgiler yeralmaktadır.

Daha sonra, Matlab kodlarından da faydalanılarak, mikrotremor data analiz yöntemleriyle zeminin H/V oranları hesaplanmıştır. İlerleyen bölümlerde ise Adapazarı'nın lokasyonu, depremselliği, son depremde aldığı hasar (Kocaeli 1999, M_w = 7.4), jeolojik yapısı ve zemin özellikleri hakkında bilgiler yeralmaktadır.

Akabinde, data analiz sonuçlarına dayanarak Adapazarı'nın değişik bölgeleri için hakim frekanslar/peryodlar saptanmıştır. Daha sonra yine bu data analiz sonuçlarına göre, şehrin iki ana zemin formasyonu olan Akveren ve alüvyon formasyonları açıkça ayırdedibilir hale getirilmiştir.

Sonuç olarak, Adapazarı'nda yapılmış 200'den fazla etüdün sonuçlarından, zeminlerin hakim peryodlarına göre, bölgenin zemin sınıflamasının mikrobölgeleme haritası elde edilmiştir.

1 INTRODUCTION

The main purpose of this study is to determine the resonance frequencies of the soils in Adapazarı to provide preliminary interpretation of the subsurface structure and its variation and to propose zonation based on the shape of the observed vibrative H/V spectral ratios.

Local site conditions and local effects are the most important factors when an earthquake strikes a populated area. As a result it becomes important to determine local dynamic behavior of soils and structures before seismic events.

Local site response may be evaluated by empirical and theoretical methods. Theoretical methods allow a detailed analysis of the parameters considered in the evaluation. However, they require detailed data of layers of the soil being modeled. Empirical methods, on the other hand, are based on seismic records on sites of different geological conditions; thus, relative amplitudes and dominant periods are determined directly. The main disadvantage of this approach is the requirement of a high number of recorded earthquake data. In regions with low seismicity it would be necessary to make observations for a long time to obtain a reasonably complete data set. As an alternative, in the last few years, another approach has become popular: the use of ambient seismic noise or microtremors.

Microtremors are low amplitude vibrations, which are easy and inexpensive for evaluating frequency properties of surface grounds. It can be used in any engineering application, such as classification of soils, prediction of shear wave velocities, evaluation of predominant periods of the soil. Therefore, microtremor measurement is widely accepted as a powerful tool to determine the dominant period of soil.

Microtremor has been implemented for the calculation of some important characteristics concerning soil or rock sites for the last few years. Although the application is new, the theory goes back to the 1950's. Microtremor can be used as a preliminary analysis prior to standard penetration test.

The fundamental frequency or period of the soil can give the engineer a valuable insight on the types of structure, which should be built for that specific site. The H/V method (developed by Nakamura in 1989) which calculates the spectral amplification factor(s) of the local site by dividing Fourier amplitude spectrum of the horizontal record to that of the vertical record.

Several microtremor techniques are present such as single station microtremor which uses only one point recorded at a time and also array microtremor which records several points at a time scattered geometrically either as a grid or as an enlarging circle.

Furthermore, the results obtained with microtremors allow the determination of zones with typical dynamic behaviors. This fact becomes very important in microzonation studies of urban areas. Thematic maps from microtremors may be considered as a preliminary zonation of the area of interest. The maps must be complemented with geotechnical studies and more detailed modeling of the dynamic behavior of soils.

As the evaluation of surface soil conditions is very important from a standpoint of earthquake mitigation, short period of microtremors observations were densely carried out in the Adapazarı city in the following chapters, located at the most hazardous region in Turkey, on the North Anatolian Fault (NAF), and Nakamura’s method (1989) was applied to determine predominant periods. Additional microtremor studies were done in Golcuk and in Izmir.

2 FEATURES OF MICROTREMOR

2.1 Introduction

There are several small amplitude vibrations which appear on surrounding ground surface. The period range of such vibrations is from 0.1 to 10s. vibrations that have small periods, less than 1s, are currently called microtremors or Kanai's microtremors (Seo, 1996) and those with larger periods are called microseisms (Taga 1993). The origin of microtremors is due to traffic noise, heavy machinery facilities, household appliances etc; where small waves propagate from artificial sources surrounding daily life. Kanai et.al. (1954) have originally introduced a theoretical interpretation and practical engineering application of microtremors, especially easy and inexpensive way for evaluating frequency properties of surface ground. They have many engineering applications, such as soil type classification of soil layers, prediction of shear wave velocity of the ground and the evaluation of predominant periods of the soil layers.

Generally, the waves associated with microtremors are excited by surface sources such as wind–structure interaction, traffic and vibrations from machines and pumps. Long-period microtremors in the frequency range between 0.05 and 0.8 Hz are often due to sources such as ocean waves. Source effects have an important impact on the H/V ratio because the source location and mechanism determine the amplitude of each mode.

The difference between the seismic survey and ambient vibration measurements lies in the frequency range of the waves considered. For exploration seismics the analyzed energy is centered around 70 Hz, while for the ambient vibrations the range of frequency is between 1 and 10 Hz.

The soil parameters can be obtained either geotechnical or geophysical investigations at the site. Soil investigation can be carried out in two ways. One of them is static such as boring, well logging, Penetration test and the other way is dynamic investigation methods, which are microtremors, seismic reflection and refraction measurements.They may be obtained through direct, active in situ measurements such as P- and S-wave seismics, surface wave measurements with single stations or arrays, and down-hole and cross-hole techniques, as well as through drillings and subsequent laboratory measurements. Of special interest are passive methods based on ambient noise, or microtremors, due to their low costs. These methods can be applied in urban areas where in general it is not possible to carry out active measurements due to the lack of space for the experimental set-up or the impossibility of using explosive sources. It is well known that the spectral features and polarization of microtremors exhibit a good correlation with the site geological condition (e.g. Lermo & Chavez-Garcia 1994). Among several proposed microtremor methods, the H/V method (Nakamura 1989) has proven to be one of the most convenient techniques to estimate the fundamental frequency of soft deposits. Extensive use of this method allows a detailed mapping of this frequency within urban areas.

2.2 Properties of Microtremors

Microtremors are defined as low energy oscillations, which have amplitudes varying between 0.01~0.001 mm and periods of 0.01-20 seconds. The sources of microtremors can be natural and/or artificial, like wind, small magnitude earthquakes, ocean waves and/or industrial noise, traffic. Microtremors are classified in terms of their periods. Excitations with periods greater than 1 sec. are considered as long period microtremors, while excitations in the period range below 1 sec. is considered as short period microtremors. Although some researchers referred long period microtremors as microseisms in their studies (Dravinski et. al., 1991; Finn, 1991; Yamanaka et. al., 1994; Trifunac & Todorovska, 2000), microtremors with periods greater than 2 sec. are generally referred as microseisms (Akamatsu et. al., 1991; Lermo & Chavez-Garcia, 1994b). Many studies were conducted to define the nature of microtremor motion (Aki, 1957; Santo, 1959; Kanai and Tanaka, 1961; Lermo et. al., 1988; Yamanaka et. al., 1993; 1994). The results of these studies showed that the classification of microtremors according to the short and long period range approximately fits the boundaries in characterization of source and the nature of microtremors. The explanation of microtremor source characteristics and important points regarding these features were discussed and summarized by Seo et al., (1990). Main criteria concerning the use of microtremors in geotechnical earthquake engineering and classification of microtremors are presented in

Table 2.1. In this table, long period microtremors are regarded as microseisms originated from natural sources like sea waves, which display surface wave characteristics; where short period microtremors are defined as excitations originating from human activities

traffic, machinery noise, etc. with constant predominant characteristics and both S-wave and Rayleigh wave like particle motion.

As seen from the source of microtremors (thus the environmental factors in close neighborhood) plays an important role on the character of microtremor motion and the spectral characteristics (

Table 2.1). These effects were also observed in different studies for both short period (Nakamura, 1989) and long period microtremors (Yamanaka et. al., 1993).

Table 2.1 Classification of Microtremors (Seo, et. al., 1990)

Microtremors	
What is the source of microtremors?	
Human Activities Traffic and/or machinery noise	Natural Forces Sea waves under weather conditions
Microtremors S-Wave, Raleigh Wave	Microseisms Raleigh Wave, Love Wave
Stable Characteristics Constant predominant period Daily variation of amplitude	Unstable Characteristics Variation of period and amplitude due to weather conditions
Can we understand the site condition from measured microtremors?	
Are they applicable for predicting seismic motions?	

From the engineering perspective, this becomes a significant issue as the vibration features of the source affects the propagation characteristics and the type of the waves dominant in motion, which are both important in spectral analysis stages. At this point, however, there is no agreement among the researchers. Some researchers think that microtremors are made up of surface waves or Rayleigh waves (Frantti, 1963; Toksoz, 1964; Konno and Ohmachi, 1998; Bard, 1998), while the others consider that microtremors are made up of waves of different types including surface and s-waves (Nakamura, 1996; Kind et. al., 2000).

As a result of different approaches and assumptions, the studies on microtremors also show a wide variation in terms of the targeted parameters since the pioneering work made by Kanai and his colleagues (Kanai, et. al., 1954). In the following years, Kanai and Tanaka (1961) have applied short microtremor measurements to estimate the local site effects with respect to Japanese Code. This approach, which can be also accepted as one of the primary studies towards microzonation approach, included the evaluation of spectral analysis of microtremors by two different techniques in terms of predominant period-maximum amplitude and maximum period-average period. Many different researchers used microtremor measurements in geotechnical earthquake engineering after these preliminary studies by Kanai and his colleagues in the 1950-1960s.

In 1960s microtremor measurements were evaluated with the results of direct spectral analyses of microtremor components (Kanai et al., 1966). New techniques were introduced after these years. Two most popular of these are the reference station and the single station (Nakamura's technique) methods, which are still used today. Reference station method was proposed by Borcherdt (1970) for analysing earthquake records to obtain site effects. Reference station method requires records to be taken in the same time interval at least at two stations, one of which should be located on a rock site. The spectral ratio with respect to the rock site would represent the transfer function at each location. The main idea underlying this approach was to eliminate the source and path characteristics from earthquake records and to estimate the local site effects. Reference station method gives satisfying results, especially in case of far (distant) earthquakes. However, due to variation in local source characteristics and their nature, microtremors observed in the reference station and other stations may change significantly, which may lead to erroneous results. This was observed by different researchers in the literature (Seo, 1992; Iyisan et. al., 1997a), where there are many others who have successfully applied the reference station method (Kagami et. al., 1986, 1991; Iyisan et. al., 1997b; Taber, 2000). The single station method is the most practical and feasible alternative among other microtremor methods. This method is simply based on calculation of the ratio of horizontal to vertical microtremor spectra to estimate the site amplification and predominant soil period. Although there were other studies on the H/V spectrum of microtremors (Shiono et. al., 1979; Kobayashi, 1980) before Nakamura's work (1989), this method is recognised as Nakamura's technique. There are still many arguments about the theory of Nakamura's technique among the researchers (Konno & Ohmachi, 1998; Bard, 1998; Taber, 2000; Tsuboi et al., 2001), but many studies (Ansal et. al., 1997, 2001c; Chavez-Garcia et. al., 1996; Lermo & Chavez Garcia, 1994a; Bodin ve Horton, 1999; Teves-Costa et al., 1996) showed that it provides fair results, especially in terms of predominant soil periods, if velocity contrast is present and two or three dimensional discontinuities are negligible in the geological setting of the investigated area. Regardless of the aim and the used technique; microtremor measurements became an inseparable part of microzonation studies as a result of their feasibility. In Manual for Zonation on Seismic Geotechnical Hazards (1993, 1999), ISSMGE included microtremor measurements besides the other methods in second level microzonation studies. Many different researchers used microtremor measurements in microzonation project to determine different characteristics and their geographical variation (Norio et al., 1996; Lachet et al., 1996; Gaull et al., 1995; Delgado et al., 2000; Nakamura & Saita, 1994).

2.3 Microtremors in Geotechnical Earthquake Engineering:

2.3.1 Estimating Dynamic Characteristics of Surface Layers

A method that employs microtremor has been introduced for estimating dynamic characteristics of surface layers, in early 1950. Then the use of this method has received a lot of criticism considering uncertainty about source of microtremor. After the introduction of the Nakamura’s technique (H/V; Nakamura, 1989), many people have paid a renewed great attention for estimating dynamic characteristics of ground and structures using microtremor, since clear and reliable information was provided by very simple and inexpensive noise measurements. In recent years, although several researchers claimed that theoretical ground of this technique is not clear and consensus based on experiment could not be reached, there have been many successful experimental studies based on this technique. Many theoretical studies have been performed for explaining the types of waves included in microtremor and checking the applicability of the QTS (Quasi-Transfer Spectra) technique. It was suggested that the peak on H/V ratio can be explained with the fundamental peak of Rayleigh waves.

The Horizontal to Vertical Spectral Ratio (HVSR) has been used by many researchers to characterize conditions in terms of the dynamic response of the soil, and one of its variants proposed by Nakamura(1989).

2.3.2 Investigation of Vulnerability of Ground, and Structures

Other possible use of products from predominant frequency and amplification factor for hazard estimation is also given. As it is well known, occurrence of earthquake damage depends upon strength, period and duration of seismic motions. These parameters are strongly influenced by seismic response of surface ground and structures. This reality makes investigation of vulnerability of ground and structures an important issue. For this purpose, a vulnerability index which is called K values was proposed by Nakamura (1996). K values are simply derived from strains of ground and structures. Formulation of K values for ground (Kg) and some application examples are explained in the following section.. These new values give a chance to estimate vulnerabilities of all types of structures and ground before the real damage occurs.

2.3.3 Observation of Seismic Ground Motion

Damages caused by the recent earthquakes are concluded as a direct result of local geological conditions affecting the ground motion. Best approach for understanding ground conditions is through direct observation of seismic ground motion, but such studies are restricted to areas with relatively high rates of seismicity. Because of these restrictions in other methods, such as high rates of seismicity and the availability of an adequate reference site, non-reference site methods have been applied to site response studies. Microtremor is a very convenient tool to estimate the effect of surface geology on seismic motion without any need for other geological information.

In the analysis of local seismic hazard, dynamic ground shaking and permanent ground failure are the two most important effects, at least with respect to buildings and lifelines. Dynamic ground shaking is the important factor for buildings. Ground shaking refers to the amplitude, frequency, composition and duration of the horizontal and vertical components of the vibration of the ground produced by seismic waves arriving at a site. These effects depend largely on the local geological ground conditions. By knowing these conditions, the related hazard can be estimated by means of empirical methods or numerical simulation techniques. Therefore, the investigation of the local ground conditions is of primary interest and should be the first part of any site-specific hazard and risk assessment.

The H/V ratio of microtremor is seen to be similar with that of earthquake motion. Nakamura (2000) explained the H/V spectrum ratio of microtremor using the wave propagation theory for the body waves. Based on this, the similarity of the H/V spectrum ratios for microtremor and earthquake motion can be easily explained because earthquake motions consist mostly of body waves.

The Standard Spectral Ratio (SSR) technique requires a suitable rock (reference) site in the vicinity of the sediment site of interest. Yet in practice it is difficult to find a proper reference site, as ‘rock’ sites often have a response of their own(Boore and Joyner, 1997). For the above reasons, a nonreference approach, namely the horizontal-to vertical spectral-ratio (HVSR) technique, whereby site response (transfer function) is approximated by spectral ratios between the horizontal components of ground motion and the vertical component, has been steadily gaining popularity. The method was originally proposed for microtremors (e.g. Ochmachi et al., 1991), and Lermo and Chavez-Garcia (1993) were among the first to apply it to earthquake recordings.

Application for Estimation of Seismic Motion

In order to gather earthquake information at an early stage and to establish an efficient traffic control just after an earthquake, Japan Highway Public Corporation (JH) has been developing a new seismometer network along their expressways since the 1995 Kobe Earthquake. In the study of Maruyama et al.(2000), the estimation of seismic motion along expressways are calculated by using microtremor measurements.
The horizontal-to-vertical (H/V) Fourier spectrum ratios were calculated for microtremors observed at four JH seismic stations and four K-NET stations. The H/V ratios for the earthquake motions observed at these seismic stations were also calculated. It was observed that the H/V Fourier spectrum ratios for the microtremor and seismic motion are similar. Hence, using the H/V ratios for microtremor as quasi transfer functions, the earthquake records at the microtremor observation points can be predicted. It is concluded that this idea can be applied for the estimation of seismic motion along the expressway networks in Japan.

The H/V ratio of microtremor is seen to be similar with that of earthquake motion. This similarity was also observed at all the other seismic stations in this study. In this study, the agreement among the peaks of the H/V spectral ratio of microtremor, transfer function for the S-wave, and H/V ratio of the fundamental mode Rayleigh wave was also observed.

Based on the similarity of the H/V spectrum ratio of earthquake motion and that of microtremor, the seismic motion at a JH seismic station is estimated by using an earthquake record at the nearest K-NET station and the H/V ratios of microtremor observed at the two stations. They assume the soil structure, in which the two seismic stations have the common baserock because the two stations are closely located. The (complex) H/V spectrum ratio of the earthquake motion at the surface of the K-NET station is obtained by ratio of transfer functions between the surface and bedrock. Due to similarity of the H/V spectrum ratios for earthquakes and microtremors, the ratio of knet groun motion is nearly equal to the ratio of microtremors. After this assumption the ratio of these parameters calculated. As a result the ratio of H/V spectrum ratios of microtremors at the two points can be approximated as the ratio of the Fourier spectra of horizontal motions.

In addition to this approximation, it is assumed that the Fourier spectrum and the velocity response spectrum with zero damping. Now it is easy to calculate the response spectrum of JH station by multiplying the response spectrum of the KNET station with the H/V ratio of JH station.

Also considering the close distance between a JH seismic station and a corresponding K-NET station, it is assumed that the phases of the acceleration records at the two points are same. Obviously this is not true, but it may be allowed as a crude assumption. Under this assumption, the Fourier spectrum at the JH station can be computed by multiplication of the Fourier spectrum of KNET ground motion with the the H/V ratio of JH station (Figure 2.1).

Employing the inverse Fourier transform to the predicted Fourier spectrum, the acceleration time history at the JH station can be estimated.

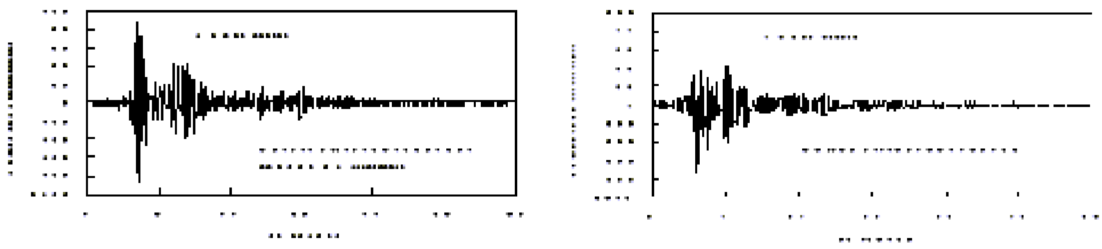


Figure 2.1 Comparison of Predicted Acceleration Time-History with the Recorded Acceleration at JH Utsunomiya Station

However, the proposed method has advantage such that it does not require soil column data. The predicted S_A by the response spectrum estimation produces small values in the short period range due to the limitation of approximation bys

2.3.4 Non-Linear Effects

Measured parameters can be used in theoretical models to predict site response (Field et.al 1990). The main disadvantage of this method is the high cost and time consumed in conducting the geotechnical or geophysical surveys. The application of microtremor measurements, alternative in estimating site response is an attractive one because the method is inexpensive and fast. The first use of microtremors to estimate the earthquake site response was introduced by Kanai(1957). It is important to note that, because of possible nonlinearities, the question of the extent to which weak motion signals can be used to predict strong motion behavior remains, and the answer may vary according to soil type. Nonlinear effects tend to reduce the amplitudes of the spectral peaks and shift them towards slight longer periods. However, several studies show good correlation between weak and strong motion (Aki, 1988: Lermo et.al., 1988: Borcherdt et.al., 1989).These studies demonstrated that under certain circumstances and with certain limitations, microtremors can be used to estimate earthquake site response. In particular, it is possible to identify the resonance fundamental period in surface layers which have a sharp impedance contrast with respect to their substratum (Lermo et.al., 1988:Field et.al., 1990)

The standard approach involves the standard spectral ratio (SSR) method, requiring a suitable reference site (rarely available).The usual approaches to evidencing nonlinear effects involve looking for amplitude-dependence in spectral ratios either between sediment and rock surface motions – a technique known as standard spectral ratio (SSR), (Borcherdt, 1970) – or between motions at different depths within the deposit. Yet the two approaches encounter certain practical problems. In practice it is difficult to find a proper reference site, as ‘rock’ sites which often have a response of their own (e.g. Cranswick, 1988; Steidl et al., 1996; Boore and Joyner, 1997). For the above reasons, a nonreference approach, namely the horizontal-to vertical spectral-ratio (HVSR) technique, whereby site response (transfer function) is approximated by spectral ratios between the horizontal components of ground motion and the vertical component, has been steadily gaining popularity. The method was originally proposed for microtremors (e.g. Ochmachi et al., 1991), and Lermo and Chavez-Garcia (1993) were among the first to apply it to earthquake recordings.

Theoretical investigations (e.g., Lachet and Bard, 1994;Dravinski et.al., 1996)and experimental studies (e.g., Field and Jacob, 1995; Field, 1996 Konno and Ohmachi, 1998) have shown that Nakamura’s method successfully identified the fundamental resonant frequency; a very relevant data for the assessment of local site effects.

Recently, Dimitriu et al. (1999, 2000) proposed the use of the (nonreference) horizontal-to-vertical spectral-ratio (HVSR) technique to assess nonlinear site response. The purpose of the Dimitriu,(2002) article is the non-linear sediment response during the 1994 Northridge Earthquake (Mw 6.7) to test it on Northridge-earthquake data.

The (HVSR) technique has been found to correctly display the frequencies of site resonances, particularly of the dominant one, with a tendency to underestimate their amplitude (e.g. Theodulidis et al., 1996; Lachet et al., 1996; Dimitriu et al., 1998; Raptakis et al., 1998). Here it is attempted to test HVSR method on the most popular strong-motion dataset, namely the accelerograms of the 1994 Northridge Mw 6.7 earthquake.

Another valuable study about detecting non-linear response of the soil in the case of the Kobe earthquake , (Japan, 1995) from Lachet;, Bard and Irikura (2000) can be noted here. One of the aims of this study is to test the ability of the H/V ratio technique to indicate the occurrence of non-linearity, when applied on data from the main shock and aftershocks of a big earthquake. In the case of the Kobe earthquake, the H/V ratio of the main shock and of a collection of available aftershock recordings has been calculated for each site. The aim is to test straightforward methods to investigate their ability to reveal non-linear phenomena. Simple straightforward methods are applied to test their ability to detect the non-linear response of the soil. Recordings of the main shock and aftershocks of the 1995, Hyogo-ken Nanbu (Kobe) earthquake are used. Two different techniques are used: the H/V ratio (spectral ratio between horizontal and vertical components of motion) and the high frequency spectral decay of acceleration spectra (parameter ‘kappa’).

Non-linear effects are investigated using a collection of data for 12 sites situated on different geological structures in the Kobe and Osaka areas. the H/V ratio and the parameter ‘kappa’ is calculated.For each site, recordings of the main shock and a set of aftershocks are considered Both variations of the amplitude of the H/V ratio and of the frequency position of the amplified band-width are observed. The high frequency spectral decay of the motion, characterized by κ parameter, is assumed to be related mainly to the near-surface attenuation. Variations of kappa are then related to non-linear behavior of the soil during the Kobe earthquake.

They also confirmed that H/V ratio is an effective tool to estimate the fundamental frequency of a site independent of the kind of signal used; real earthquakes or ambient noise. On the contrary, these same studies indicate that one must be very careful with the use of the H/V ratio amplification level whose significance is still not well understood. Bard et al., 1997 conducted a statistical analysis on many data sets, showing a general trend for the noise H/V ratio underestimating the amplification level with respect to the classical spectral ratio. This is the reason why they suggest the use of the H/V ratio amplitude only as a relative indicator of site amplification, in comparison of one site with another or one period with another.

A signal to noise ratio threshold value of 3 has been applied to the data. If these H/V ratios present a relative decrease of the amplification level for higher peak ground accelerations (PGA), it would indicate a non-linear behavior of the soil characterized by a loss of energy on the horizontal components. Looking at these results, the following ratio was calculated:

(H/V ratio of the main shock) / (average H/V ratio of all aftershocks)

The following general trends was pointed out. In the low frequency range (below 2 Hz) the H/V ratio for the main shock is slightly larger than for the aftershocks. On the contrary, for frequencies higher than 2 Hz, this tendency is reversed, giving an H/V ratio for the main shock nearly systematically lower than that of the smaller aftershock events. This last trend is consistent with what could be expected in case of non-linearity of the soil layers, as discussed before.

2.3.5 Site Effect Determination

Numerical methods for estimating site effects require modeling of the subsurface, primarily shear-wave velocities of the sedimentary layers and underlying rock and thickness of each layer. In many cases, it is difficult to construct such models by only using conventional geophysical methods and borehole information, especially with regard to the deeper sediments.

Owing to the fact that the H/V spectral ratio techniques are relatively simple and inexpensive, they should be performed in site response investigations to support and verify theoretical calculations.

Site effect determination for Caracas, Venezuela was studied by Duval et al. (2001). After the 6.4 Caracas earthquake that occurred in 1967, July the 29^{th},which caused extensive damage, investigations were undertaken by American soil specialists (Seed et.el.1970; Weston Inc. 1969:Whitman 1969). It was observed a good correlation between the frequencies of damaged buildings and the calculated frequencies of the sites. It was one of the first for which the importance of the site effects noticed. Because of this reason they tested Los Palos Grandes district with the method based on microtremor measurement in 1995.The main interesting feature of the 1967 earthquake in Caracas was the geographical distribution of damage. Structural damage to high buildings (10-12 stories) was concentrated in Palos Grandes. It was noted that this damage distribution suggests a links between sediment thicknesses and damaged building height. Also, computations of the first mode of the building vibrations confirmed this link. They aimed to provide experimental resonance frequency of soil in this basin.

184 measurements were carried out throughout the city. As a result, it is seen that H/V curves totally agree with the results that high buildings collapsed in an area that soil resonance frequency fits with estimated building frequency. Moreover, maximum amplification values were observed in an area where major damage occurred.

Another example is done at Almeria city, Spain. The evaluation of soil surface condition is very important from a standpoint of earthquake disaster mitigation. Short-period microtremor observations were densely carried out in Almera City,Southern Spain and Nakamura’s method was applied for determining predominant periods(Vidal and K.Seo 2001). Microtremors observed at 173 sites with 400m intervals in rock sites and 200m in relatively soft soils. The difference of predominant periods between hard rock and soft soil sites is very clear and it has been observed that distribution of predominant periods depends on heavily on the subsurface soil conditions.

2.4 Case Studies

Chavez-Garcia et al. (1996) presented a complementary study to microzonation of Mexico City where the authors studied the site effects at two counties that are located at the north of the city and that have been recently incorporated into the Mexico City conurbation. Measurements of microtremors at 67 points and weak motion recordings from a temporary digital seismograph network were analyzed according to HVSR technique to extend the existing predominant period map of Mexico City. Additionally a map of maximum relative amplification was proposed. Both maps were found to be consistent with local geology and suggested to be useful for a detailed microzonation study of the region.

Chavez-Garcia & Cuenca (1998) presented a study to improve microzonation of Acapulco, Mexico. Two maps that reflect the fundamental characteristics of the site effects in the area were proposed: dominant period and maximum relative amplification. The microzonation was based on three basic sources of data: strong motion records obtained from 7 permanent stations, weak motion data obtained from a temporary digital seismograph network of 6 stations, and measurements of microtremors at 35 sites. The strong motion data included recordings from 24 events with magnitudes of 3.5 to 6.9. The data was analyzed using both SSR and HVSR techniques The weak motion data included recordings from 8 events in more than 4 stations, 3 events in more than 3 stations and a large number of events in 1 or 2 stations.

They were analyzed using three techniques: SSR, HVSR and the computation of response spectral ratios (RSR). In the third method the velocity response spectra ratios at 5% damping were computed. Finally, microtremor recordings obtained at 35 sites were analyzed by Nakamura's technique. The resulting transfer functions obtained from weak and strong motion data using HVSR method are very similar to those obtained using SSR technique. This good agreement was observed both for dominant period and for the average value of maximum relative amplification. RSR technique applied to weak motion data also revealed similar values of dominant period. Amplification factors obtained from this method were in general half of those determined from SSR. Comparing the results with those obtained from microtremor data showed that microtremors could provide a good estimation of dominant period. The maximum relative amplification factors obtained with this method were also good within an uncertainty factor of 2. Relying on the results obtained at this study the authors concluded that microtremors were useful tools to interpolate sparse earthquake data. The resulting microzonation maps of dominant period and maximum relative amplification factor were presented as based on the integration of all data obtained in the study.

Regnier, M. et al. (2000) presented a microzonation study conducted to evaluate possible site effects across Port Vila, Vanuatu, located very near to New Hebrid subduction zone. In this study the resulting maps were obtained in terms of predominant frequency and approximated amplification of the ground motion. The microzonation was based on microtremor measurements obtained at 100 sites across Port Vila. Nakamura's technique was used to estimate the site response. Using these results together with the topographic map and available borehole information four zones were identified. The resulting map showed that except for a few sites, for most of the city there is no significant site effect. These findings were in agreement with the damage observed at previous earthquakes.

Gutierrez, C. et al. (1992) described a site effect study carried out in Acapulco based on strong motion data from eight events (4.2=M=6.9) recorded by 6 accelerographs in the city. 4 of these instruments were located at soft sites while the other 2 were located at firm sites. One of the hard sites was selected as the reference site. Spectral amplification ratios for both S waves and S-wave coda were computed. The spectral amplifications of S wave coda were found to be very similar to those of S waves. Microtremor measurements at the

6 strong motion sites were also performed. Fourier amplitude spectra of the microtremor recordings were interpreted to obtain average spectral ratio curves for each site. The comparison of results evaluated from strong motion and microtremor data showed that the agreement was not good. Thus, authors conclude that microtremors can only give rough estimate of site response at the area of interest and caution is needed for its use at elsewhere.

Ochiai, et al. (2000) conducted a microzonation study based on microtremor measurements carried out for Sagami Plain, located in Kanto district of Japan. The microtremor measurements included fix-point continuous measurements at 3 sites and high density moving measurements at 932 sites dividing the area of interest into 500mx500m grids. HVSR technique was used to evaluate the predominant period for each of the grids. Fix-point continuous measurements were used to check the stability of HVSR technique. The resulting map of predominant periods was found to be closely related with the depth of alluvial deposit that was known from available borehole data as shown successively in Figures 2.2, and 2.3.

Figure 2.3 shows the result of microzonation in the Sagami Plain based on the high density moving measurements shown in Fig. 2.2. The zone A, where located near the mouth of the Sagami River, predominant periods are distributed between 1.0s and 1.5s, and these values were the longest periods. In the zone B located at east of the Sagami River, the predominant periods were between 0.8s and 1.2s, in the zone C, located in the basin of the Sagami River between 0.5s and 1.0s, in the zone D located in the east end and west end in the Sagami Plain between 0.3s and 0.5s, and finally in the zone E located plateau area between 0.1s and 0.4s. The result was closely related with depth of alluvial deposit which was indicated Fig. 2.2.

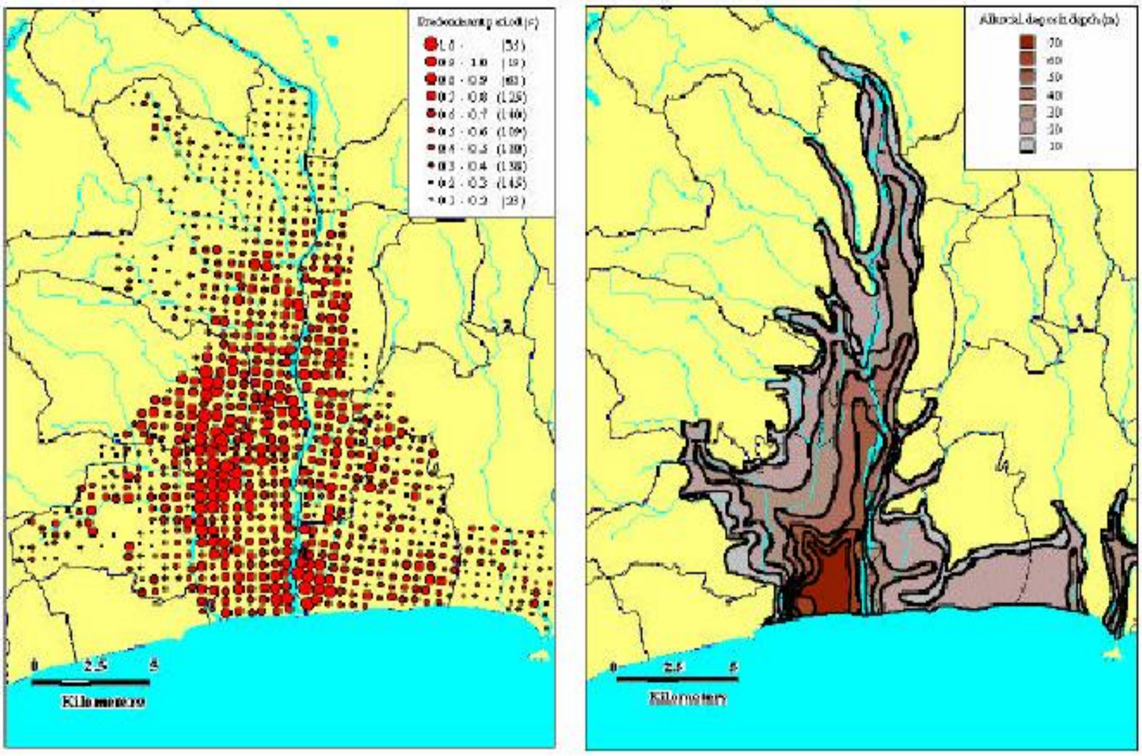


Figure 2.2 The result of high density moving measurements and alluvial plain depth with the depth contours (after Ochiai, et al., 2000)

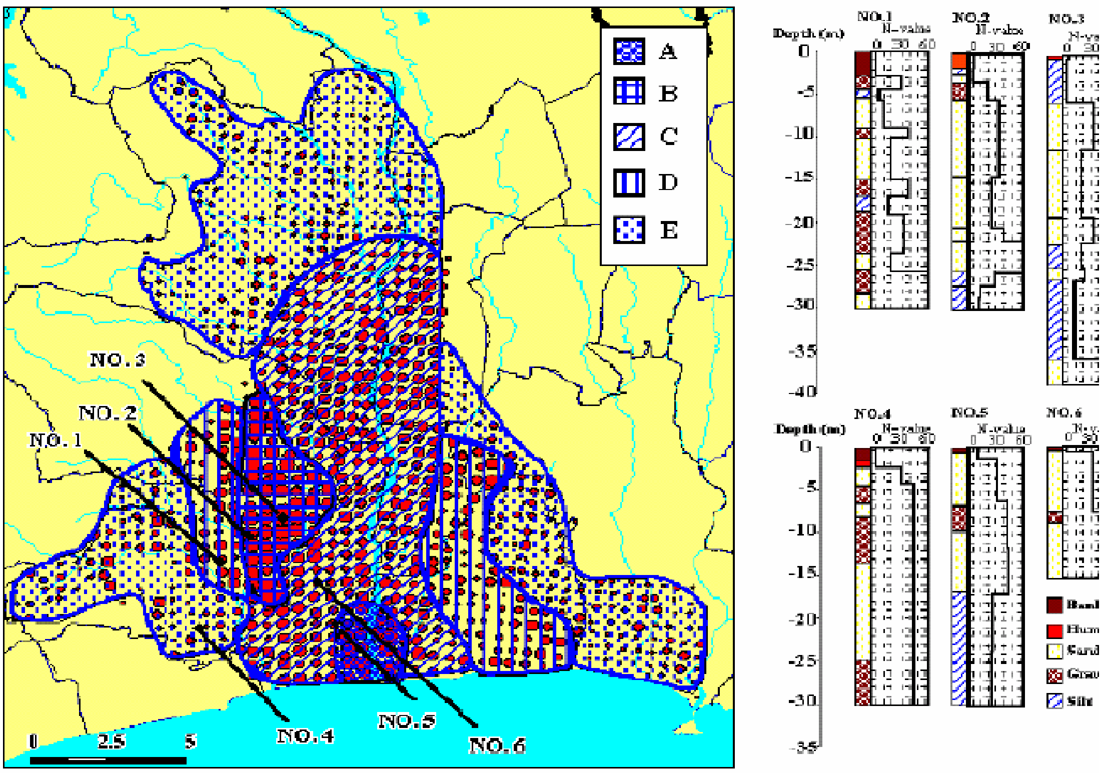


Figure 2.3 Seismic microzonation and typical soil profiles for each zone (after Ochia etal.,2000)

Lermo & Chavez Garcia (1994a) described a site effect study carried out for Mexico City. The study resulted in maps of dominant period and maximum amplification relative to a firm site within the city. The data used was a compilation of strong motion data and microtremor measurements. Strong motion data consisted of acceleration time histories from 9 events recorded at 81 locations in Mexico City. Microtremor data consisted of recordings at 409 points compiled from measurements of different groups during 1985-1992. Analysis of strong motion data was done using SSR technique. Empirical transfer functions were calculated by considering a hypothetical reference station which resulted from the average of all Fourier spectra recorded on firm soil in Mexico City for each earthquake. A map of maximum relative amplification was produced at this stage of the study. In the next step, information from microtremor analyses performed by different groups with different techniques was compiled into a common format database. It was observed that different techniques by different groups lead to the same results. At 13 locations microtremor and strong motion data were both available. A very good agreement was observed between the results obtained from two types of data. Integration of all strong motion and microtremor data resulted in a map of dominant period for Mexico City. Based on this study some modifications were proposed by the authors to improve the current microzonation of the city. Bour et al. (1998) presented an experimental study carried out on a plain of 60 km2 near South France. Microtremor measurements at 137 points were obtained. The recordings were analyzed according to Nakamura's technique. H/V spectral ratios calculated by this method were then compared with those obtained from 1D numerical simulation (SHAKE91). The fundamental frequencies were in good agreement. The amplification levels were sometimes different. H/V spectral ratios were used to produce microzonation maps: a map of resonance frequency and maps of amplification levels as a function of frequency range. The conclusion was that the microtremors provide a very useful complement to the numerical methods for determining the fundamental frequencies of the surficial formations in the linear domain and both methods should be combined so as to better constrain the microzonation of a region.

Lermo & Chavez-Garcia (1994b) reviewed the applicability of microtremor measurements to evaluate site response of soft soils. Microtremor measurements obtained in Mexico City, Oaxaca and Acapulco were used to compare three most common methods of analysis: interpretation of Fourier amplitude spectra, computation of spectral ratios relative to a reference site and Nakamura's technique. In order to evaluate the results obtained from microtremor measurements they were compared to those obtained from standard spectral ratios method applied to weak and strong motion data recorded at the sites where microtremors were performed. The comparisons showed that microtremors allow for determination of the dominant periods with good reliability in the range of 0.3 to 5Hz. The best results were obtained from Nakamura's technique, which also could give rough estimation of the amplification level where the local geology was relatively simple. The authors recommend the use of this technique since they believe that it compensates for the source effects in microtremor measurements. They conclude that the microtremors are very useful in complementing other site effect studies.

Konno & Ohmachi (1998) assuming that microtremors consist of surface waves, the H/V has been formulated in terms of Rayleigh and Love waves in layered soils. The authors have concluded that peak periods in H/V ratios of fundamental mode Rayleigh waves agree well with fundamental periods of transfer functions for vertically incident S waves, and the H/V ratio tends to show a trough at half of the peak period when site has soft surface soil. Based on these, the authors recommend using the periods of not the peaks but also the troughs in the H/V ratios of microtremors in view of estimating the fundamental periods. The amplification factor has been correlated with H/V peak ratio of fundamental mode Rayleigh waves. In the process, when smoothed with logarithmic function, the H/V peak ratio was found to be directly related with the amplification factor, especially when proportion of Rayleigh waves in microtremors is 0.4, the peak ratio becomes nearly equal to the amplification factor (Ansal et al. ,2002)

Caserta et.al. ,(2000) studied of site effects in the area of NocerA Umbra (Central Italy)during the 1997 Umbria-Marche seismic sequence.
Standard spectral ratios to a reference site (Tuckerand King, 1984) and horizontal-to-vertical spectral ratios for both microtremor (the so-called Nakamura technique, see Nakamura, 1989; Ohmachi et al., 1991) and earthquake recordings (also known as the receiver function method, see Field and Jacob, 1995) were used to quantify the level of amplification at each site valley of the Topino river

The three techniques identify the main resonance peaks, though the standard spectral ratio averages are larger than the averages obtained with the other techniques. This systematic difference for sedimentary sites was already found by other authors (Lermo and Chavez-Garcia, 1993; Lachet and Bard, 1994; Field and Jacob, 1995, Bonilla et al., 1997).

Receiver function and Nakamura’s techniques fail in detecting the frequencies of the higher modes at soft sites, in agreement with Field and Jacob (1995) and Lachet et al. (1996).

Luzon et.al. , (2001) had a numerical experiment on the horizontal to vertical spectral ratio in flat sedimentary basins. They compute the seismic response using the HVSR technique at various locations in the free surface of the basins, and compare it with the response calculated with the horizontal sediment bedrock spectral ratio(SBSR) and with the horizontal coamponent(HC) of the transfer function for the displacement at the same locations. The comparison shows that, in general, HVSR cannot provide the predominant period of a site due to the fact that this technique cannot predict accurately the spectral amplification levels. On the other hand, the HVSR provides an erroneous response in the sedimentary basins, which have a low-impedance contrast, with respect to bedrock. It is also noted that this technique can reasonably well predict the fundamental local frequency when there is a high impedance contrast except in the center of the basin.

Toshinawa et.al. ,(2003) , the geologic-profile estimates of Kofu basin, Japan, was studied by making use of microtremor observations.
Two geologic profiles of Kofu basin, Japan, are estimated by making use of microtremor observations. Microtremors in horizontal and vertical components were recorded at 209 points which constitute two perpendicular lines: Because the horizontal to vertical spectral ratio of microtremors peaks at the resonance period of the ground, the spatial variation of the predominant peak shows that of the sediment thickness when shear-wave velocity of the sediment is laterally homogeneous.

In Zaslavsky. And A. Shapira (2003), they have encountered some difficulties to find out the site response investigations at several sites for bridge design in Israel, located along or near the seismically active Dead Sea transform. There, and in many other places they found it very useful to constrain the subsurface models by considering site response functions evaluated by using the H/V spectral ratio techniques.

Also in Pinsky, &Zaslavsky, (2003) from Gophysical Institute of Israel, used microtremor measurement and H/V technique to obtain site effect modeling estimation.

3 TECHNIQUES USED IN MICROTREMOR ANALYSIS

3.1 Introduction

Three main techniques have been proposed for microtremor analysis: direct interpretation of the Fourier transform (or autocorrelation spectrum), spectral ratios relative to a reference site and spectral ratios of horizontal to vertical components. Besides these methods there is another exploration technique using microtremors with seismometers array which an alternative to the conventional seismic survey.

The response spectra analysis, Kagami technique and Fourier transform analysis proved to be powerful tools for the analysis of effects of strong earthquakes. The Nakamura technique showed some deficiencies in some strong motions since the obtained spectra did not show clear trends as the other methods did. In the case of weak motions, the response spectra, Fourier analysis and Nakamura technique showed similar results. Microtremors showed clear results when the Nakamura technique was used to evaluate dominant periods. Periods obtained with microtremors were very similar to those obtained with the strong and weak motion records. In this study Nakamura technique is used.

Nakamura (1989) proposed a straightforward technique to evaluate local site effects by calculating the spectral ratio between the horizontal components and vertical component of the observed motion at the same site. The microtremors are interpreted as Rayleigh waves propagating in a single layer on a half space. Additional assumptions are that microtremors are due to very local sources such as traffic and vibrations from machines and pumps , hence, deep sources that are not related to earthquakes are neglected; and also that local sources cannot affect the signals recorded at the base of the soil layer.

Microtremor analysis using the Nakamura technique proved to be a valuable tool to determine dominant periods of vibration of shallow soft soils with simple layer distribution and plastic behaviors. Furthermore, the results obtained with microtremors allow the determination of zones with typical dynamic behaviors. This fact becomes very important in microzonation studies of urban areas. Thematic maps from microtremors may be considered as a preliminary zonation of the interest area. They must be complemented with geotecnical studies and more detailed modeling of the dynamic behavior of soils. The good correlation between the microtremors and earthquake data can be observed in shallow depth of sediments (30 m), where the high contrast in velocities between soft soils and the rock basement.

As microtremors dominantly consists of surface waves rather than body waves, we can extract phase velocities of surface waves from microtremors in the form of dispersion as a function of frequency or period. To estimate phase velocities of surface wave in microtremors, there are two principal methods**: the frequency-wave number method** call F-K method, Capon 1969) and the **spatial auto-correlation method** (Spac method, Aki 1957).

3.2 Fourier analysis

In this technique, the Fourier spectrum for the horizontal components of the recorded data is calculated in order to determine dominant frequencies of movement. Two assumptions required are: microtremors consist of vertically propagating S waves, and the source spectrum of a microtremor is mainly white noise. Lermo et al. [1994] used this technique to determine dominant periods in Mexico City. The periods obtained with microtremors were compared with those obtained with earthquake records; good correlations between them were observed, but relative amplitudes were not determined due to the dependency of the amplitudes of the traffic and local sources. Good results have been achieved by other investigators using this technique trying to infer dominant periods in soft soils [Lermo et.al.1994, Kobayashi et.al.,1991,Field et.al. 1993).

3.3 Kagami technique

Fourier amplitudes of the reference site and soft site is calculated. For the analysis of earthquake data, the S wave part of the seismogram is selected. The ratio of the smoothed amplitude Fourier spectra is considered as the transfer function between the soft soil site and the reference station. The Kagami spectrum is given by

$$E_K(w) = H_S(w) H_r(w) \quad (1)$$

where EK(w) is the Kagami spectrum, Hs(w) the horizontal component spectrum of the signal in soft soil, and Hr(w) the spectrum of the horizontal component in the hard rock site. To use this method it is required to identify a common wave train for the two stations of interest (Ojeda et al, 1996).

3.4 H/V Technique

The main challenge to determine site amplification characteristics from ambient noise is the removal of source effects. This is often achieved by assuming white source spectra over the frequency range of interest or by dividing the sediment site spectra by that observed at a bedrock site (Field andJacob,1990).An alternative method to remove the source effects was proposed by Nakamura(1989). The site response is obtained as the ratio between the horizontal and the vertical noise spectrum components. Recent applications of this method have successfully identified the fundamental resonant frequency.

Nakamura developed H/V technique with relating borehole investigations together with strong motion records analysis, on the various geological site conditions. It was hypothesized that the vertical component of ambient noise keeps the characteristics of source to sediments surface ground, is relatively influenced by Rayleigh wave on the sediments. Therefore It can be used to remove both of the source and the Rayleigh wave effects from the horizontal components. It is effective to identify the fundamental resonant frequency of a sedimentary layer, with implied amplification factors that are more realistic than those obtained from sediment to rock site ratios. Many researchers (Ohmachi et. al., 1991; Lermo et. al., 1992; Field and Jacob, 1993, 1995) have showed that how such H/V ratio of noise can be used to identify the fundamental resonant frequency and amplification factor of sediments.

Looking to the examples in the study of Nogoshi and Igarashi (1971) which compared H/V of Rayleigh wave with that of microtremors and concluded that microtremor was mostly composed of Rayleigh wave, some of theoretical studies (Lachet and Bard, 1994; Konno and Ohmachi, 1998; Bard, 1998) suggested that the peak on H/V can be explained with the fundamental mode of Rayleigh waves. If we think that this approach is true, microtremor should be considered to consist of only Rayleigh wave. On the other hand, if we check the examples given on Nogoshi and Igarashi (1971) carefully, we can clearly see that, at the peak frequency of H/V of Rayleigh wave, the energy of Rayleigh wave is very small, nearly close to the zero. Rayleigh wave has its maximum energy at near through frequency of H/V. Because of this, peak of H/V cannot be explained by Rayleigh wave energy. As it is explained by Nakamura (1989), H/V of microtremor at peak frequency range can be explained with vertical incident SH wave.

In general, longer periods correspond to the soft soil zones and the shorter ones can be found in hard and middle hard soil zones. The predominant periods corresponding to hard rock and soft soil sites are clearly different.

As the microtremors are interpreted as Rayleigh waves propagating in a single layer on a half space, there is additional assumptions that microtremors are due to very local sources. Hence, deep sources are neglected and also that local sources cannot affect the signals recorded at the base of the soil layer.

Site effects would be given by

$$S_e = H_s(w) / H_b(w) \qquad (1)$$

Since internal waves of microtremors contain surface waves, it is necessary to correct them by removing surface waves effects. Nakamura assumed that the effect of Rayleigh waves is included in the spectrum of vertical surface waves (Vs) and not in that for the base of the layer (Vb). Therefore, this effect is defined as:

$$A_s(w) = V_s(w) / V_b(w) \qquad (2)$$

Removing the Rayleigh waves effect, the spectrum for the site becomes:

$$S_m = S_e(w) / A_s(w) = (H_s / V_s) / (H_b / V_b) \qquad (3)$$

Nakamura showed experimentally, using borehole records and microtremors that

$$H_b(w) / V_b(w) \sim N_s w) \qquad (4)$$

Despite the apparent appeal of Nakamura's method (source, radiation patterns, directivity and path effects are discarded), the validity of its results and assumptions has not yet been established, especially in deep soft layers.

3.4.1 Waves in Microtremor and Characteristics of Strong Ground Motion

Many observations and experiences on microtremor records show that microtremor consists of both body and surface waves, but there is no established theory concerning what kinds of wave motions the microtremor is made up from. In Nakamura (1989), the purpose of the author was the estimation of the amplification factor caused by multiply refracted vertical incident SH waves. For this purpose, Rayleigh wave contained by microtremor was considered as noise and eliminated inside the H/V process.

He observed records from different stations even for the same earthquake are different because of the different site characteristics. On the other hand, for different earthquakes same site gives almost same type of records. In other words, it may be said that, affecting dynamic characteristics, the effect of surface layer is most critical among the other factors. For the investigation of dynamic characteristics, boring is one of the most accurate method, but it is costly and time consuming and is not available all the time. If we measure both at surface Hf and basement Hb and take the ratio we can get the transfer function. Method, which employs microtremor, is well known and there may be some cases that transfer function calculated from Hf/Hb ratio and from velocity model of boring data show some differences. The reason for this is basically the evidence of surface waves. In practice Rayleigh wave should be eliminated to estimate transfer function correctly. H/V method (Nakamura, 1989) was introduced for this purpose and verified with both strong ground motion and microtremor data.

3.4.2 Relation Between H/V of Microtremor and H/V of Rayleigh Waves

Nakamura (1989), gives theoretical definition of the H/V technique with multiple refraction of SH waves. On the other hand, there is a group of researchers who try to explain the peak of H/V ratio with the evidence of Rayleigh waves. As it is mentioned before, microtremor consists of many kinds of waves. Link to the surface waves is based on the assumption that noise predominantly consists of surface waves. Under this assumption Bard (1998) explains that, many researchers are agree on following two arguments; First, H/V is basically related to the ellipticity of Rayleigh waves because of the predominance of Rayleigh waves in vertical component. Second, this ellipticity is frequency dependent and exhibits a sharp peak around the fundamental frequency for sites displaying a high enough impedance contrast between the surface and deep materials. This approach simply comes from the similarity of the figures of H/V ratio of microtremor and H/V of fundamental mode of Rayleigh waves, but just looking to this similarity this conclusion cannot be reached.

For different wave-lengths, Ohta (1962) calculated H/V and phase velocity of Rayleigh waves for two layers model for various impedance ratio (varying between 1.2-4.5) and Poisson's ratio (varying between 0.25-0.49) both in sedimentary and basement layers.
Figure 3.1 shows the change of impedance ratio for frequencies of through and peak of H/V and minimum group velocity of Rayleigh waves. For minimum group velocity (for almost all impedance ratio values), frequency changes between 1.5- 2. On the other hand, only for the peak frequency varies in a wider range for different impedance ratio. The energy of Rayleigh wave is almost zero at peak frequency of H/V, and at the trough frequency of H/V the energy becomes to maximum. When the impedance ratio is greater than 2.5, Rayleigh wave does not affect to the H/V peak of ground motion. And on the other hand, when the impedance ratio is less than 2.5, Rayleigh wave affects to the H/V peak of ground motion. It is consistent with the experience of many researchers measuring microtremor. Figure 3.1 shows the change of H/V ratio of peak and trough of Rayleigh wave versus impedance ratio. In this figure, for impedance ratio around two, there is not a big difference in the H/V of Rayleigh wave. For the impedance ratio bigger than two, H/V ratio for peak of Rayleigh wave increases immediately. It seems impossible to estimate the impedance ratio from the H/V peak of Rayleigh wave. All these examples prove that, as it was explained by Nakamura (1989), H/V peak is mostly related with SH wave and cannot be explained with the Rayleigh waves.

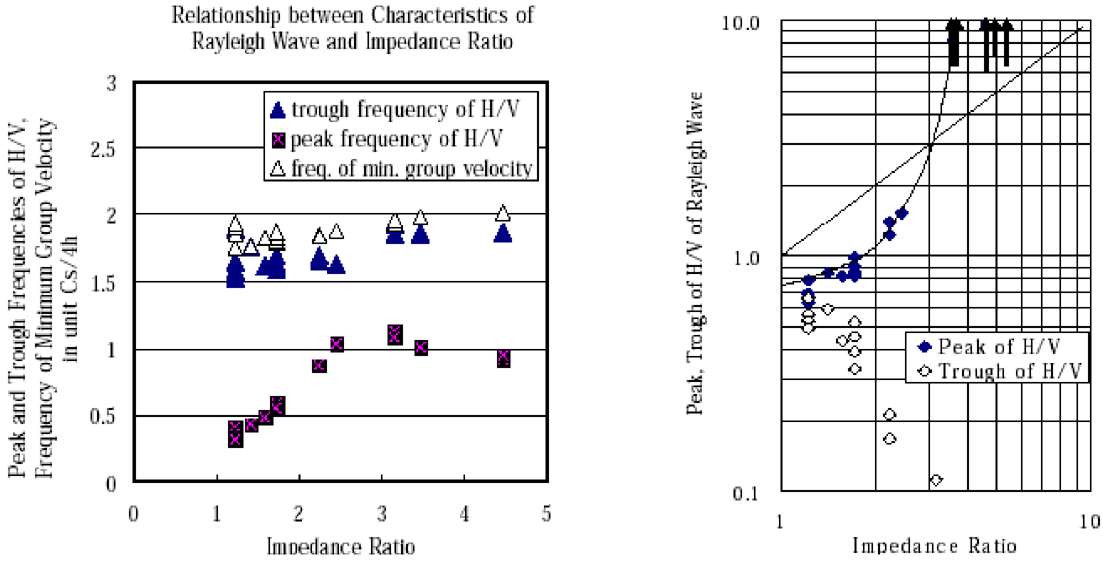


Figure 3.1 Relationship Between Charc. of Raleigh Wave and Impedance Ratio

3.4.3 H/V Ratio Technique

Figure 3.2, shows the typical geological structure of sedimentary basin. Here microtremor is divided into two parts considering it contains Rayleigh wave and other waves. Then, horizontal and vertical spectra on the surface ground of the sedimentary basin (Hf, Vf) can be written as follows.

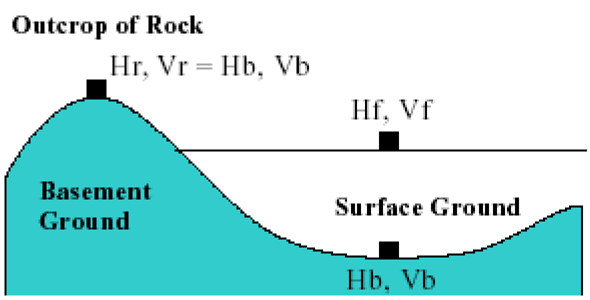


Figure 3.2 Typical Geological Structure of Sedimentary Basin

$H_f = A_b * H_b + H_s \qquad V_f = A_v * V_b + V_s \qquad (1)$

$$T_h = \frac{H_f}{H_b} \qquad T_v = \frac{V_f}{V_b} \qquad (2)$$

where A_h and A_v are amplification factor of horizontal and vertical motions of vertically incident body wave. H_b and V_b are spectra of horizontal and vertical motion in the basement under the basin (outcropped basin). Hs and Vs are spectra of horizontal and vertical directions of Rayleigh waves. T_h and T_v are amplification factor of horizontal and vertical motion of surface sedimentary ground based on seismic motion on the exposed rock ground near the basin. In general, P wave velocity is more than three-four times of S wave velocity. In such sedimentary layer, vertical component cannot be amplified (Av=1) around the frequency range where horizontal component receives large amplification. If there is no effect of Rayleigh waves, Vf=. Vb. On the other hand, if Vf is larger than Vb, it is considered as the effect of surface waves. Then estimating the effect of Rayleigh waves by Vf/Vb (=Tv), horizontal amplification can be written as,

$$T_h^* = \frac{T_h}{T_v} = \frac{\frac{H_f}{V_f}}{\frac{H_b}{V_b}} = \frac{QTS}{\frac{H_b}{V_b}} = \frac{\left[A_h + \frac{H_s}{H_b}\right]}{\left[A_v + \frac{V_s}{V_b}\right]} \quad (3) \qquad \text{where ,} \quad QTS = \frac{H_f}{V_f} = \frac{A_h * H_b + H_s}{A_v * V_b + V_s} = \frac{H_b}{V_b} \cdot \frac{\left[A_h + \frac{H_s}{H_b}\right]}{\left[A_v + \frac{V_s}{V_b}\right]} \quad (4)$$

Figure 3.3, shows a schematic comparison of Horizontal (Hf), Vertical (Vf), Hf/Hb (spectral ratio of sediment site to the reference site) and Hf/Vf (H/V technique). As it can be followed QTS is smaller than the theoretical transfer function. Since Hf includes the effects of Rayleigh waves, Hf/Hb is bigger than the theoretical transfer function. If influence of Rayleigh wave becomes larger, QTS<1 in the wide range of frequency and if influence is small, QTS locally expected to be smaller than one, in the narrow frequency range at frequency several times higher than Fo, because of the influence of vertical motion.

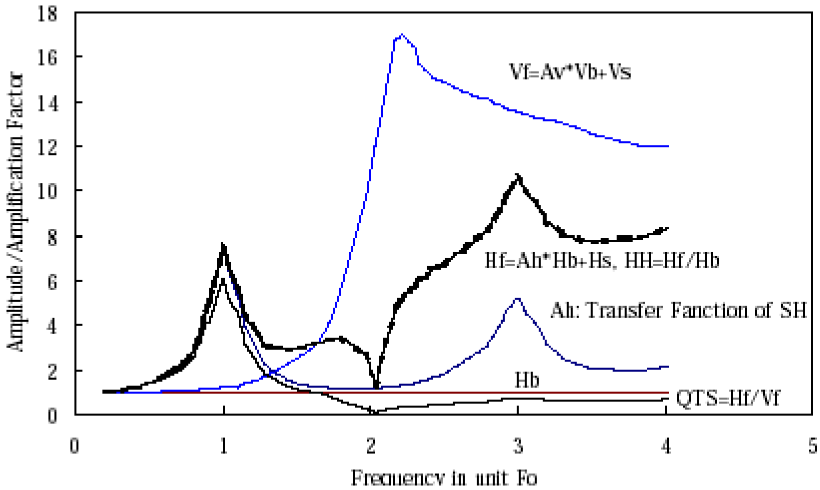


Figure 3.3 Schematic Comparison of Horizontal, Vertical and Spectral Ratio of Sediment Site to the Reference Site

Main waves consisting of microtremors are either body waves or Rayleigh waves, or depending on the location and other conditions can be mixture of both waves. For such microtremors, if we calculate QTS, first order proper frequency by multiple reflections of SH wave in the surface layer and its amplification factor can be calculated correctly. More explanation regarding Rayleigh waves can be found in Nakamura(1996).

3.4.4 H/V of Earthquake Data

H/V ratio is also used in evaluation of earthquake data. Also it gives similar results as microremor.

Figure 3.4(a), shows H/V of strong ground motion of two earthquake different earthquake recorded at the same station. Although waveforms look different, when we take H/V, they look similar. Another example can be found also in a recent study of Okuma et. al. (1999) which is given in Figure 3.4(b). Results again show that

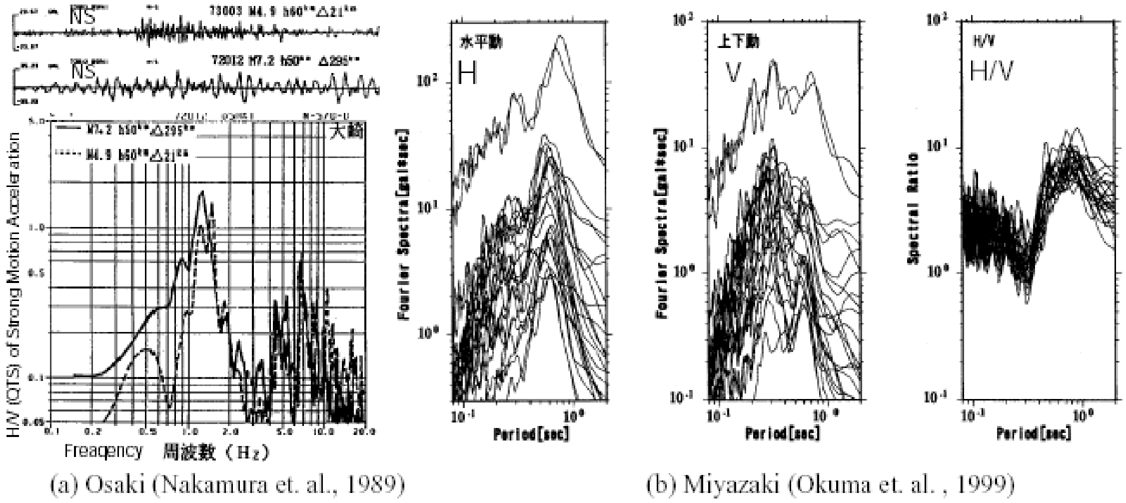


Figure 3.4 H/V Strong Motion For Earthquakes Recorded @ Same Station

H/V gives similar characteristics for the different earthquakes recorded at the same stations. of earthquake motion indicate the transfer function of local surface ground, as same as QTS of microtremor.

3.4.5 Vulnerability Indexes, K-Values For Surface Ground

Transfer funcations of microtremors is also used to detect the vulnerability surface ground.

Among the other approaches, microtremor is the easiest and cheapest way to understand the characteristic features without causing any damage to the structure. Using microtremor data, in a short period of time, present method is able to give valuable information about the natural frequency, amplification factor, vibration mode characteristics as well as week points of every type of ground and structures. With the present approach by defining weak points, it is possible to obtain real earthquake damage before earthquake occurs K values have been proposed by Nakamura (1996) for accurately estimating earthquake damage of surface ground and structures. Only the formulation of Kg, K value for ground, will be given as an example of application of outputs from QTS method. For calculating Kg, shear strain of the ground is considered. Figure 3.5 simply shows the shear deformation of surface ground.

$$\gamma = A_g \frac{d}{h} \qquad (5)$$

where Ag is amplification factor of surface layer, h is thickness of surface layer and d is seismic displacement of the basement. Putting the S wave velocities of the basement and surface layer (Cb and Cf) natural frequency F of the surface layer can be expressed as,

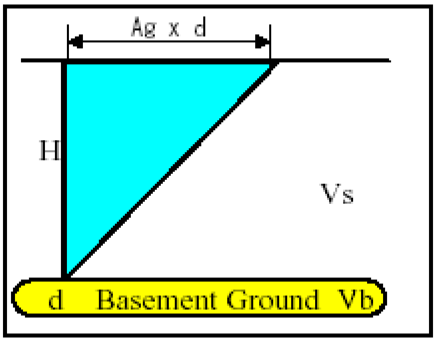


Figure 3.5 Surface Ground Deformation

$$F_g = \frac{V_b}{4A_G h} \qquad (6)$$

Acceleration α in the basement can be written as

$$K_g = \frac{A_g^{\ 2}}{F_g}$$

Kg is a value corresponding to the site and can be considered as a vulnerability index of the site, which might be useful to select weak points of ground.

K values for various types of structures and some application examples can be found in Nakamura (1996), Nakamura (1997), Nakamura and Gurler (1999).

3.4.5.1 Application Examples of K Values

Local Site Effect of Kobe

Yutaka Nakamura, Tsutomu Sato, and Masayuki Nishinaga

The 1995 Hyogo-Ken-Nanbu Earthquake caused heavy damage in Kobe city and its surrounding area. To clear the relationship between damage and local site effect, a month after the earthquake, microtremor measurement was performed. Distribution of vulnerability index Kg value for ground confirmed the damage belt. In this paper, microtremor measurement was made in damaged and surrounding area to clear the relationship between damage and local site effect. In this paper, they aimed to prove that the cause of damage belt was because of the influence of local site effect. Each profile has 15-20 points, total 25 profiles.

Briefly, it is reported that amplification factor (A) has large values in the area where heavy damage occurred.

Kg value reflects local site effect and corresponded with the damage belt and liquefaction as well. It is possible to conclude that the damage of 1995 Hyogo-Ken- Nanbu Earthquake was related to dynamic characteristics of the ground. The damage area between mountain parts and sea parts shows larger Kg value and bigger damage ratio.

Vulnerability Investigation of Roman Collisseum Using Microtremor

In this paper, the vulnerability characteristics of Roman Colloseum was investigated with microtremorNakamura et al. 2000).

Detailed measurements were performed at each floor and vulnerability indices called K-values which are simply derived from strains of ground and structure, proposed by Nakamura (1996, 1997) are calculated and weak points that may collapse during the earthquake are found.

The reliability of this new index is checked by relating with the damage on outer structure caused by 1349 Appennino Central Earthquake.

Results of Analysis of Colloseum as follows: Maximum acceleration values calculated for vulnerable points that are grasped by K values checked with the acceleration value caused by 1349 earthquake. It successfully explains the damage of outer wall during this earthquake. It is concluded that maximum acceptable acceleration values for the supporting wall has a connection showed that, this point is very weak especially in the radial direction and may have more damage from MM VI-VII intensity earthquake.

3.5 Array Microtremor

The knowledge of the seismic site transfer function is important, both in seismic source studies, in order to separate site effects from the earthquake spectrum, and for assessing the seismic hazard. This can be particularly high in areas geologically characterised by soft sediments, which may produce amplification of the ground motion at low frequencies (Aki, 1988).Conventional seismic exploration methods such as reflection or refraction survey are not easy to apply apply in urbanized area for the limitation of using artificial source. Applying these survey techniques, it is also difficult to estimate the S-wave velocity structures that are important for the study of earthquake engineering. An exploration technique using microtremors with seismometers array is a new one as the alternative to the conventional seismic survey.

We can extract phase velocities of surface waves from microtremors in the form of dispersion as a function of frequency or period.The inverswion process applied to the observed phase velocities can estimate geological structures of the S –wave velocity.However, this inveersion process is assumed that the structures beneath the employed sesimometers are the horizontally homogeneous layers.

To estimate phase velocities of surface wave in microtremors, there are two principal methods**: the frequency-wave number method** call F-K method, Capon 1969) and the **spatial auto-corrolation method** (Spac method, Aki 1957). While the SPAC method makes use of a special circular array, the F-K method has no limitation of array configuration. From the numerical investigation or the observed results, the range of wavelengths possible lo estimate phase velocities of surface waves in microtremors by using the SPAC method is longer than that by using the F-K method.(Miyakushi et.al. 1996) Theoretically the SPAC method is superior than the F-K method for the estimation of phase velocities in microtremors

Several experimental evidences properly show a clear likeness between the noise spectral shape and the weak motion spectral ratio (Malagnini et al., 1989; Morales et al., 1991; Fischer and Hough, 1992). Limitations to the method arise when nonlinear effects are produced by strong ground motion (Ohta et al., 1978; Chin and Aki, 1991; Aki, 1993). One of the unsolved problems regarding the noise method in predicting site response is related to the possible presence of localised noise sources, which can affect the spectral shape of the signal (Udwadia e Trifunac, 1973; Aki, 1988; Field et al., 1990; Sato et al., 1991; Milana et al., 1996). In order to take into account this effect and, consequently, to better constrain the applicability of the noise method, it is convenient to use a seismic array to localise the noise sources. Moreover, using small arrays it is easy to obtain the noise velocity dispersion curve, from which it is possible to deduce a local velocity model (Anderson and Dorman, 1973; Ferrazzini et al., 1991; De Luca et al., 1997; Chouet et al., submitted)

3.5.1 Array Techniques

In order to calculate the back-azimuth and the apparent slowness of the wavefield composing the noise, we used frequency-wavenumber spectral analysis. We followed the methods used by Lacoss et al. (1969) and Capon (1969, 1973) which will be described below in the points (a) and (b), respectively. Milana et al. (1996) used the same approach to study the ambient noise recorded at an array set up in Central Italy. In their paper a discussion about the limits of applicability of these two methods and the advantage of using both contemporarily is reported.

3.5.1.1 Beam Forming (BF) Method

Putting an array on the x-y plain, a given wave field f(x,y,t) may be decomposed into plain waves by the Fourier transform:
(Aki, Richards, 1980). The BF method (Lacoss et al., 1969) estimates the power spectral density according to the following relation:

$$P^{\mathrm{BF}}(\mathbf{k}, \omega) = 1/N^2 \mathbf{U} * (\mathbf{k}) S(\omega) \mathbf{U}(\mathbf{k}),$$

where **U**j (**k**) = exp(i**kr**j) = N elements of the vector **U**(**k**); N = number of array stations; **U_** = Hermitian of **U**; S(!) is the cross-spectral matrix, whose elements are expressed by

where dL u is the discrete Fourier transform of length L of the signal at the j th station in the **r** position; the am are the weights of smoothing performed on 2M+1 adjacent frequencies; j and k are the station indexes.

3.5.1.2 High Resolution (HR) Method

This f -k spectral technique (Capon 1969; 1973) estimates the power spectral density according to the following relation:

$$P^{\mathrm{HR}}(\mathbf{k},\omega) = \left[\mathbf{U} * (\mathbf{k}) S^{-1}(\omega)\mathbf{U}(\mathbf{k})\right]^{-1},$$

where the notations are the same as in the beam forming.

Applying the High Resolution or Beam Forming method we obtain a frequency-wave number spectrum. The max peaks of such a spectrum, at a given frequency band, provide the wave vectors, at that frequency, associated with the sources of the noise-field. In this sense we ‘locate’ the possible localised noise sources. From the estimate of the wave vector at different frequencies, it is possible to compute the velocity dispersion curve.

3.5.1.3 Spatial correlation method

When the noise wavefield is composed of the superposition of randomly positioned noise sources, the frequency-wavenumber spectrum must be flat. Under this last assumption the velocity dispersion curve can be obtained by the so-called spatial correlation method described below.

This method was developed by Aki (1957) and is based on a statistical investigation of the stationarity in time and space of the noise signal. Based on these assumptions and referring to the semicircular array geometry Figure 3.6, it can be shown that the azimuthal average of spatial coefficients of noise on the peripheral instruments with respect to the central station, would have predictable patterns as a function of frequency that could be used to obtain information on the seismic properties of the medium (Mahdyiar, 1996).

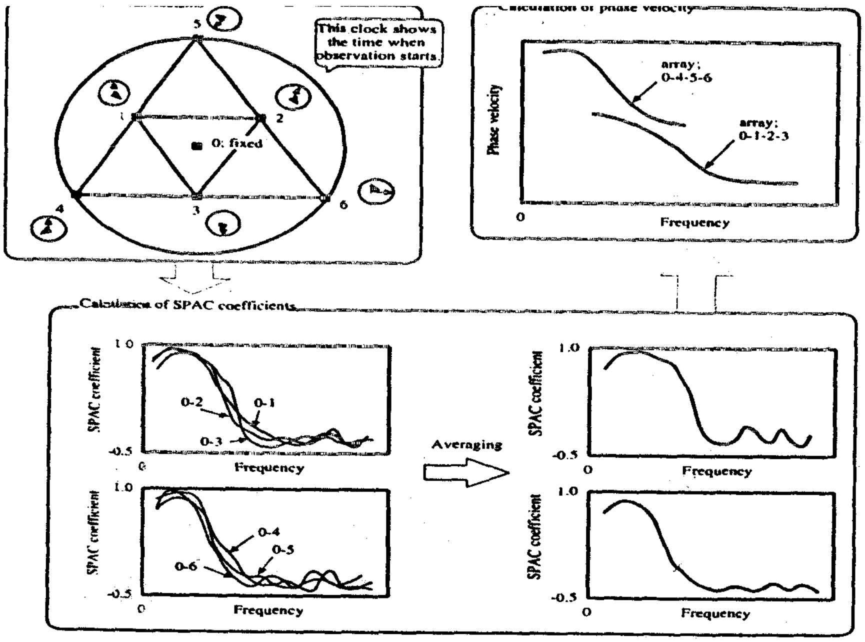


Figure 3.6 Schematic View of Array Microtremor

Considering the noise composed of surface waves, the correlation coefficient for Rayleigh waves at frequency w, distance r, azimuthally averaged, takes the form

$$\rho(r, \omega) = J_0(r\omega / c(\omega)), \qquad 6$$

in which J_0 represents a Bessel function of order zero, c(ω) is the wave velocity dispersive function.

Also it is noted in Morikawa&Toki(1998) that, the SPAC coefficients denoted by equation (2) can be directly calculated in frequency domain using the Fourier transform of observed microseisms: that is,

$$\rho(r,\omega) = \frac{1}{2\pi}\int_0^{2\pi} \frac{Real[S_{CX}(\omega;\ r,\theta)]}{\sqrt{S_C(\omega)\cdot S_X(\omega;\ r,\theta)}}\,d\theta, \qquad 7$$

where Rea!(•) stands for the real part of a complex ralue, *Sc(w)* and *SX(w; r, θ)* are power spectra of microseisms at two sites C and X, respectively, and *Scx(w; r, θ)* is cross spectrum between the two sites. This equation means that the SPAC coefficients are obtained by averaging normalized coherence function defined as co-spectrum between two sites with regard to direction θ.

Since equation (7) can be directly obtained from observed microtremors using techniques such a FFT (Fast Fourier Transform) method, the phase velocity at w is computed from the argument of Besset function of equation (6).

Computing the correlation coefficient at different frequencies and at a fixed distance, it is possible to get an experimental correlogram p(r,ω), from which a dispersion function c(ω) can be calculated, identifying the zeros, maxima and minima of the experimental correlogram, and equalising the arguments of the experimental function with the ones of the Bessel function.

- The spacing among the stations is irregular, to avoid spatial periodicity in the signal sampling (Horike, 1984). The arrays' sizes are chosen according to the expected velocities of the surface medium; in fact, the range of wavelengths to be analysed is strictly dependent on the geometry of the array (the minimum and maximum wavelengths are twice the minimum spacing among stations and twice the maximum linear extension of the array, respectively). Not-suitable dimensions could produce spatial aliasing, and hence, biased estimates of the physical parameters (apparent velocity, azimuth of the wave front). The maximum array size has been designed according to the expected seismic velocities.
- The wave field analysis in the f-k domain is valid on the hypothesis of a laterally homogeneous medium; consequently, we chose, sites characterised by lateral homogeneity, deduced from the available geological information.
- for each of the investigated sites. At that time there was moderate human activity, with a lower number and a higher stability of sources, as required by f -k spectral analysis.
- The hypothesis of randomly distributed sources and space stationarity, required by Aki's method, is reasonably better fulfilled during the daytime, because the presence of many sources of noise, as for example the vehicle traffic and in general the human activity, which are spread off in the easurement areas. During the night

time the possible presence of isolated monochromatic sources, located close to the array area, could make the space stationarity hypothesis unrealistic.

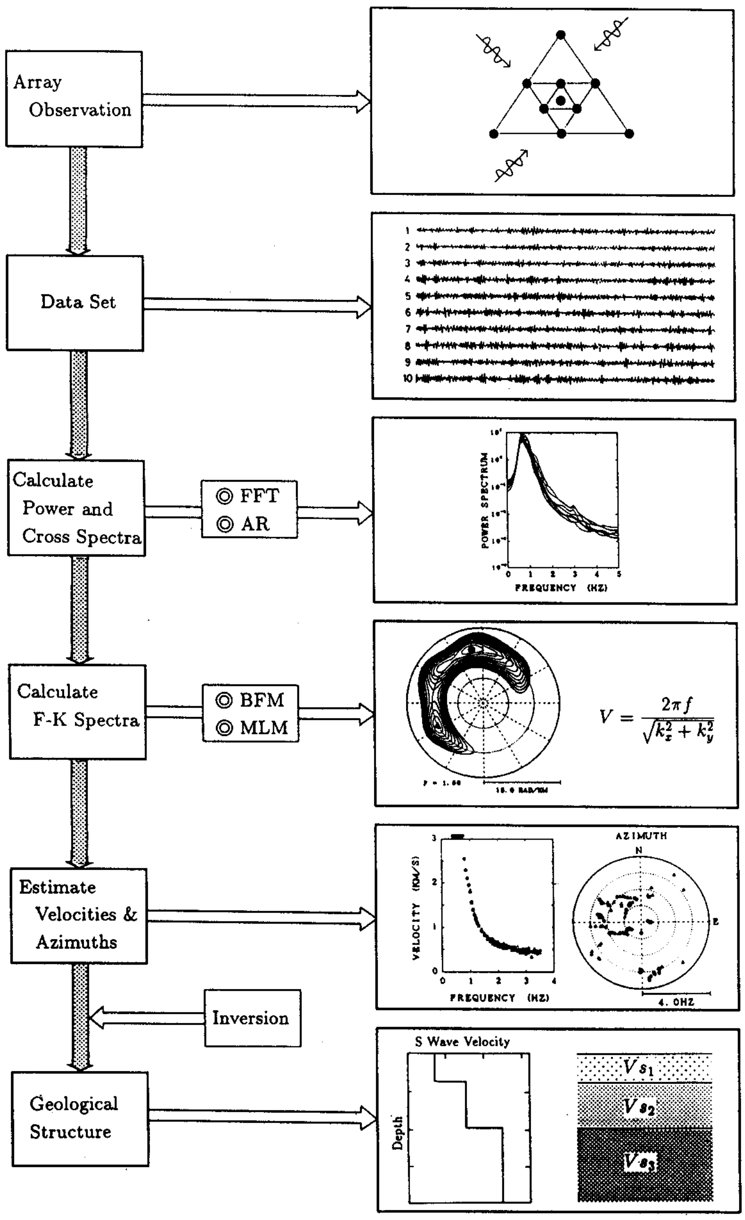


Figure 3.7 Flow of Data Analysis by the f-k Method

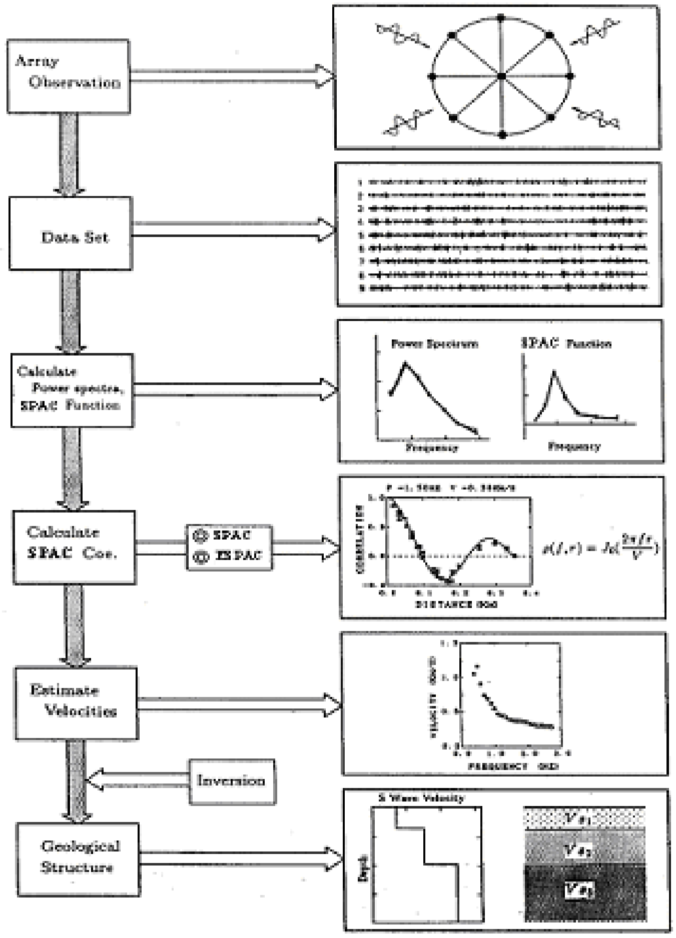


Figure 3.8 Flow of Data Analysis by the SPAC Method

4 MICROTREMOR STUDIES AT ADAPAZARI

4.1 Adapazarı Geology

4.1.1 Location of Adapazarı

Adapazarı is an agricultural, business and industrial city to the east of Istanbul, Turkey with a population of around 200 000. Total area of 4,821 km^2 is situated between longitude of 29º 57' and 30º 53', and latitude of 40º 17' – 41º 13(Figure 4.1 and 4.2).

Figure 4.1 Location of Adapazarı

Figure 4.2 Location of Adapazarı with respect to North Anatolian Fault (NAF)

4.1.2 Geologic Setting of Adapazarı

Adapazarı sits on a deep alluvial basin at an altitude 28 m next to the Sakarya River and the depth of sediments under the city has been estimated to be more than 400m in places.

Adapazarı is located at the edge of a sedimentary basin called by the name of the city. The basin, which is former lake bed, is underlain by thick sediments of clay. Quaternary alluvium, primarily consisting of silt and fine sand, deposited by Sakarya River and its tributaries overlay the lake sediments. Depth to the bedrock exceeds 300 m at several locations over the basin. Hills encompassing the north and east of the basin are comprised of pre-quaternary soft to medium rock formations of igneous and sedimentary origin. (Bakır 2000,Önalp 2000,Bray et.al. 2001))

Most of the city is situated over the Quartenary alluvial sediments of the basin, but small part on the south is underlain by Cretaceous Flyshoid formation, which is in turn overlain by Eosene Limestone on the west. Average elevation of the city is about 30 m with a mild slope towards north on the south, then rather smooth surface topography on the north over the plain. Various of bedrock depth underneath the city is depicted in Figure 4.3

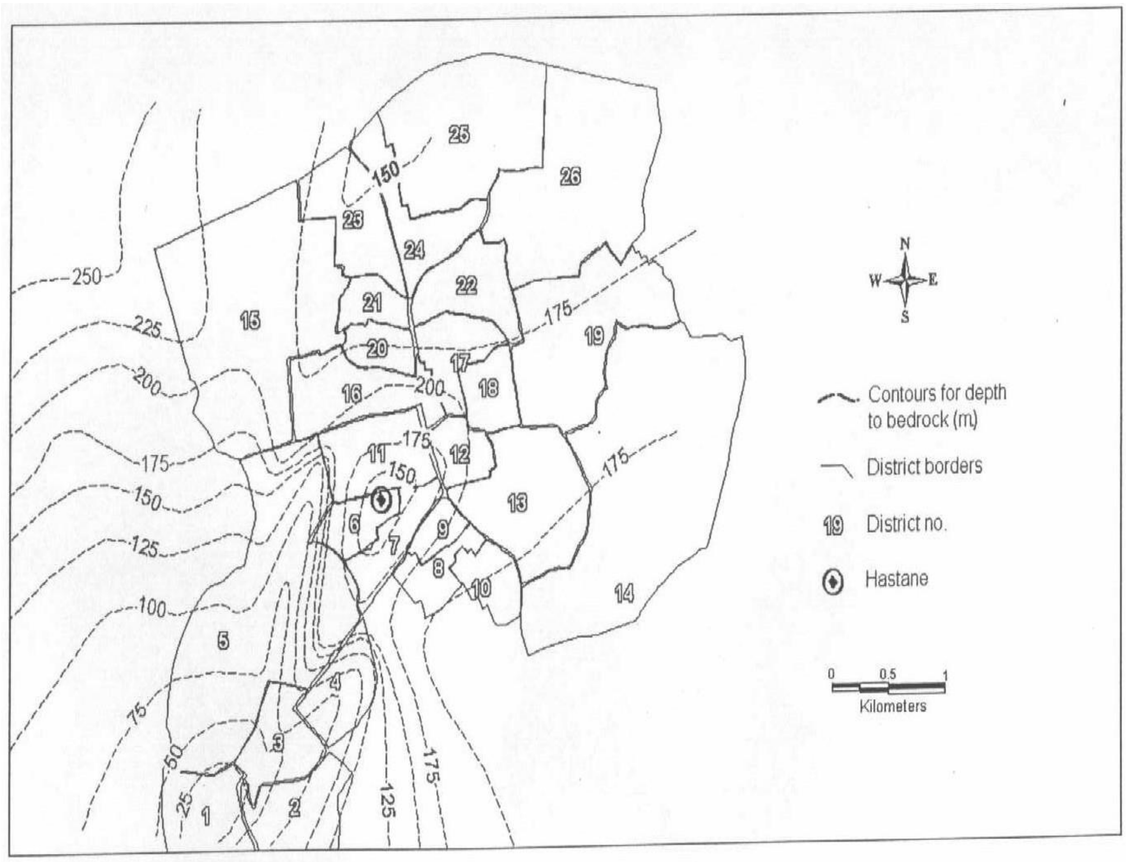


Figure 4.3 Contours for depth to bedrock

Accordingly, thickness of alluvium is highly variable, increasing from a few meters on the south through north, reaches 200 m under the densely urbanized central section. The ground level is consistently high throughout the city, ranging between 0.2 m to 3 m depths from the ground surface, even in the driest season.

The vicinity of Sakarya (imar) Construction Department is situated on the prevailing stiff and shallow soils, mainly decomposed of Eosene Limestone. The depth of bedrock is about 200 m under Hastane district which is mainly soft soil.

The geological map of Adapazarı region is given in 3D view in Figure 4.4**.** Outstanding features of the study area are the outcropping of Permian-Triassic red sandstones and grey dolomites; sandstones and quartzites outcrop on hills to the north. Upper cretaceous formations intrude from the southwest containing marl, sandstone and their mixtures with limestones. The Lower-Mid Eocene Upper Cretaceous is overlain by basalt, agglomerate and tuffs in Serdivan a suburb of Adapazarı to the west.

The deep alluvium however dominates the area and the majority of the population settled on it despite the frequent earthquakes, flooding of Sakarya River and malaria since the III Century A.D, hence its Turkish name; the island market. The will of the people to survive in this precarious area has been attributed to the city's important location on the East-West trade route. A boat was used for the transportation between the island and nearby areas. Floods of the Sakarya River that occurred nearly every two years filled the area covered by water. At present, two rivers run near the city from the south to north. The Sakarya River runs on the east side of the city and flows into the Black Sea. The Cark River, which runs on the west side of the city, flows out from the Sapanca Lake and into the Black Sea. Because the Sakarya River is much wider than the Cark River, the present town area is supposed to be an alluvium plain formed by the Sakarya River.

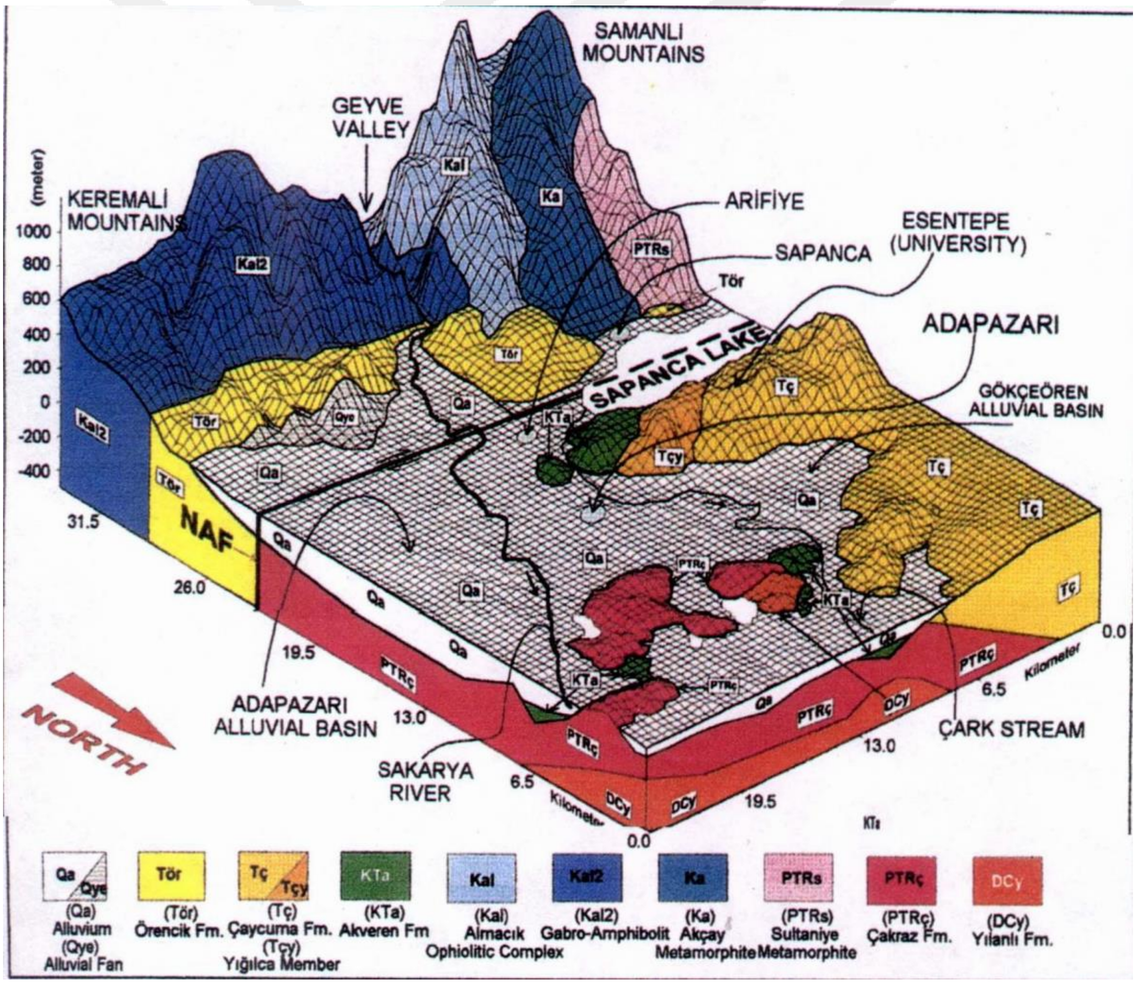


Figure 4.4 The geological Map of Adapazarı region

4.2 Site Characteristics of Adapazarı

4.2.1 Seismicity of Adapazarı

Adapazarı, the provincial capital of Sakarya is located in the immediate vicinity of the North Anatolian Fault. It is located 8 km north of the North Anatolian Fault (NAF). The NAF is a 1200 km east – west trending right lateral fault that cuts across the northern Turkey. This fault has been known to be active approximately every decade. The North Anatolian Fault affected the city within the last 60 years. The last four severe earthquake had been recorded on 26 June 1943 with local magnitude of 6.6 had an epicenter 10 km east of the city, 1957, whereas Mudurnu earthquake on 22 July 1967 with local magnitude 6.8 had an epicenter 27 km away in the south-east direction. The most devastating earthquake stroke Adapazarı on 17 August 1999. Figure 4.2 shows the location of Adapazarı and Figure 4.2 shows the location of Adapazarı with reference to the North Anatolian Fault (NAF).

Seismic activity of Adapazarı region is depicted in Figure 4.5. The tabular form of the seismic events of magnitude 5 and greater is given in

Table 4.1. Totally 3768 event was recorded between the years 1900-2003. These data is obtained from Kandilli Observatory and Earthquake Research Institute. Detailed information of the events is as follows;

M=1 - 1.9	38
M=2 – 2.9	2381
M=3 – 3.9	1149
M=4 – 4.9	159
M=5 – 5.9	36
M=6 – 6.9	1
M=7 – 7.4	4

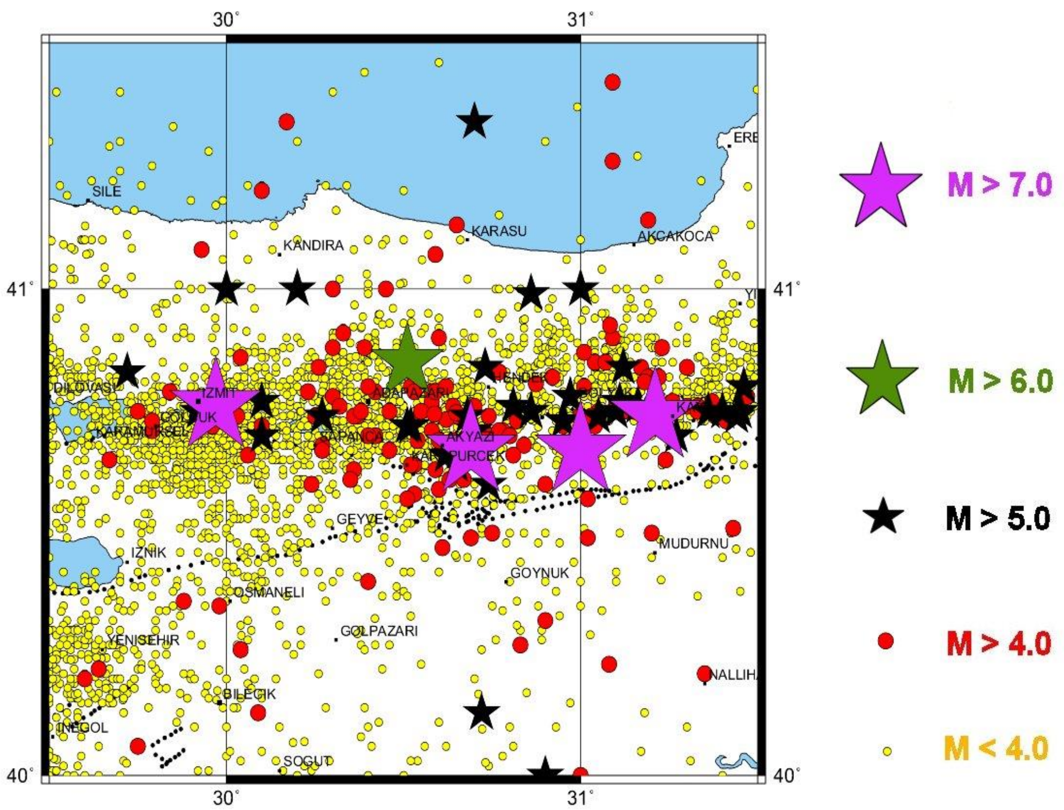


Figure 4.5 Seismicity of the Region Between 1900-2003

Table 4.1 Greater Than M=5 Eq. for (29.5E-31.5E and 40.0N-41.5 N) Between 1900-2003

Date	Time	Lat	Lon	Depth Km	M
17.08.1999	00:01:38	40.76	29.97	18	7.4
22.07.1967	16:56:58	40.67	30.69	33	7.2
12.11.1999	16:57:21	40.74	31.21	25	7.2
26.05.1957	06:33:35	40.67	31.00	10	7.1
20.06.1943	15:32:05	40.85	30.51	10	6.5
26.05.1957	09:36:39	40.76	30.81	10	5.9
27.05.1957	11:01:35	40.73	30.95	50	5.8
13.09.1999	11:55:29	40.77	30.10	19	5.8
23.08.2000	13:41:28	40.68	30.71	15	5.8
16.12.1926	17:54:05	40.13	30.72	10	5.7
11.11.1999	14:41:26	40.74	30.27	22	5.7
Date	Time	Lat	Lon	Depth	M

21.08.1907	00:00:00	40.70	30.10	15	5.5
29.05.1923	11:34:02	41.00	30.00	25	5.5
20.06.1943	16:47:57	40.84	30.73	10	5.5
05.04.1944	04:40:43	40.84	31.12	10	5.5
17.08.1999	03:14:01	40.64	30.65	15	5.5
26.05.1957	08:54:51	40.60	30.74	40	5.4
30.07.1967	01:31:02	40.72	30.52	18	5.4
12.11.1999	17:18:00	40.74	31.05	10	5.4
24.01.1928	07:36:12	40.99	30.86	10	5.3
22.10.1905	03:42:00	41.00	31.00	27	5.2
26.12.1957	15:01:45	40.83	29.72	10	5.2
31.08.1999	08:10:52	40.75	29.92	17	5.2
12.11.1999	17:17:00	40.75	31.10	10	5.2
12.11.1999	17:27:00	40.75	31.40	10	5.2
12.11.1999	17:30:00	40.75	31.45	10	5.2
02.02.1944	03:33:17	40.74	31.44	40	5.1
26.05.1957	09:13:59	41.34	30.70	10	5.1
12.11.1999	17:23:00	40.76	31.16	10	5.1
01.02.1944	06:08:52	40.70	31.27	10	5
06.01.1956	14:52:59	41.00	30.20	10	5
01.06.1957	05:26:59	40.75	30.86	50	5
22.07.1967	17:48:07	40.66	30.62	26	5
22.07.1967	18:09:55	40.72	30.51	35	5
19.04.1970	13:33:04	40.00	30.90	0	5
17.08.1999	09:02:12	40.77	31.11	16	5
22.08.1999	14:30:59	40.74	30.68	5	5
07.11.1999	16:54:42	40.71	30.70	10	5
12.11.1999	18:14:00	40.75	31.36	10	5
17.11.1999	08:15:26	40.80	31.46	9	5
19.11.1999	19:59:08	40.78	30.97	9	5

4.2.2 Damage at Adapazarı in 1999 Kocaeli Earthquake

Adapazarı suffered the largest level of gross building damage and life loss of any city affected by Kocaeli Earthquake (Bray and Stewart 2000). Turkish government indicate that a total of 5078 buildings (27% of the building stock) were either severely damaged or collapsed. Almost 2% of the city population were killed during the 1999 Kocaeli Earthquake. The overall damage level was strikingly low in the southern section of the city, situated over stiff and shallow soils, despite mere average distance of 5 km from the ruptured fault. As a general trend, concentration of damage over the city is increased rapidly through north. The greatest impact was received by the tall structures located on the soft and thick alluvial soils. The ratio of collapsed and heavily damaged buildings exceeded 22% of at central districts where alluvial soil thickness ranges between 125 m and 200m.

The liquefaction phenomenon was widespread almost along the fault. Structures were heavily damaged in the region due to liquefaction. Liquefaction induced ground failures caused sinking, settlement and tilting of structures. The effects of liquefaction have been observed in many places in the city. Severe damage has been observed in Tığcılar district as a result of liquefaction.

4.2.3 Formations of Soils

The soils of Adapazarı originate from the meandering streams of Sakarya and the Çark. Sakarya is the sixth longest river in Turkey running from the Anatolian highland to Black Sea in 830 km. The latter drains the excess water from Lake Sapanca to the black Sea joining Sakarya River further to the north. It is thought that Sapanca is a pull-apart lake formed by the fault, which has moved south in geological time.

Sakarya river appears to have often changed course in the Holocene going through what is now the city of Adapazarı, resulting in the deposition of sediments ranging from clays to well graded sands and gravels. There is evidence backed by the now stranded roman bridge built by emperor Justinianus with the spurs now in the downstream side, that there has been considerable tectonic uplifting or subsidence reversing the location and the direction of flow. These activities have caused formation of marshes, even bogs that are identified by highly organic layers at as deep as 100 metres.

In the later times when the town of Adapazarı was fully established, Sakarya continued to flood the area annually although the velocities were now significantly diminished. The top 5 – 10 m of the alluvium therefore overwhelmingly contains nonplastic silts and silty sands. Clays of low plasticity are found where flood waters remained long after the flood receded forming what the elders of the city call ‘fish holes’ as recently as 1965. Taming of Sakarya River by the four dams built upstream has ended the era of rapid sedimentation.

A typical current soil profile in the city can be described a top layer of frequently alternating nonplastic silts and clays down to 5 m, below which dense sands or medium overconsolidated clays are met.

4.2.4 Local Soil Profile

To assess the local soil condition information, numerous boreholes drilled in Adapazarı Central Municipality Area before and after the 17 August, 1999 earthquake is used. Two different governmental departments made borehole investigations. The shallow boreholes of various depths ranging between 10 and 60 m include those drilled for ground investigation purposes regarding construction work and as a part of the comprehensive ground investigation program initiated by the Municipality of Adapazarı after the earthquake. Secondly, boreholes reaching up to 150 m depth were drilled by the State Water Works Department to assess the ground water reserve in the area. Deep and shallow borehole locations are depicted in Figure 4.6

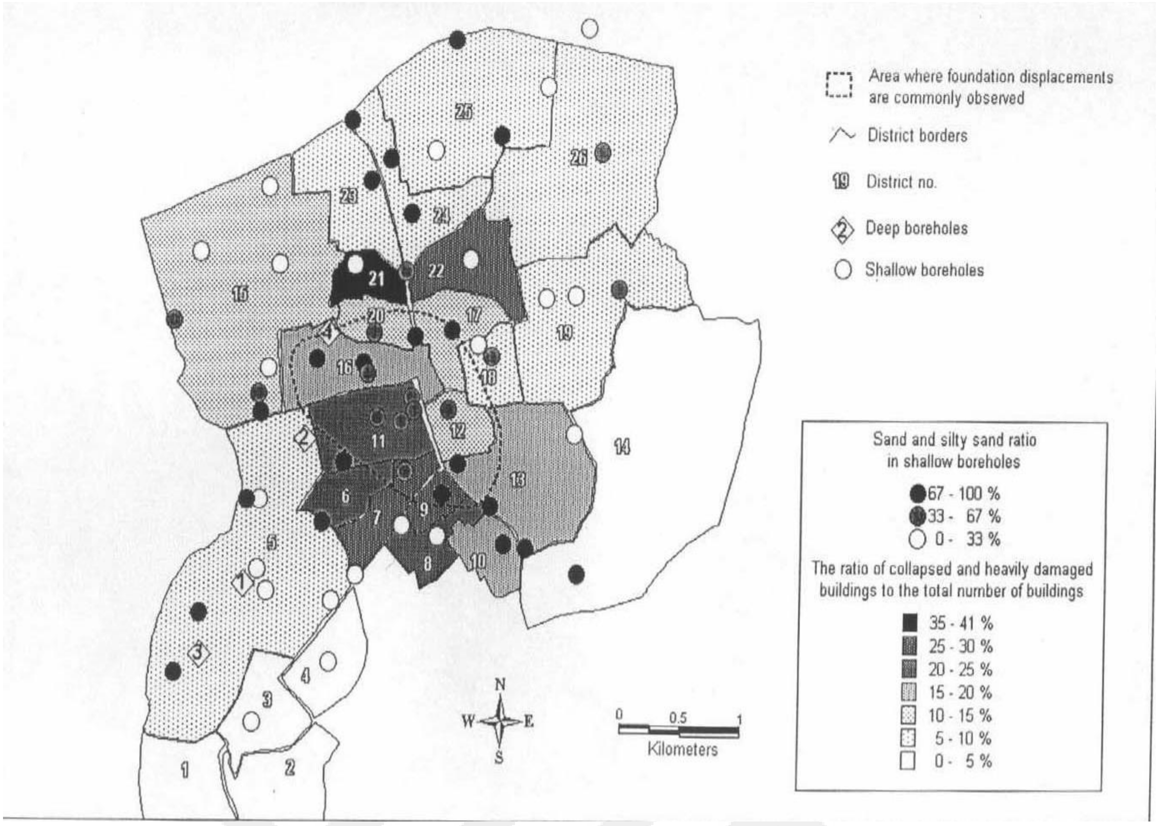


Figure 4.6 Deep and shallow borehole locations

Shallow boreholes revealed that the ground water level varied between 0.8 m and 2.8 m. Beneath a usual fill up to 2 m thickness at the ground surface, the top 15 m of the deposits dominantly consists of alternating sand, silty sand and sandy, clayey silt layers, with occasional clay and gravel bands, whereas bulk of the fine grained soils is of low plasticity. The soil property ranges acquired from the related data for the top 15 m of deposits. According to Unified Soil Classification System, almost 50 % of the soils in this depth range are classified as sand an d silty sand with the Standard Penetration Test blow counts (SPT-N_{60}) indicating , in general, a relative density of loose to medium in the op 10 m and medium to dense at greater depths. Lateral variation of soil types observed in the top 10 m borehole logs indicates a concentration trend of sands and silty sands in the central districts. Another general trend is that below a depth of 10 m, clays increasingly dominate with increasing depth.

Thick layers of occasionally silty sandy clay are observed to underlie the surface soils consistently in the logs of all four deep boreholes, none of which attaining the bedrock. Available data within limited depths up to 50 m point out a consistency range generally between stiff to hard and a highly variable plasticity index range (17- 58%). Clays continue until the end of boreholes, except being intersected by strata of gravel of variable thickness below a depth of 80 m. Logs of all four available deep boreholes and representative soil column are presented in Figure 4.7.

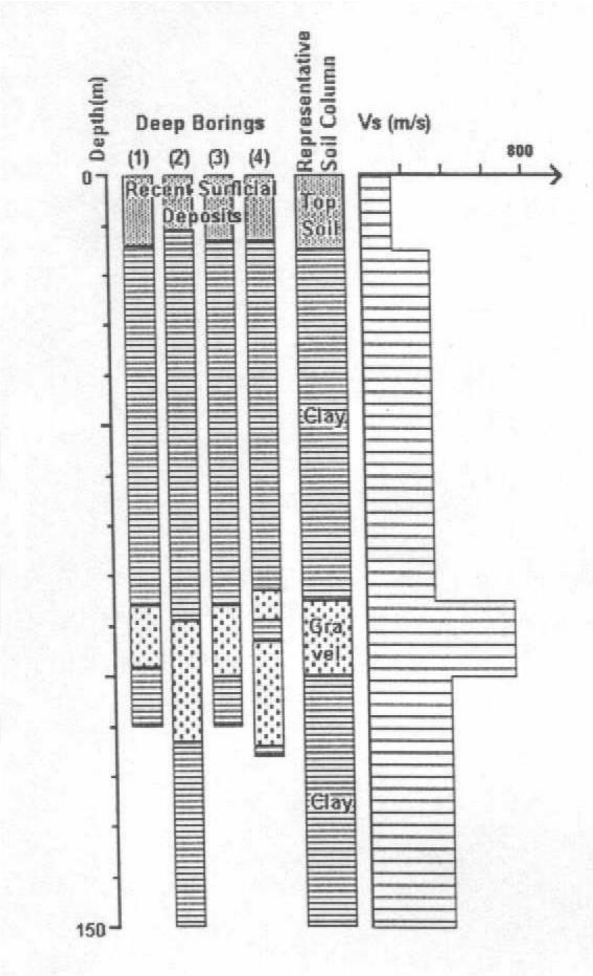


Figure 4.7 Deep Borehole logs

4.3 Data Analysis

The microtremor measurements used in this study was obtained from site work in Adapazarı and from Drm project.

4.3.1 Procedure of the Database

The following common data processing steps are used to evaluate the microtremor measurement. To assess the quality of the data, we first visually inspected the records to ensure that the record was not contaminated by the noise generated either by the instrument or by the cultural noise.

To achieve visual inspection, firstly, for one of the horizontal component, five sets of a time window of 100-sec duration was selected. After removing the mean from the selected parts, the start and the end of the windows of components are tapered by 10% cosine window and the Fourier amplitude spectrum was calculated. Then, we observed the five spectrums in the same window to see the coherence of the records by considering the peaks and the frequencies. The process was done until the five spectrums were suitable.

Next, time windows of 100-sec duration of the vertical and the other horizontal component were selected according to the chosen horizontal component. The start and the end of the windows of components are tapered by 10% cosine window to eliminate the noise due to non-zero element at the beginning and at the end of the data. Then bandpass filtering of 0,15Hz and 10 Hz was achieved. The Fourier spectrum was then estimated from the time history using a Fast Fourier algorithm. This process was also completed for the other selected parts. Spectrums were smoothed by a simple moving average filter to remove narrow peaks. It was used Hanning window in the calculation.

Smoothing operation helped us to obtain the actual information. If there exists a local peak, the H/V ratio may give larger peaks due to that localized peak. The average horizontal spectrum is computed by getting the geometric mean of the components. The resulting spectrum and vertical spectrum was divided to obtain H/V ratio.

All of the five ratios were compared visually by plotting in two different way; first in different figures, second, in the same figures. Checking the peak frequencies and amplitudes had made final benchmark of the records. Finally, mean of the records was calculated and plotted.

4.3.2 Site Work

Between 10th and 20th of the September 2003, I participated a site work of the research group from Japan. Hiroshi Okada from Hokkaido University and Kazuyoshi Kudo from Tokyo University were the leader of the group.

Array and single station observations of microtremors were carried out near the permanent strong-motion observation sites and the damaged areas, after the Kocaeli, earthquake of 17 August 1999. Measurements were done at the strong motion stations named Adapazari ADU, ADC, SKR, Bayındırlık site and all over Adapazari.

The major objectives were to determine the *S*-wave velocity structures at the sites and to understand the site effects on strong motion or damage. Beside, single station microtremor measurements were also completed. Array observation of microtremors is a useful method for determining the *S*-wave velocity structures in a sedimentary basin and single station microtremors are useful method for determining peak frequency of the basin with less practical restriction than the other geotechnical methods.

Three-component seismometers is in a small mobile box. We can connect external seismometer or accelerometer if it is needed. The recorder includes a GPS receiver and runs with a compact battery in the box. The GPS receiver provides a precise clock signal for the timing of recording. Seismic signals were digitized at a rate of 100 Hz, and the data resolution was 24 bits. The files were stored in a hard disk

The sampling frequency of Drm datas is 31.25Hz, whereas the duration of the record is 30 minutes generally.

4.3.3 Instruments

The portable seismograph used in this study was originally developed for temporal observation of strong and weak earthquake motions (Kudo *et al.*, 1998). It is composed of a triaxial accelerometer (Akashi Co. Ltd.) of the highly damped (*h* _ 26) moving coil type (natural frequency of 3 Hz), a signal conditioner (amplifier and filter) and a data logger (24 bits digitizer, 20 megabytes flash memory, and Global Positioning System time synchronization; Hakusan- Kogyo Co. Ltd.). A flat response (_3 dB) of ground acceleration is attained from 0.1 Hz to an aliasing frequency. The sensitivity of the sensor is 1 V/*g* and optionally 5 V/*g*; *g* denotes the gravity. Instruments were also used for aftershock observations without amplification. The clipping level of a sensor is 150 cm/sec; the maximum observable acceleration is 1*g* at 1 Hz or 10*g* at 10 Hz. The allowable input level of the data logger is selectable, 1 or 5 V. Total weight including an inner battery (2 kg) is 7 kg. The low-pass filter for cutoff frequencies at 2, 5, and 30 Hz is provided.

Figure 4.8shows the coherences of instrumental responses obtained using simultaneous recordings of microtremors at the same foundation. It is apparent that there is no use for instrumental correction in the frequency range between 0.1 and 10 Hz.

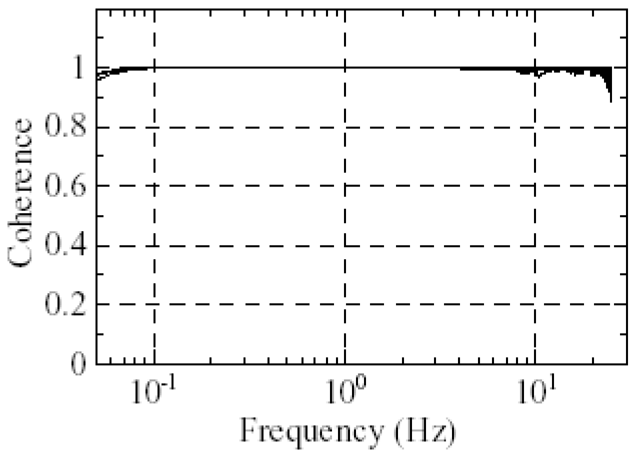


Figure 4.8 The coherences of instrumental responses used in this study

Table 4.2 Instrument specifications

Sensor:	JEP-6A3 (Akashi co. ltd.)
	heavily over damped moving coil type accelerometer
Damping constant	26
Natural frequency	3.0Hz
Flat response	0.1-80 Hz (- 3dB)
Sensitivity:	1V/G, 5V/G
Clipping level	150cm/s
Logger:	DATAMARK LS-8000WD
	(24bitA/D: Hakusan-Kogyo)
Sampling:	50/100/200Hz
Actual resolution:	20-21 bits
Clock:	GPS synchronization
Accessories	
Amplifier:	10000 max.
Filter:	Low-pass (2, 5, 30Hz)
Weight:	7kg including inner battery (7Ah)

Figure 4.9 Instrument with external accelerometer connected

Figure 4.10 Instrument installation

Figure 4.11 Setting up the data logger

Figure 4.12 Microtremor measurement

Figure 4.13 A scene from microtremor mesasurement

5 INTERPRETATION OF MICROTREMOR MEASUREMENT RESULTS

5.1 Microzonation

In order to reduce damage in a future earthquake, it is important that the weak points that came to light in the damage pattern of the earthquake be avoided in future development. The most effective measures are the reduction of the vulnerability of buildings and other structures and the development and application of appropriate land use plans. Microzonation is a valuable tool to define the location and quantifying the degree of the earthquake hazard. Such information guides planners, businesses and individuals in both avoiding the hazard (choosing where and how to build) and mitigating it (strengthening existing structures and planning for emergency response)

A microzonation study is designed to map and evaluate the different components of local seismic hazard at the scale of a study area. When the effort is multidisciplinary, combining information and interpretations from the geologic seismologic, tectonic, geotechnical and engineering disciplines, microzoning is most definitive and useful. Depending on the scale chosen, the parameters obtained from different locations in seismic microzonation studies are not always precise and may not reflect the existing conditions for structural design. Therefore site-specific investigations need to be performed in each site for more accurate and safer design. A classification in terms of priority levels can be used to overcome this situation and parameters determined from seismic zonation studies may be used in the design process of the selected structures, i.e. one or two storey residential buildings. On the other hand, site specific studies, including in situ and laboratory tests, must be obligatory in assessment of the required parameters for the structures with higher importance levels (Ansal. A, Erdik et.al 2002).

One of the most important issues in any microzonation is the selection of the appropriate scale to be adopted in the final output that would be the seismic zonation maps with respect to different parameters. The scale for the indented output maps in the light of the contemporary seismic microzonation methodologies is towards adopting scale of 1:5000 with suggested mesh size of 0.005 x 0.005 degrees roughly, 500 m x 500m in identifying, aggregating and analyzing the available data sets. In the following, main steps of microzonation studies shall be summarized.

There are different ways of performing microzonation. Zoning for ground motion, slope stability and liquefaction are the main categories, which also includes three grades under it. In the grade-1, it is based on compilation and interpretation of existing information available from historic documents, published reports and other available databases. Maps are in the range 1:1000 000 to 1:50 000. Second level of zonation consists of improved information according to grade at moderate cost. For instance, aerial photographs can help understanding local geology and additional field studies may be performed. Microtremor measurements are considered in grade-2 zonation. The scale is about 1: 100 000 to 1:10 000. In the grade 3, very high and very detailed level of zonation is required, for example in scales in range 1:25000 to 1:5000. Additional site investigations may be incorporated into computer aided analysis of seismic ground response, slope stability behavior etc.

Table 5.1 Use of Data for Three Levels of Zonation

	Grade-1	Grade-2	Grade-3
Ground motions	• Historical earthquakes and existing information • Geological maps • Interviews with local residents	• Microtremor • Simplified geotechnical study	• Geotechnical Investigation • Ground response analysis
Slope instability	• Historical earthquakes and existing information • Geological and Geomorphological maps	• Air photos and remote sensing • Field studies • Vegetation and precipitation data	• Geotechnical investigation • Analyses
Liquefaction	• Historical earthquakes and existing information • Geological and geomorphological maps	• Air photos and remote sensing • Field studies • Interview with local residents	• Geotechnical investigation • Analysis
Scale of mapping	1:1,000,000~1:50,000	1:100,000~1:10,000	1:25,000~1:5,000

1. Zoning for Ground Motion

Zoning for ground motions addresses one of the most fundamental aspects of seismic hazards assessment. Initially, seismic forces acting structures are related to ground motion. Also, ground motions are related to soil failures, which can further lead to damage to structures.

Several factors such as source, path and site effects can affect the ground motion. An assessment of ground motion depends on the seismicity, attenuation of groun motion and local site effects on ground motion.

A. Local Site Effects : Geological And Geotechnical Site Characterization

Local site effects on ground motion are considered to be the most significant factor in zoning of ground motion. Local site effects can be defined as the of predicted motions at the outcrop, where there is no significant site-specific amplification of motion. Then actual motions at the local site can be computed.

The main purpose of this step is to identify main geological and tectonic formations within the boundary of the area of concern. There is some relationship between the geology and site amplification, however zoning maps based on surface geology may not provide definitive information for site-specific evaluations.

Additionally subsoil condition pertinent to subject area should be determined via in situ tests such as SPT, CPT and laboratory tests conducted on undisturbed samples. It should be kept in mind that these tests should consist of two groups, of which the first group is needed to determine soil classification, grain size characteristics and index properties of soil, whereas the second group are conducted to obtain stress-strain and shear strength characteristics of soil. Sieve analysis, Atterberg limits, natural water content tests are considered in the first group. For the second group of tests, resonant column, impulse wave velocity measurements, and cyclic triaxial, cyclic simple shear tests shall be done.

Even if site investigation is not available at a site, indirect information about the geotechnical properties of the site can be obtained by microtremor measurements. Ambient vibrations are measured by high sensitive of seismometers.

Another valuable tool for evaluating local site effects is compiling data on the distribution of damage induced during past earthquakes. As the area of damage does not by itself give a quantitative evaluation of ground motion intensity, the damage is often expressed by seismic intensity to achieve better quantitative evaluation.

B. Assessment of Seismic Hazard

There are two general approaches in determining seismic hazard: deterministic and probabilistic. The deterministic approach is based on selected scenario earthquakes and specified ground motion probability level. On the other hand the probabilistic approach, which is much superior and preferred in microzonation studies considers all possible earthquake scenarios all ground motion probabilities. In both approaches empirical attenuation relation ships are utilized for calculation of the seismic hazard in terms of PGA, PGV, Arias Intensity and Spectral Accelerations.

2. Assessment of The Liquefaction Susceptibility

Liquefaction, which is the loss of shear strength as a result of increase in pore water pressure in loose, saturated granular soils when they are subjected to cyclic loading, is an important consideration in microzonation studies. Either in situ tests or laboratory tests are used in order to determine liquefaction resistance of soils. Although the most conventional way of estimation is utilization of SPT and CPT tests for this purpose, Ansal (1991) and Finn (1993) emphasize the importance of laboratory tests.

Cyclic stress ratio (CSR) is calculated from an empirical relationship based on peak horizontal surface acceleration, acceleration of gravity, total and effective vertical overburden stress, and stress reduction factor. In using the empirical relationships based on SPT, CPT and shear wave velocity the procedure is based on relating the cyclic resistance ratio (CRR) of the soil with N/SPT value, tip resistance of the cone and shear wave velocity values respectively. Cyclic resistance ratio determined is valid for an earthquake of magnitude M=7.5. For earthquakes with other magnitudes a scaling factor MSF is applied to adjust CRR to other magnitudes.

Factor of safety against liquefaction is defined as ratio of CRR to CSR, adjusted to any magnitude by multiplying with MSF. In microzonation for liquefaction, the site is divided into zones considering the factor of safety values calculated against liquefaction.

3. Assessment of Landslide Hazard

For conducting landslide hazard analysis three basic approaches (consisting of statistical, pseudo-static, permanent-displacement approaches) exist. The comprehensive microzonation procedures identify areas with different degrees of susceptibility and of slope instabilities. The slope failure potential is evaluated considering geotechnical properties of soil and rock layers, slope geometry as well as peak ground acceleration.

5.2 Using GIS For Microtremor Evaluation

The fundamental frequencies and amplitudes of Adapazarı obtained from microtremor measurements are transmitted to maps with the help of Geographical Information System (GIS). The software used to achieve transferring the parameters is named MapInfo.

The geographical Information Systems are used to execute the analysis of every kind of information varies geographically. The basis of this method is using the data and mapping tools. After transferring the data onto the map, it is easy to make queries on the map with respect to data.

Microtremor measurement results and geographical coordinates that are obtained by GPS (Global Positioning System) is prepared by a spreadsheet program. This database is imported to GIS program. This database consists of columns of the site name, latitude and longitude of the site, calculated frequency and amplitude.

Microtremor measurements were achieved for the Adapazarı region. To estimate the H/V ratio of microtremor records, first Fourier amplitudes of horizontal and vertical components is calculated. By using the amplitudes the ratio is computed. The calculation procedure is explained in the fourth chapter.

Determining the fundamental frequency of the site according to Nakamura Technique is achieved by the peak frequencies. Because of the cultural noise, wind etc or complex soil stratum, there can be same peaks at the same ordinates. The existence of the same peaks makes it difficult to evaluate the results. All of the H /V ratios figures can be found in the chapter seven.

5.3 Evaluation of Microtremor Data

The microtremor application locations in Adapazarı district are illustrated below in the Figure 5.1. The figure is divided into 500x500m square grids, and they are named horizontally A,B,C,… and vertically 1,2,3,…

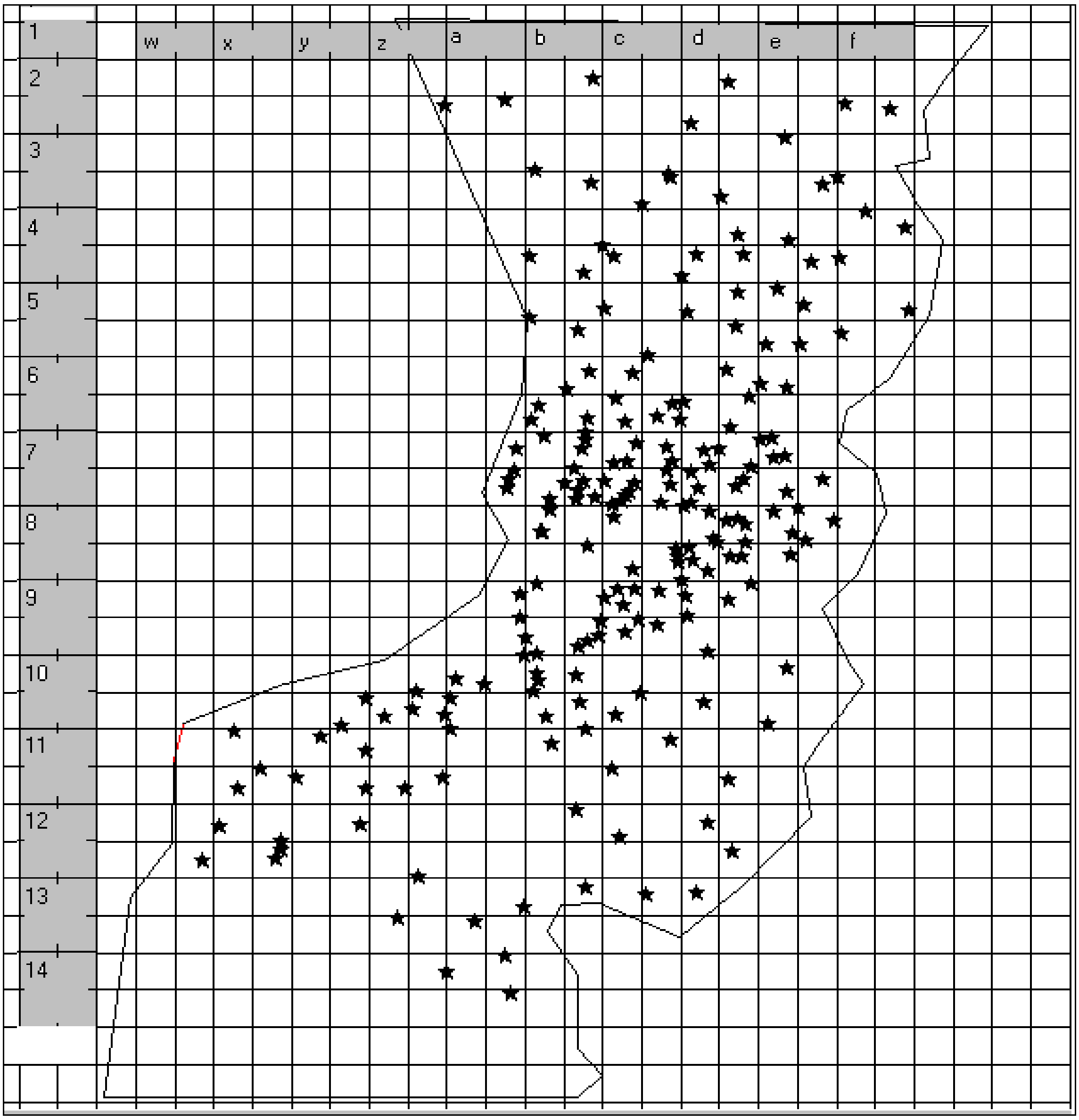


Figure 5.1 Microtremor application locations in Adapazarı

All ambient vibration records for the Adapazarı region can be interpreted in several categories. These are some noisy records, which surpasses the information. Some records which have one clear peak. Some spectrums with two or more peaks due to complex soil stratum which have almost same amplitudes. Also there are some flat spectrums.

In soil structures with two or more strong impedance contrasts, it is expected to obtain several peaks related to the fundamental modes. This two-layer case can be observed in the northern part of Adapazarı area (above the 40.76^0 N latitude). At the sites such as C-05, C-06, the analyses results are good examples of this type of spectrums. The peaks can be easily seen in the Figure 5.4.

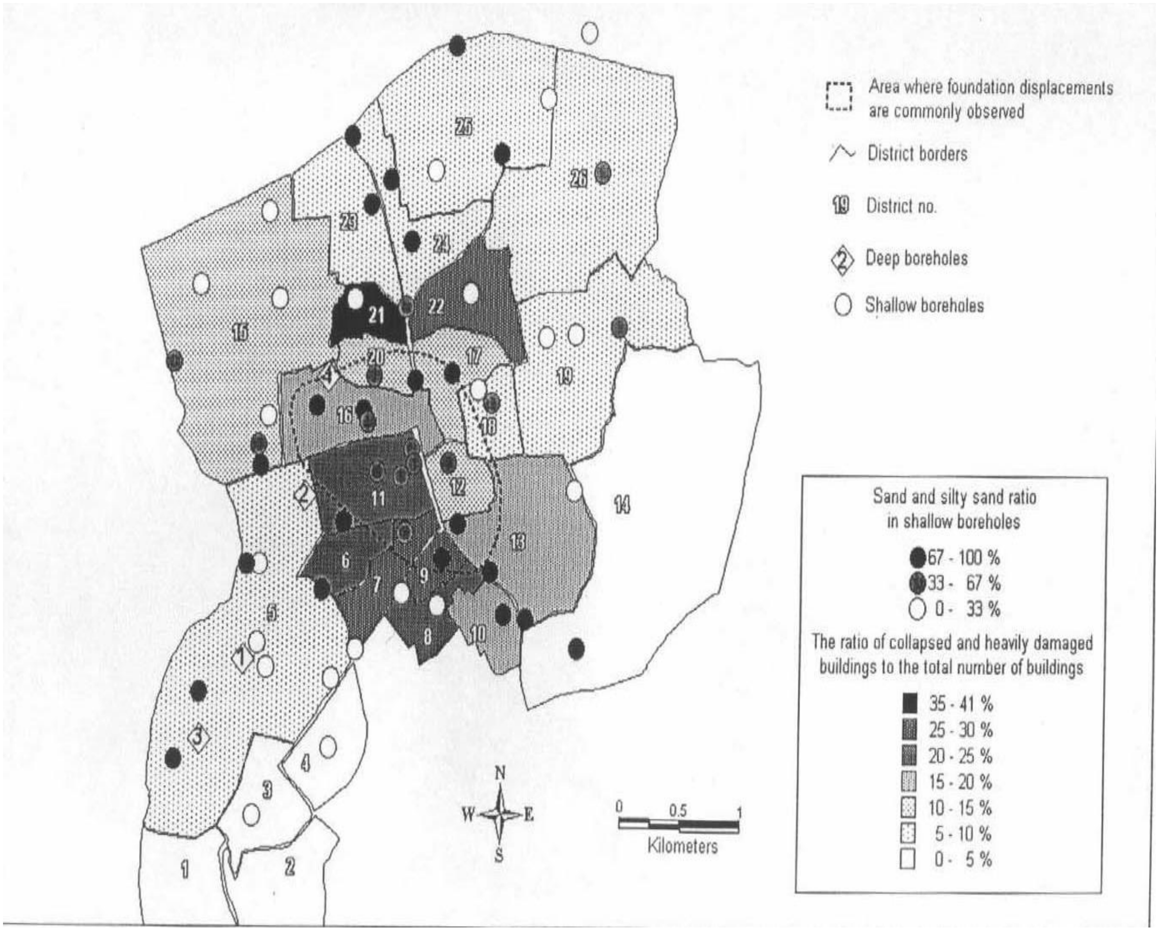


Figure 5.2 Damage distribution of Adapazarı

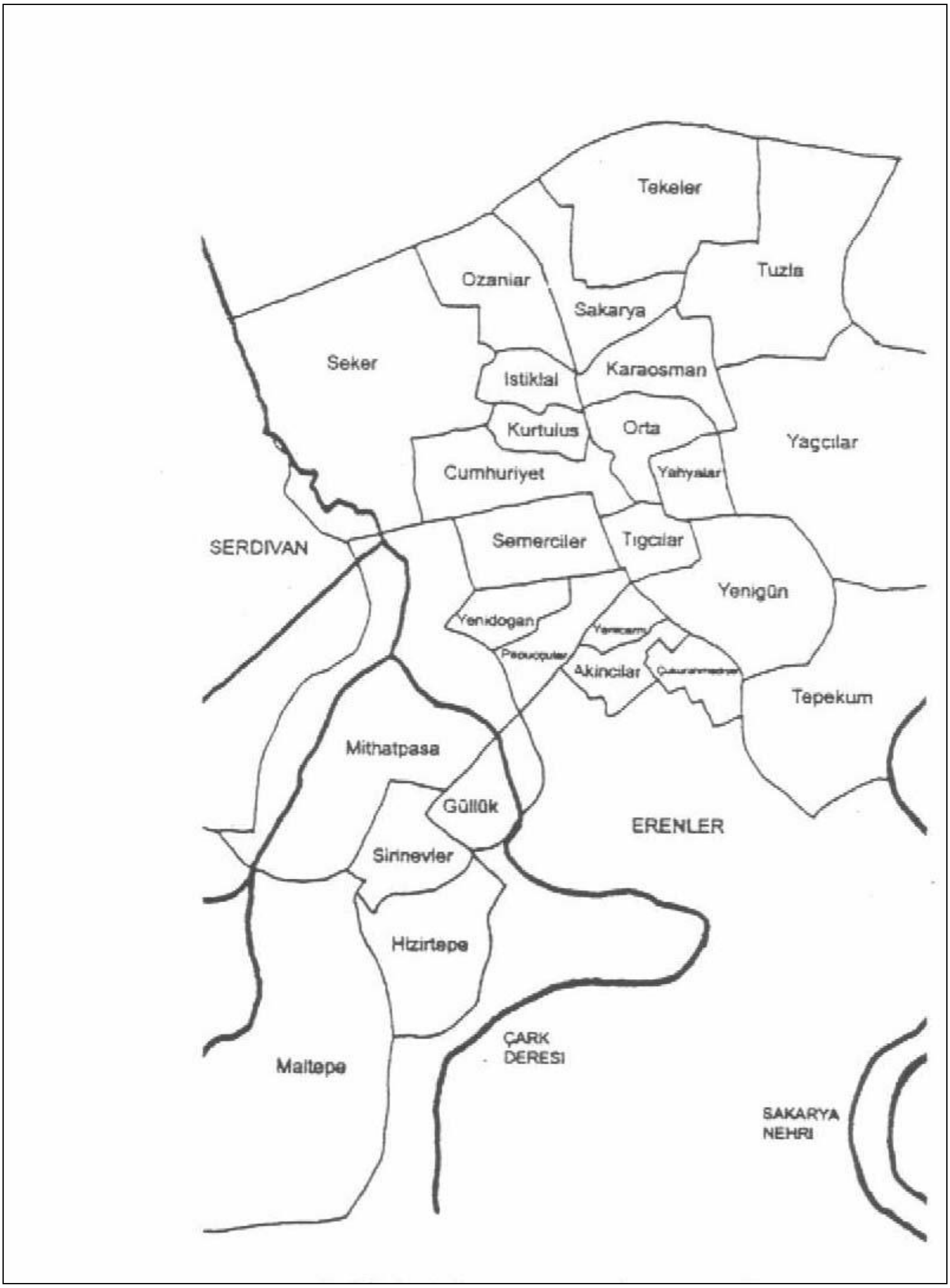


Figure 5.3District of Adapazarı

In the Figure 5.4, the three graphs are the H / V ratios of one site that are computed from the microtremor measurements of the zone C-06. As shown in the figure, H / V ratios of the site give two similar peaks, which makes it difficult to find out the fundamental frequency and amplitude of the site. If it is assumed that noise content is very low, having different soil layers gives almost similar response in different vibration periods. At this zone, two significant peaks give the idea of two different layers. The greatest peak is chosen as the fundamental frequency of the site if it is necessary to give one result for one site in microzonation maps.

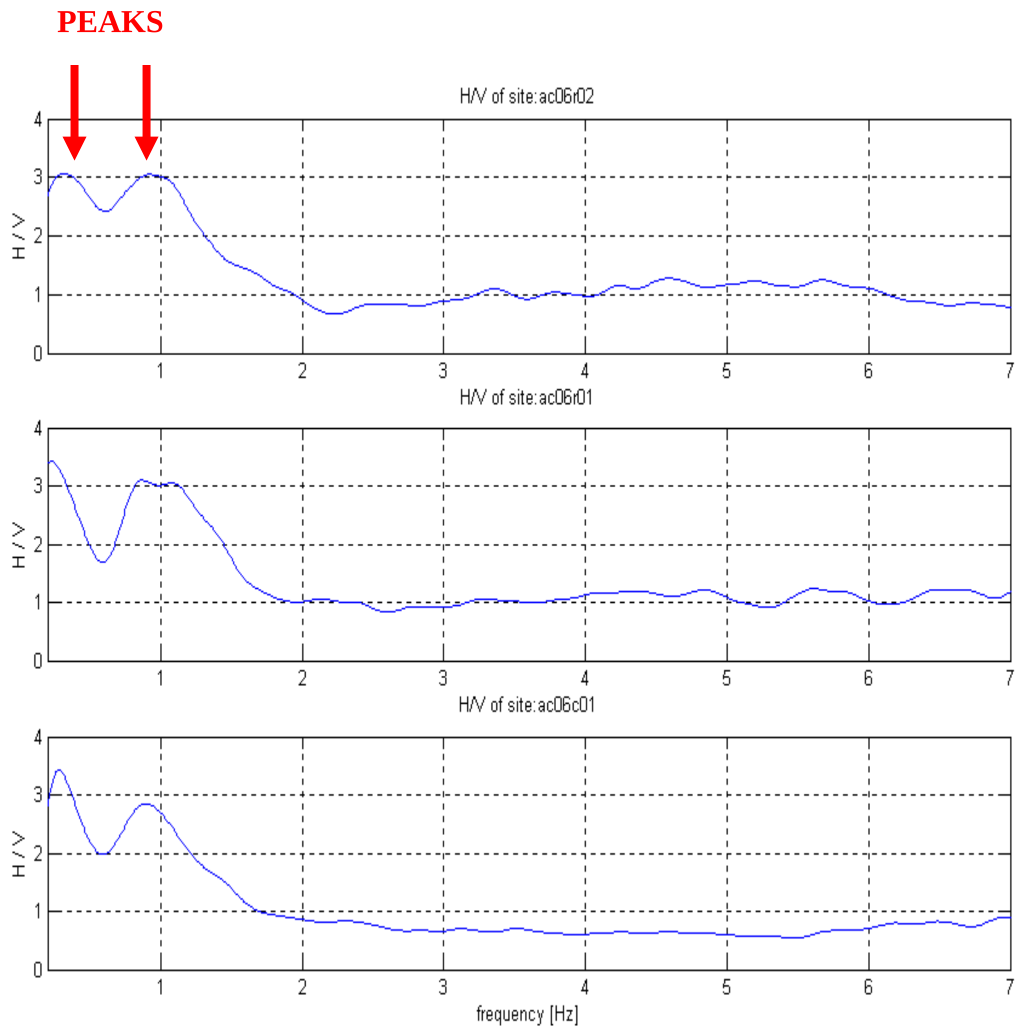


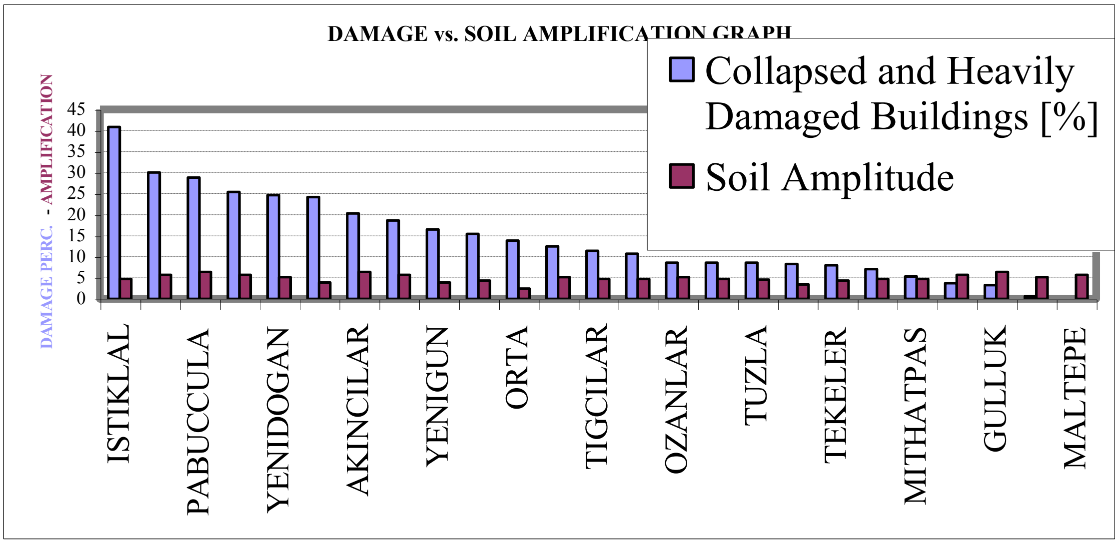
Figure 5.4 Spectrums with two peaks. Site C-06

In the graphs, the first peak is found @ about 0.3 Hz. and the second one is @0.8 Hz. The peaks have almost the same amplitudes, which means two different soil layers give similar responses to ground motions at different frequencies.

In the northern part of Adapazarı region, amplitudes have lower values, which are found between 1.60 and 4.00. Furthermore, in the nearby areas frequencies are found close to each other, however the amplitude distribution is very wide. The districts of the northern part are Seker, Ozanlar, Sakarya, Tekeler, Tuzla, Cumhuriyet, Kurtulus, Istiklal, Orta, Karaosman, Yahyalar and Yagcilar.

Table 5.2 The building Damage Statistics and Microtremor results

District No	District	Collapsed and Heavily Damaged Buildings	Amplitude	Fundamental Freq.
7	PABUCCULAR	28.8%	6.4	0.92
8	AKINCILAR	20.3%	6.4	1.25
4	GULLUK	3.3%	6.4	3
22	KARAOSMAN	30.0%	5.72	0.35
9	YENICAMI	25.4%	5.72	1.25
10	CUKURAHMEDIYE	18.6%	5.72	1.75
3	SİRİNEVLER	3.7%	5.72	1.75
1	MALTEPE	0.0%	5.72	0.35
6	YENIDOGAN	24.6%	5.14	0.56
15	SEKER	12.5%	5.14	0.35
23	OZANLAR	8.6%	5.14	0.35
2	HIZIRTEPE	0.6%	5.14	0.56
21	ISTIKLAL	40.8%	4.69	0.35
12	TIGCILAR	11.4%	4.69	0.77
20	KURTULUS	10.7%	4.69	0.56
24	SAKARYA	8.6%	4.69	0.35
19	YAGCILAR	7.1%	4.69	0.69
5	MITHATPASA	5.3%	4.69	0.56
26	TUZLA	8.6%	4.53	0.35
16	CUMHURİYET	15.4%	4.31	0.77
25	TEKELER	8.0%	4.31	0.35
11	SEMERCILER	24.2%	3.84	0.35
13	YENIGUN	16.5%	3.84	0.92
18	YAHYALAR	8.3%	3.42	0.56
17	ORTA	13.8%	2.46	0.92



In Table 5.2, heavily damaged and collapsed building percentages (Bakır, 2000) are listed with respect to descending amplitudes and fundamental frequencies.

In the northern part of the Adapazarı, heavy damage was seen especially in Istiklal and Karaosman districts, in the 1999 Koceali earthquake. In Istiklal and Karaosman, the amplifications were found about 4.69 and 5.72, respectively, which are quite high. As seen in these two examples, damage distribution coincides with the microtremor measurement results in this study. This shows the reliability of microtremor technique while making a hazard analysis according to soil amplification, at a site, in large scale.

In the western part of middle region, main soil type is Akveren formation. In this region another type of spectrum observed in the microtremors analysis, which is flat spectrums with implicit peaks. As shown in Figure 5.5, this type of spectrums can be observed in sites with no clear difference of shear wave velocities of layers, especially in sites with rock formation.

Flat types of spectrums observed in hill sites. As seen on Figure 5.5 no clear peak can be observed in H/V ratio. This zone can be considered as bedrock. The geological information of the basin is consistent with the H/V ratios. In the middle west part of the basin, Akveren formation existence can be easily distinguished. The districts are northern part of Mithatpasa district.

In the Akveren formation, the amplitudes are found about 1.5 and 2.5, which means the rock formations have quite low amplitudes with respect to soft formations over bedrock.

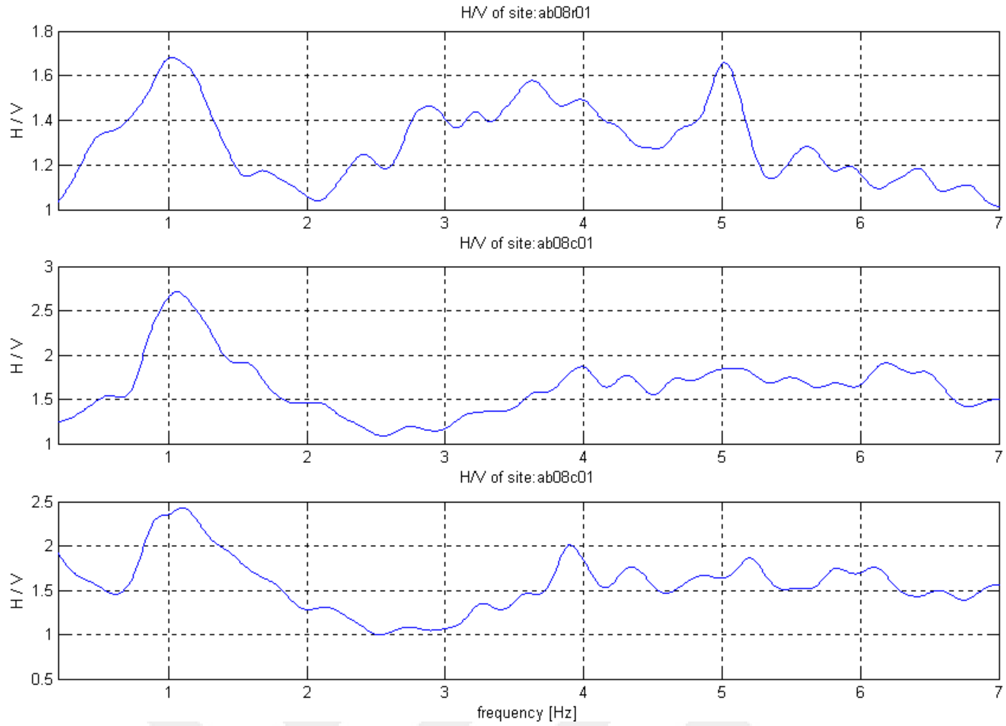


Figure 5.5 Flat spectrum of Akveren. B-08

In the center of the middle region of Adapazarı, alluvial formation exists. Also there is transition zone between Akveren and this zone. At this zone, observed fundamental frequency values vary between 0.69Hz. to 9.00Hz., this difference depends on the rapid increase at the thickness of soft sediment. At the border of the Akveren basin, the fundamental frequency gets higher values, and decreases as getting closer to the center region. Similarly, this transition zone exists between north and the middle region of Adapazarı and causes large spatial variation of fundamental frequencies. An example to this transition zone spectrum is given in the Figure 5.6.

The amplitude of the H/V spectral ratio at the fundamental frequency is an indicator for the S-wave velocity contrast between bedrock and soft layers. The higher the amplitude, the larger the velocity contrasts. Middle part of the Adapazarı area gives higher amplitudes due to the soft soil formation over the bedrock. Nakamura technique is suitable for such a case. It is also noted (Delgado et.al 2000) that this technique gives better result if shear wave contrast is high.

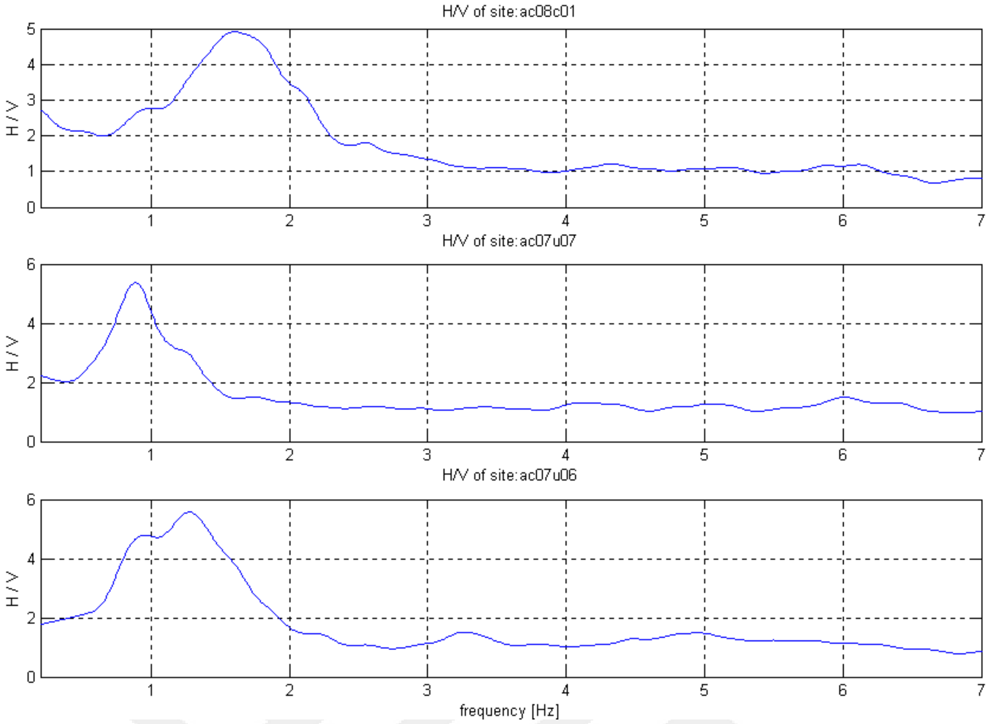
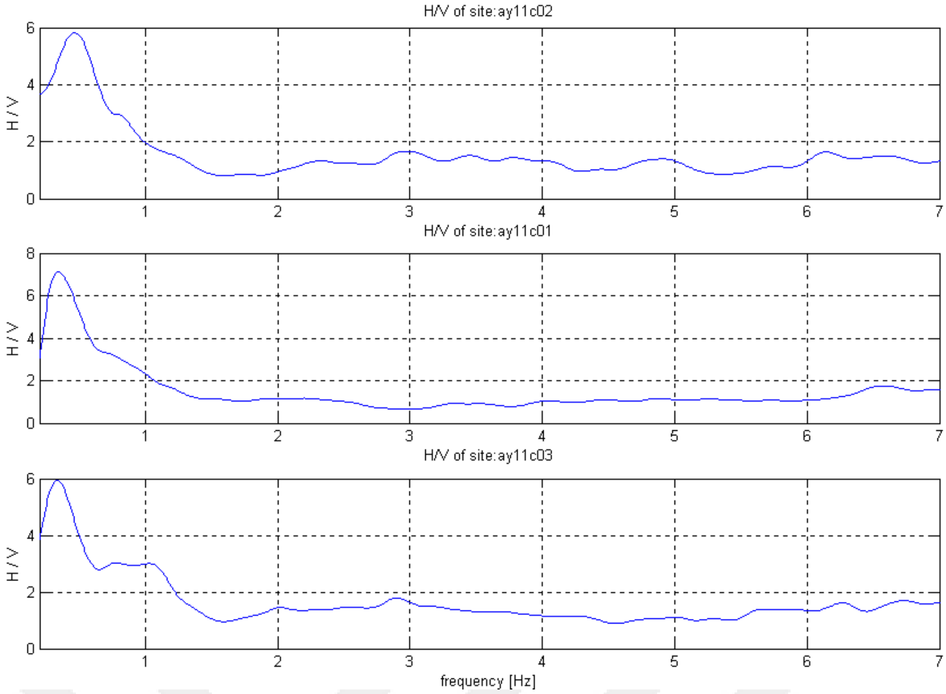


Figure 5.6 Spectrum of middle region of Adapazarı. Site C-08

In this zone, Semerciler, Tıgcılar, has amplitudes of 3.59 and 4.53. Yenidogan, Pabuccular and Yenicami districts showed higher amplitudes between 4.84 to 6 , which is related to heavy damage.

The south part of the Adapazarı region, the H / V spectral ratios are about 0.20Hz. to 0.48Hz. with one clear peak. Due to the large amplitude of H / V spectral ratio, it indicates a velocity contrast between bedrock and soft soil. This may be due to soft layer , and shallow bedrock. Maltepe, Hızırtepe Sirineveler and Gulluk districts are located in this zone. The amplitudes are 4.84, 5.44 and 6 a. However building damage was not higher.



In the following, a thorough description is given about the whole area row by row.

As a result of the microtremor measurements according to Nakamura Technique, the fundamental frequencies of Adapazarı area are varies between 0.2 Hz to 10 Hz and amplitudes are between 1.3 and 9.3. The variation of these parameters is depicted in maps, which prepared by software of Geographical Information System (GIS) named MapInfo.

Northern parts of the Adapazarı area, the fundamental frequencies of the sites a02 to e02, which are at the first line of the grid, are varies 0.35 Hz to 0.47 Hz. If the second and third line of the grid is observed, where Seker, Ozanlar, Tekeler, and Sakarya districts are located,the results are about 0.25. At the fourth line of the grid, in Istıiklal. the fundamental frequency values change between 0.3Hz. to 0.85Hz. It is also same at the fifth and sixth lines of the grid.

At the seventh line of the grid, nearby area of Akveren the fundamental frequency ranges are about 1Hz and 1.30 Hz. At the western parts of this grid the value comes to 2.29 Hz and reaches up to 3.33 Hz. The higher values are the proof of rock formation Lower values are observed at eastern parts of the seventh grid, which is the center of basin.

After the eighth line, the frequency values become greater. Over 2 Hz, 3 Hz and 4 Hz results can be observed, because still Akveren formation exist. Sites w10 to z10 has lower frequencies about 0.3 Hz. In addition to this, amplitudes are getting higher values in this region because of the rock site called Akveren formation.

There is also a transition zone, which shows itself as greater amplitudes. Except the transition zone there are some areas that has larger amplitudes. At southwestern of the Adapazarı area, the largest amplitudes are observed. The layer of the soft sediments causes the largest amplitudes of the H/V ratio.

The middle of the Adapazarı basin, an example of one peak at the fundamental frequency was calculated. The frequency of the peaks varies 0.7 Hz to larger frequencies up to 9Hz. It depends on the thickness of the soft sediments.

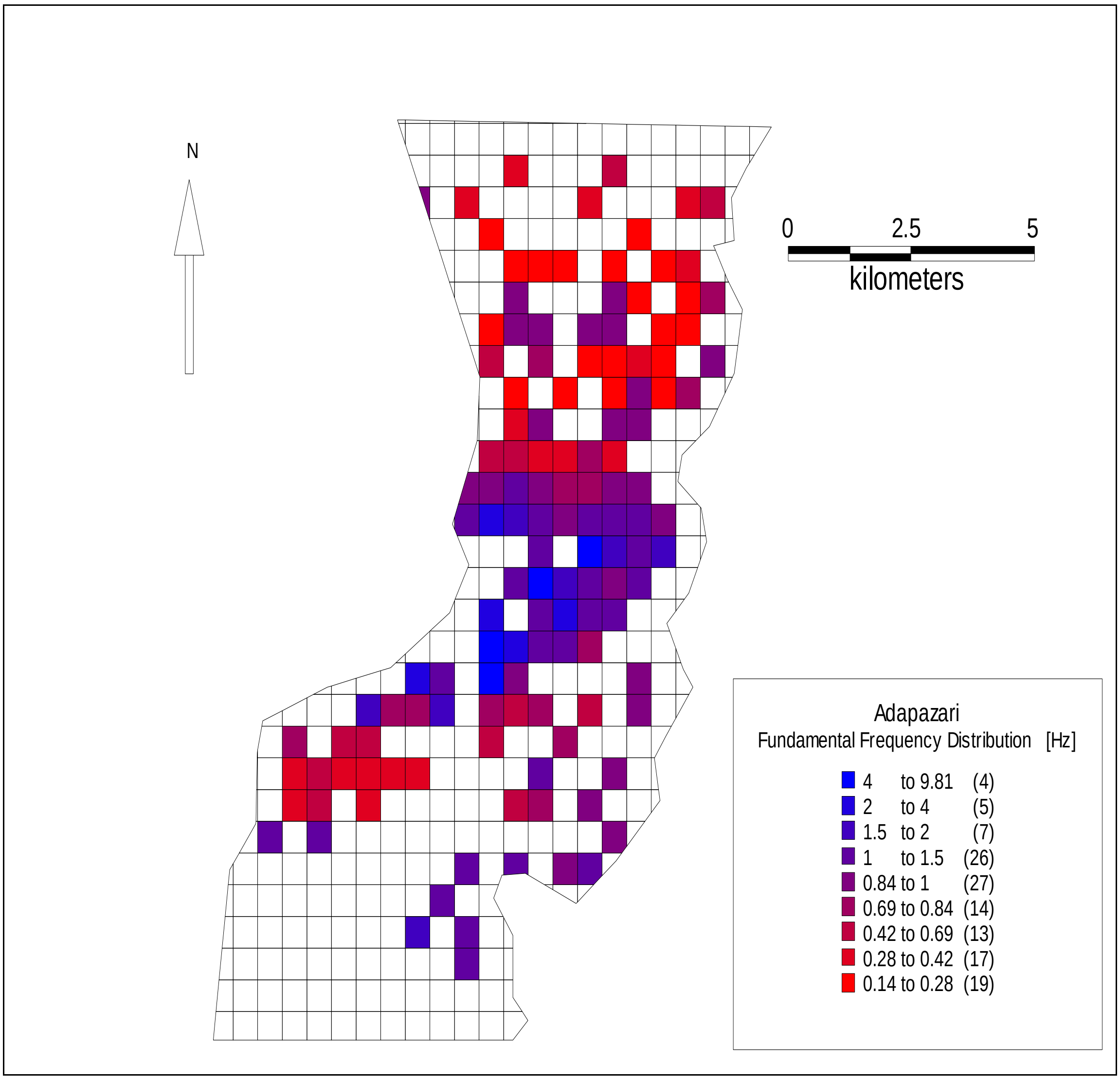


Figure 5.7 Fundamental Frequency Distribution of Adapazarı

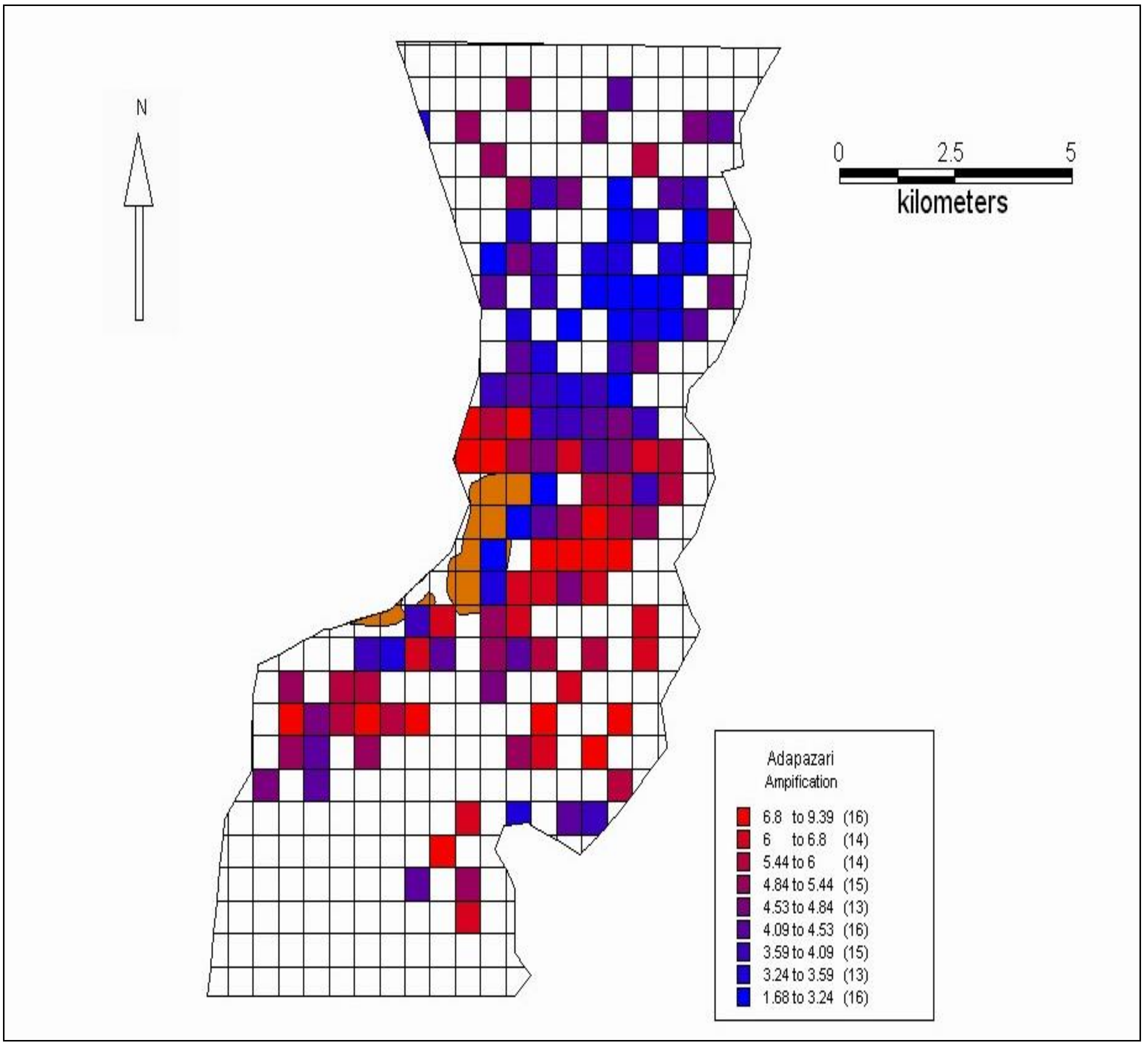


Figure 5.8 Amplitude Distribution of the H/V ratio

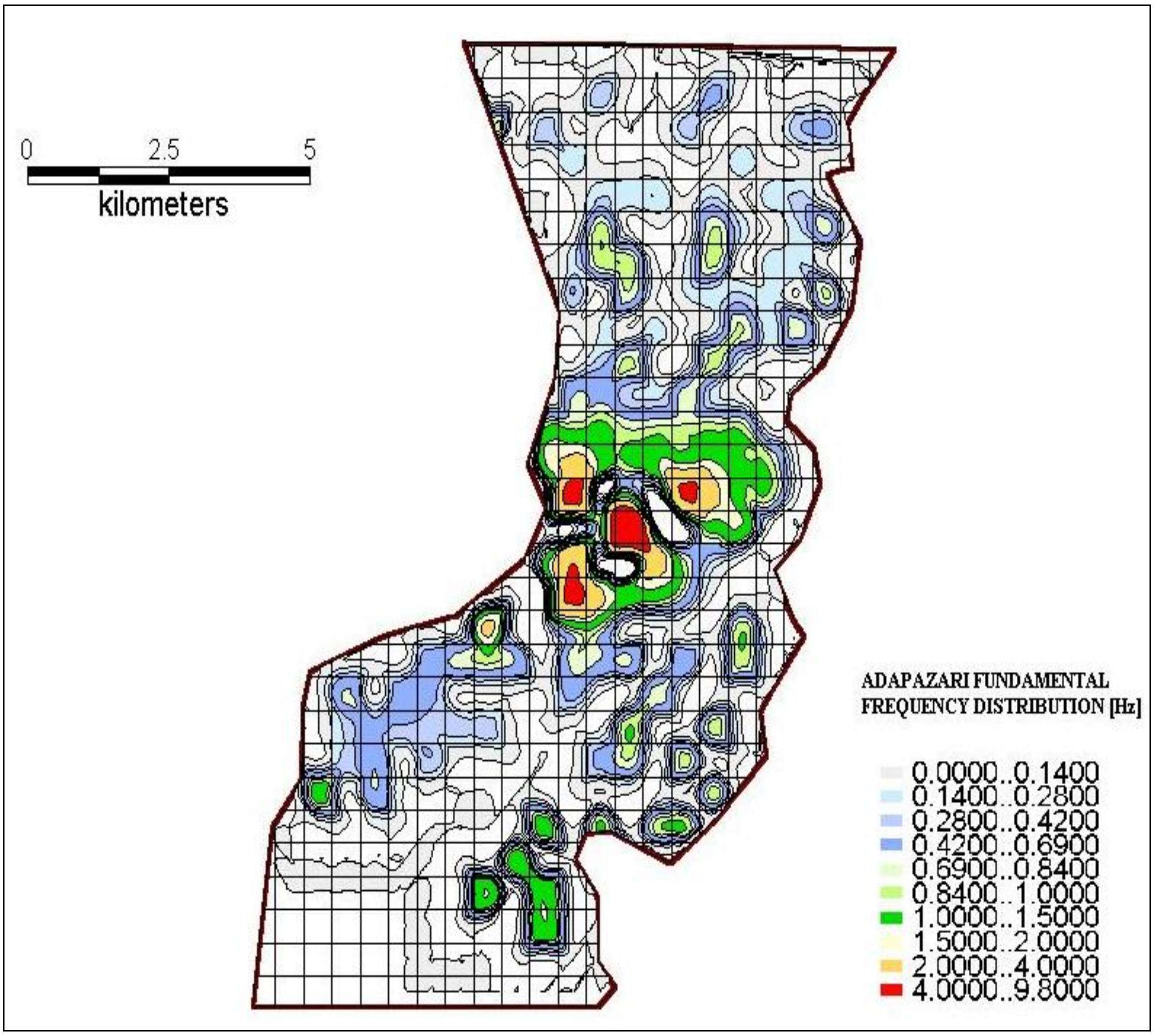


Figure 5.9 Fundamental Frequency Distribution of Adapazarı

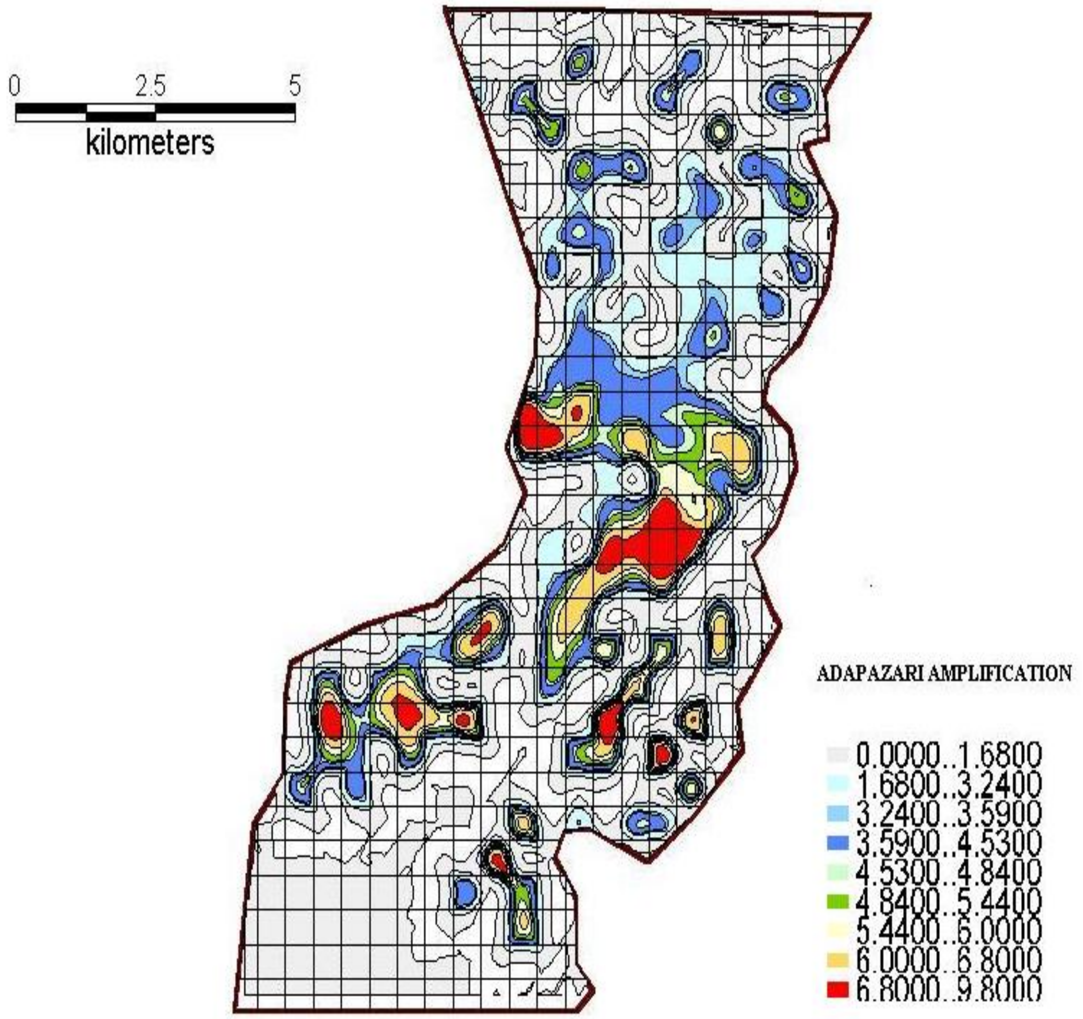


Figure 5.10Amplification of Adapazarı

6 CONCLUSION

In seismic zones, local site conditions and local effects are the most important factors that affect the ground motion characteristics when an earthquake strikes a populated area. Therefore, it becomes crucial to determine local dynamic behavior of soils and structures before seismic events. In this manner, using microtremor measurements is a very practical tool, while making a hazard analysis of a site according to fundamental frequencies, because of it is being quite easy, inexpensive and applicable.

In this project, to benchmark the utility of this method, Adapazarı region is chosen to apply microtremors to provide a comparison of soil amplifications and the observed structural damage distribution the last earthquake. To calculate the amplifications and fundamental frequencies, the Nakamura technique (1989) also known as H/V ratio method is used.

The H/V spectral ratio approach provides a simple means of determining the predominant frequency of a site, which enables the engineer to establish a map of fundamental frequencies. Thematic maps from microtremors may be considered as a preliminary zonation of area of interest. They must be complemented with geotechnical studies and more detailed modeling of the dynamic behavior of soils.

The microtremor measurements were applied at 200 points in different regions of Adapazarı. The peak/fundamental frequency varies in the north of the basin at 0.3 Hz with the second peak at 0.8 Hz, which can be considered as the existence of the two layers. The amplitude range differs from 1.60 to 4.00.

In the middle west of Adapazarı Basin, higher fundamental frequency and lower amplitudes are observed at the edge of Akveren formation, which can be considered as the proof of the rock site. Not to mention the fact that, only a few measurement was done at that region. When the velocity contrast is low, no resonance occurs at the surface layer so, the resulting spectral ratios are flat. This phenomenon is observed at the Akveren region. The middle of Adapazarı region’s fundamental frequencies lay between 1 to 2.00 Hz. and the amplifications are about 4.50 to 6.00.

At the southern part of the Adapazarı basin, higher amplitudes are seen. The characteristic of the H/V ratio of this zone is to have one clear peak. This can be due to soft layer over shallow bedrock which makes the velocity contrast.

The observed damage distribution of Adapazarı, during Kocaeli 1999 earthquake corresponds to spatial variations of soil amplifications found in this project. For instance, in the northern part of the Adapazarı, heavy damage was seen especially in Istiklal and Karaosman districts, in the 1999 Koceali earthquake. In Istiklal and Karaosman, the amplifications were found about 4.69 and 5.72, respectively, which are quite high. Also, higher amplification values and higher damage distribution is observed at Akıncılar and Yenicami district. As seen in these two examples, damage distribution coincides with the microtremor measurement results in this study. This shows the reliability of microtremor technique while making a hazard analysis according to soil amplification, at a site, in large scale. However, in the southern part of the Adapazarı region, the amplification has a value about 6.00 where lower damage distribution is observed.

These results demonstrate the utility of H/V ratios of microtremors in the investigation of soft deposits, as it rapidly and accurately determines the fundamental frequency of a soil at low costs. Since the type of signal processing can significantly influence the amplitudes of the calculated spectral ratios, it can be used as a contrast of soft stiffer and soils.

As a result, the zonation maps have great importance as an initial document for planning future uses of the area. Also, it is functional for seismic zoning, because it helps to recognize the characteristics of the materials, which are more susceptible to amplify the motion during an earthquake.

REFERENCES

1. Al .Yuncha, Z, and luzon, F. (2000), On the horizontal to :Vertical Spectral Ratio in Sedimentary Basin, Bull. Sesi. Soc. Am 90 (49 1101-1106

2. Ansal, A.M., Iyisan, R., and Ozkan, M., (2001) Microtremor Measurement for the Microzonation of Dinar, Pure Appl. Geop.158 2525-2541

3. Ansal. A., Erdik.M., et.al. (2002),State of the Art Report,Review of current Literature on Seimic Microzonation, Project Merm, Drm, İstanbul

4. Bakır, B.S. and Sucuoglu H. (2000) An Overview of Local SiteEffects and the Associated Building Damage in Adapazarı dıring the 17 August 1999 Izmit Earthquake, Bulletin Seism. Soc. America

5. Bard, P. Y., Duval, A., Lebrun, B., Lachet, C., Reipl, J., and Hatzfeld, D..(1997),Relaibility of the H/V Techqnique for Site Effects Measurement: An Experimental Assesment, soil Dyna. And Earthq. Eng.

6. Bard, P.-Y., 1998. Microtremor Measurements: A tool for site effect estimation? State-of-the-art paper, Proc. of 2nd International Symposium on the Effects of Surface Geology on Seismic motion - ESG'98, Yokohama, Japan.

7. Bolton Seed H., Idriss, I. M..,Dezfullian, H.(1970), relationships Between Soil Conditions and building Damage in the Caracas earthquake of July 29, 1967. In Report NEERC 70-2, College of Engineering University of California, Berkeley,California,Feb.1970

8. Bonilla, L.F., steidl, J.H., Lindley, G.T., Turnakin, A.G., archuleta, R.(1997),Site Apmlification in the San Fernando Valley, California:Variability of Site Effect estimation Using the S-Wave, coda, and H/V methods. Bulletin of the Seismological society of America 87, 710-730

9. Borcherdt, R.D.(1970), Effects of Local Geology on Ground Motion Near San Fransico Bay, Bull. Seismo. Soc.Am,60

10. Bray et.al (2001). Ground Failure in Adapazarı, Turkey, Proc. Workshop, 15.ICSMFE, Istanbul

11. C. Lacave-Lachet;, P.Y. Bard1;, J.C. Gariel & K. Irikura,(2000) Straightforward methods to detect non-linear response of the soil.Application to the recordings of the Kobe earthquake (Japan, 1995) Journal of Seismology 4: 161–173

12. Campillo, M., Gariel,J.C., Aki, K. and sanchez-Sesma, F.J. (1989), Destructive Strong Ground motion in Mexico City:Source, Path and Site Effects During Great 1985 Michiocan Earthquake, Bull. Seismo. Soc. Am.

13. Caserta, F. Bellucci, G. Cultrera, S. Donati, F. Marra, G. Mele, B. Palombo & A. Rovelli (2000)Study of site effects in the area of Nocera Umbra (Central Italy) during the 1997 Umbria-Marche seismic sequence A. Journal of Seismology 4: 555–565

14. D. Fäh, F. Kind, D. Giardini(2000) Structural Information Contained In Microtremor H/V Ratios Swiss Seismological Service, Eth- Zurich, Switzerland

15. Dimitriu, P., Papaioannou, C., and Theodulidis, N. (1998). Euro- Seistest strong motion array near Thessaloniki, northern Greece: A study of site effects. Bull. Seism. Soc. Am., 88, 862-873.

16. Dimitriu, P., Theodulidis, N., and P-Y. Bard (2000). Evidence of nonlinear site response in HVSR from SMART1 (Taiwan) data. Soil Dyn. and Earthq. Eng., 20, 155-165

17. Dravinski M, Ding G, Wen K. Analysis of spectral ratios for estimating ground motion in deep basins. Bulletin of Seismological Society of America 1996;86(3):646±54.

18. Duval, A. M., Bard, P. Y., Me´neroud, J. P. and Vidal, S. Mapping site effect with microtremors. In Proc. 5th International Conference on Seismic Zonation, Vol. 3, Nice, France. Ouest Editions Presses Acade´miques, Nantes, pp.1522–1529.

19. Duval, A.M., Meneroud, J.p., Vidal, S. and Bard, P.Y. (1994), Usefullness of Microtremor Measurements For Site Effect Studies, In Proc. 10th European Conf Earthquake Eng.Vienna,Austria

20. Duval,A. –M, Vidal, S. , Menereoud,J.P. ,Singer, A. , Santis, F.De. ,Ramos, C. ,Remereo, G. ,Rodriguez, R. ,Pernia, A. ,Reyes, N. ,Griman, C. (2001),Caracas,Venezuela,Site Effect Determination With Microtremors, Pure Appl.Geophys 158.2513-2523

21. Erken, A.(2001) The role of Geotechnical Factors on Observed Damage in Adapazarı during 1999 Earthquake, 15 th International conference on soil Mechanics and Geotechnical Engineering, Istanbul, Turkey

22. F. Luzon, Z.Al Yuncha, F.J. Sanchez Sesma and C. Ortiz-Aleman (2001),A Nuemerical Experiment on the Horizontal to vertical Spectral Ratio in Flat Sedimentary Basins,Pure appl. Geophys158(2001) 2451- 2461

23. Field, E H; Hough, S E; Jacob, K H (1990) Using microtremors to assess potential earthquake site response: a case study in Flushing Meadows, New York City : Bull Seismol Soc Am V80, N6, Dec 1990, P1456–1480,

24. Field, E.H. and Jacob, K.H.(1995).A comparison and Tests of Various Site Response Estimation Techniques, Including Three that are not Reference-site Dependent, Bull. Seism. Soc. Am. 85

25. H. YamanakaM. TakemuraH. IshidaM. Niwa (1995) Characteristics of long-period microtremors and their applicability in exploration of deep sedimentary layers, InterJour.of Rock Mechanics and Mining Science & Geomechanics Abstracts, Vol 32, Is6, Page 273A

26. Gaull, B.A., Kagami, H., Eeri, M. and Tanıguchi, H. (1995), the :Microzonation of Perth, western Australia, Using Microtremor Spec.Ratios, Earthquake. Spectra 11

27. Gutierrez, C. and Singh, K.(1992). A Site Effect Study in Acapulco, Guerro, Mexico: Comparison of Results from strong Motion and Microtremor Data, Bull. Seism. Soc. Am 82

28. Haskell, N.A. (1953), The Dispersion of Surface Waves on Multilayered Media, Bull. Seismo. Soc. Am.

29. Kanai, K.(1957) The Requisite Conditions for Predominant Vibration of Ground, Bull Earthq. Res. Ins.Tokyo Univ,31

30. Kanai, K., and Tanaka, T.(1961),On microtremors, VIII, Bull Eq. Res. Ins 39

31. Konno, K. and Omachi, T.(1988), Ground Motion Chracteristics Estimated from Spectral Ratio Between Horizontal and Vertical Components of Microtremor, Bull Seis. Soc. Am. 88(1)

32. Kudo, K., T. Kanno, H. Okada, T. Sasatani, S. Ling, N. Morikawa, M. Takahashi, H. Nagumo, K. Irikura & K. Pitilakis, 1999. S-wave velocity survey at EURO-SEISTEST (Volvi, Greece) by array microtremor measurements.

33. Lachet, C., and P. Y. Bard, 1994: Numerical and theoretical investigations on the possibilities and limitations of Nakamura's technique. J. Phys. Earth, 42, 377-397.

34. Lachet, C., Hatzfeld, D., Bard, P.-Y., Theodulidis, N., Papaioannou, Ch. and Savvaidis, A., (1996), Site effects and microzonation in the city of Thessaloniki (Greece): comparison of different approaches, Bull. Seism. Soc. Am. 86, 1692–1703.

35. Lermo, L., Rodriguez, M., and Singh, K. (1988), The Mexico Earthquake of September 19,1985: Natural Period of Sites in the valley of Mexico from Microtremor Measurements and from Strong motion Data, Earthquake Spectra 4

36. Lermo, J., and Chavez-Garcia, F. (1993), Site Effect Evaluation Using Spectral Ratios with Only One Station, Bull. Seismo. Soc. Am.83

37. Lermo, J. and Chavez-Garcia, F. J.(1994) Are microtremors useful in site response evaluation?. Bull. Seism. Soc. Am., 84, 1350–1364.

38. LermoF. J. Chavez-Garcia (1995) Site effect evaluation at Mexico City: dominant period and relative amplification from strong motion and microtremor records, International Journal of Rock Mechanics and Mining Science & Geomechanics Abstracts, Volume 32, Issue 7, October 1995, Pages 327A-328AJ.

39. M. Navarro, T. Enomoto, F.J. Sanchez,I. Matsuda, T. Iwatate, A.M. Posadas, F. Luzon,F.Vidal and K.Seo (2001) Surface Soil Effects Study Using Short-period Microtremor Observations in Almeria City, Southern Spain Pure appl.geophys 158 2481-2497

40. Mucciarelli, M. (1998), Reliability and Applicability Of Nakamura's Technique Using Microtremors: An experimental Approach, J. Earthq. Eng

41. Nakamura, Y.(1989) A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Rep. Railway Tech. Res. Inst., Jpn, 1989, 30(1), 25–33.

42. Nogoshi, M. and Igarashi, T. (1971), On the amplitude characteristics of microtremor, J. Seis. Soc. Japan,24

43. Novaro, O; Seligman, T H; Alvarez-Tostado, J M; Mateos, J L; Flores (1990), Two-dimensional model for site-effect studies of microtremors in the San Fernando valley : J Bull Seismol Soc Am V80, N2, April 1990, P239–251

44. Ochmachi, T., Nakamura, Y., Toshinawa, T., (1991), Ground motion characteristics in the San Francisco Bay are detected by microtremor measurements, Proc. 2nd Int. Conf. On Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics, St. Louis, Missouri, 1643–1648.

45. Önalp A. Et.al.(2000). A general Assesment of the Effects of 1999 Earthquake on the Soil Structure Interaction in Adapazarı

46. Önalp, A. Et al. (2000). Earthquake Performance of Adapazarı Basin, 8th National Soil Mechanics and Foundation Engineering,İstanbul,Turkey

47. P. Teves-Costa and L. MatiasP. Y. Bard (1996). Seismic behaviour estimation of thin alluvium layers using microtremor recordings, Soil Dynamics and Earthquake Engineering, Volume 15, Issue 3, 13 March 1996, Pages 201-209

48. Petros P. Dimitriu,(2002) The HVSR technique reveals pervasive nonlinear sediment response during the 1994 Northridge earthquake (Mw 6.7) , Journal of Seismology 6: 247–255, 2002.

49. Pitilakis, K., Anastasiadis, A.and Raptakis, D (1992), Field and Laboratory Determination of Dynamic Properties of Natural Soil Deposits, Proc. 10th World conference on Earthquake Eng., Madrid, Spain

50. R. B. Sancio, J. D. Bray, J. P. Stewart, T. L. Youd, H. T. Durgunoğlu, Akın Önalp, R. B. Seed, C. Christensen, M. B. Baturay and T. Karadayılar(2002),Correlation between ground failure and soil conditions in Adapazari, Turkey, Soil Dynamics and Earthquake Engineering, Volume 22, Issues 9-12, Pages 1093-1102

51. Raptakis, D., Theodulidis, N., and Pitilakis, K. (1998). Data analysis of the Euroseistest strong motion array in Volvi(Greece):Standard and horizontal-to-vertical spectral ratio techniques.Earthquake Spectra, 14, 203-224.

52. Riepl, J., J.-C. Gariel & P.-Y. Bard, 1998. About the use of Coda wave signals to estimate local site amplification factors. Proc. of 2nd International Synposium on the Effects of Surface Geology on Seismic motion - ESG'98, Yokohama, Japan, 523-530.

53. Rodriguez, V.H.S., & Midorikawa, S.,(2002) The applicability of microtremors in assessig soil effects on ground motion, Earthquake Engineering and Structural Dynamics, 31: 261-279

54. Sakarya Universtiy (1988), geology and .Geomorphology of Adapazarı Rept. No.1, Sakarya University, Adapazarı

55. Seo, K. (1994), On the applicability of Microtremors to Engineering Purpose. Preliminary Report of the Joint ESG Research on Microtremors After the 1993 Kushiro-Oki (Hokkaido,Japan) Earthquake.In Proc. Of 10th European Conf on Earth. Vol4

56. Seo, K. (1996), Application of Microtremors to Earthquake Damage Scenarious-Lesson Learned from recent Damaging Earthquakes. In Proc of 11th World conf on Earthq. Eng.

57. Suzuki, T., Y. Adachi, and M. Tanaka, 1995: Application of microtremor measurements to the estimation of earthquake ground motions in Kushiro city during the Kushiro-Oki earthquake of 15 January 1993. Earthquake Eng. Struct. Dyn., 24, 595-613.

58. Taga, N. (1993), Measurement of microtremors in Earthquake Ground motion and Ground Condition edited by the Architectural Ins. of Japan

59. Toshinawa T, Sugito M, Berrill J. (1995),Ground motion characteristics in alluvia obtained by microtremor measurement. Proceedings of Fifth International Conference on Seismic Zonation. 17±19 October Nice, France.

60. T. Toshinawa, M. Inoue, N. Yoneyama, Y. Hoshino, K. Mimura and Y. Yokoi,(2003), Geologic-Profile Estimates Of Kofu Basin, Japan, By Making Use Of Microtremor Observations Geophysical Research Abstracts, Vol. 5, 02079

61. Teves-Costa, P., Matias, L. and Bard, P. Y.(1996) Seismic behaviour estimation of thin alluvium layers using microtremor recordings. Soil Dynam. Earthq. Engng, 15, 201–209.

62. Theodulidis, N. and Bard, P-Y. (1995). Horizontal to vertical spectral ratio and geological conditions: An analysis of strong motion data from Greece and Taiwan (SMART-1). Soil Dyn. and Earthq. Eng., 14, 177-197.

63. Theodulidis, N., Bard P-Y., Archuleta, R., and Bouchon, M. (1996). Horizontal-to-vertical spectral ratio and geological conditions: The case of Garner valley downhole array in southern California. Bull. Seism. Soc. Am., 86, 306-319.

64. Tokimatsu, K; Shinzawa, K; Kuwayama, S (1992).Use of short-period microtremors for Vs profiling : J Geotech Engng Div ASCE V118, N10, Oct 1992, P1544–1558,

65. Weston INC.(1969),seismic Investigations in the Valley of Caracas and the Lithoral Central, Weston Geophysical Engineers International, Inc. (Weston, Massachusetts, Aug,1969)

66. Whitman, R. V.(1969), Effect of soil Conditions upon Damage to Structures-Caracas Earthquake of 29 July 1967, Massachusetts Institute of Technology

67. Y. Zaslavsky. And A. Shapira (2003)Using H/V Spectral Ratios To Constrain 1-D Subsurface Models For Seismic Hazard Assessment Geophysical Research Abstracts, Vol. 5, 01722

68. Yamanaka, H. Takemura, M., Ishida, H. and Niwa, M. (1994), Characteristics of Long-period Microtremors and Their Applicability in Exploration of Deep Sedimentary Layers, Bull Seis. Soc. Am. 884

69. Yoshida, N. Tokimatsu K. Et al.(2001) Geotechnical Aspects of Damage in Adapazarı City During 1999 Kocaeli, Turkey Earthquake, Soils and Foundations vol41, No:4 Japanese Geotechnical Society

70. Yoshihisa Maruyama, Fumio Yamazaki And Tatsuya Hamada(2000) Microtremor Measurements For The Estimation Of Seismic Motion Along Expressways, Proceedings of The 6th International Conference of Seismic Zonation Vol. II , 1361-1366

71. Yoshihisa Maruyama, Fumio Yamazaki And Tatsuya Hamada(2000), Microtremor Measurements For The Estimation Of Seismic Motion Along Expressways, Proceedings Of The 6th International Conference Of Seismic Zonation (2000) Vol. Ii , 1361-1366

72. Yutaka NAKAMURA(2000) Clear Identification Of Fundamental Idea Of Nakamura's Technique And Its Applications 12 WCEE, 2000

73. Yutaka Nakamura, E D Gurler, Jun Saita, Antonio Rovelli And Stefano Donati(2000) Vulnerability Investigation Of Roman Collisseum Using Microtremor, 12 Wcee, 2000

74. Yutaka Nakamura, E. Dilek Gurler , Jun Saita ,Dynamic Characteristics Of Leaning Tower Of Pisa Using Microtremor - Preliminary Results

7 APPENDIX

7.1 Coordinates and Results of Microtremor Measurements

Station	Latitude	Longitude	freq[Hz]	amp
aa02_c01	40,8035N	30,3669E	0,87	3,54
aa02_r01	40,8041N	30,3761E	0,35	4,84
aa03_r01	40,7955N	30,3805E	0,23	5,28
aa04_c01_sek	40,7851N	30,3796E	0,22	2,84
aa05_r01	40,7777N	30,3795E	0,42	4,09
aa06_r01	40,7670N	30,3811E	0,45	3,80
aa06_r02	40,7654N	30,3798E	0,67	3,98
aa07_r01	40,7558N	30,3828E	2,29	7,12
aa07_r02	40,7593N	30,3773E	1,09	7,03
aa07_r03	40,7582N	30,3765E	1,46	5,72
aa07_r04	40,7571N	30,3761E	3,33	3,81
aa07_r05	40,7620N	30,3775E	0,98	7,08
aa07_r06	40,7635N	30,3818E	0,96	5,44
aa08_r01	40,7518N	30,3815E	n/a	n/a
aa08_r02	40,7519N	30,3813E	4,85	2,18
aa08_r03	40,7544N	30,3828E	n/a	n/a
aa09_r01_skr	40,7370N	30,3805E	4,64	3,38
aa09_r02	40,7390N	30,3787E	n/a	n/a
aa09_r03	40,7414N	30,3780E	n/a	n/a
aa09_r04_01	40,7442N	30,3781E	1,08	1,94
aa09_r05	40,7457N	30,3808E	3,89	2,93
aa10_r01	40,7370N	30,3786E	n/a	n/a
aa10_r02	40,7347N	30,3806E	5,52	5,19
aa10_r03	40,7325N	30,3798E	1,01	4,88
aa10_r04	40,7295N	30,3820E	0,75	5,37
aa10_r05	40,7339N	30,3810E	2,06	3,89
aa11_r01	40,7262N	30,3827E	0,51	4,58
aa13_u01	40,7064N	30,3785E	1,19	6,34
aa13_u02	40,7007N	30,3755E	1,45	5,25
aa14_u01	40,6959N	30,3763E	1,44	6,04
ab02_r01_01	40,8067N	30,3894E	0,37	5,03
ab03_r01	40,7941N	30,3893E	0,26	4,95
ab04_c01_bab	40,7864N	30,3908E	0,91	3,25
ab04_c02_gen	40,7851N	30,3927E	0,94	3,62

Station	Latitude	Longitude	freq[Hz]	amp
ab04_r01	40,7832N	30,3879E	0,93	4,62
ab05_r01	40,7789N	30,3911E	0,80	3,69
ab05_r02	40,7761N	30,3871E	0,15	3,38
ab06_r01	40,7657N	30,3885E	0,48	4,23
ab06_r02	40,7639N	30,3881E	0,61	4,09
ab06_r03	40,7713N	30,3889E	0,28	4,22
ab06_r04	40,7709N	30,3952E	0,88	3,46
ab06_r05	40,7679N	30,3926E	0,30	3,89
ab06_r06	40,7690N	30,3853E	0,35	4,76
ab06_u01_sic	40,7651N	30,3942E	0,30	3,82
ab07_c01	40,7556N	30,3935E	1,07	2,90
ab07_c02	40,7551N	30,3921E	1,04	2,72
ab07_c03	40,7566N	30,3948E	1,49	6,20
ab07_c04	40,7562N	30,3943E	2,11	4,02
ab07_r01	40,7578N	30,3849E	1,54	5,37
ab07_r02_01	40,7618N	30,3875E	1,03	6,83
ab07_r03	40,7595N	30,3863E	1,09	6,46
ab07_r04	40,7604N	30,3945E	0,85	3,95
ab07_r05	40,7630N	30,3880E	0,84	5,05
ab07_r06	40,7560N	30,3895E	1,37	2,50
ab07_r07_01	40,7580N	30,3909E	1,32	4,65
ab07_r08	40,7624N	30,3958E	0,82	3,50
ab07_r09	40,7601N	30,3924E	1,03	5,43
ab07_r10	40,7559N	30,3866E	4,96	3,40
ab07_r11	40,7578N	30,3878E	1,30	4,28
ab07_r12	40,7568N	30,3871E	1,70	6,68
ab08_c01_01	40,7537N	30,3925E	1,09	2,43
ab08_r01_01	40,7501N	30,3885E	1,03	1,68
ab08_r02	40,7474N	30,3952E	9,80	4,29
ab09_c01	40,7429N	30,3936E	1,28	7,16
ab09_c02	40,7379N	30,3870E	2,32	6,02
ab09_c03	40,7386N	30,3882E	2,17	6,66
ab09_c04	40,7449N	30,3954E		
ab09_c05	40,7409N	30,3903E	2,66	4,98
ab09_c06	40,7437N	30,3909E	3,80	4,83
ab09_c07	40,7397N	30,3939E	1,10	6,08
ab09_r01	40,7392N	30,3900E	1,72	6,01
ab09_r02	40,7449N	30,3929E	1,50	7,03
ab10_r01	40,7345N	30,3867E	0,88	6,23
ab10_r02	40,7312N	30,3872E	0,77	5,08

Station	Latitude	Longitude	freq[Hz]	amp
ab10_u01	40,7297N	30,3926E	0,79	5,78
ab11_r01	40,7279N	30,3879E	0,67	4,32
ab11_r02	40,7231N	30,3918E	1,01	8,01
ab11_u01	40,7183N	30,3864E	0,51	5,06
ab12_r01	40,7149N	30,3930E	0,83	6,00
ab13_u01	40,7088N	30,3880E	1,03	3,24
ac02_c01	40,8012N	30,4043E	0,34	4,63
ac03_c01	40,7947N	30,4013E	0,21	4,72
ac03_u01_tek	40,7951N	30,4011E	0,27	3,68
ac04_r01	40,7827N	30,4028E	0,87	3,52
ac04_u01_srf	40,7915N	30,3968E	0,22	3,72
ac04_u02	40,7854N	30,4051E	0,16	2,93
ac05_r01	40,7784N	30,4036E	0,14	2,07
ac05_u01_has	40,7732N	30,3978E	0,20	2,19
ac06_c01	40,7652N	30,4024E	0,28	3,43
ac06_r01	40,7673N	30,4013E	0,23	3,42
ac06_r02	40,7657N	30,3990E	0,31	3,06
ac06_u01	40,7674N	30,4030E	0,79	3,75
ac07_c01	40,7556N	30,3936E	0,82	5,84
ac07_c02	40,7621N	30,4005E	0,78	4,04
ac07_c03	40,7571N	30,4052E	1,35	4,48
ac07_c04	40,7577N	30,3955E	0,98	5,58
ac07_c05	40,7549N	30,4030E	1,40	2,65
ac07_c06	40,7554N	30,4040E	1,98	4,80
ac07_u01_ere	40,7615N	30,4060E	0,79	4,48
ac07_u02	40,7603N	30,4013E	0,87	7,03
ac07_u03	40,7591N	30,4006E	0,92	6,57
ac07_u04	40,7553N	30,3995E	1,46	4,12
ac07_u05	40,7590N	30,4040E	0,93	7,42
ac07_u06	40,7575N	30,4010E	1,27	5,57
ac07_u07	40,7599N	30,4069E	0,89	5,37
ac08_c01	40,7481N	30,4020E	1,60	4,91
ac08_c02	40,7497N	30,4019E		
ac08_c03	40,7489N	30,4020E	2,52	6,61
ac08_c04_01	40,7460N	30,4025E	1,59	6,80
ac08_u01	40,7482N	30,4044E	1,39	7,95
ac08_u02	40,7498N	30,4039E		
ac08_u03	40,7471N	30,4068E	0,89	7,42
ac09_c01	40,7440N	30,4031E	1,05	9,38
ac09_c02	40,7415N	30,4035E	0,82	9,35

Station	Latitude	Longitude	freq[Hz]	amp
ac09_c03	40,7371N	30,4065E	0,69	6,48
ac09_c04	40,7405N	30,3988E	1,27	4,53
ac09_c05	40,7447N	30,3993E	2,59	7,12
ac09_r01	40,7412N	30,3959E	1,31	6,11
ac10_c01	40,7312N	30,4059E	0,58	5,66
ac10_u01	40,7322N	30,3963E	0,72	6,71
ac11_u01	40,7267N	30,4008E	0,79	6,13
ac12_u01	40,7166N	30,4066E	0,90	7,36
ac13_r01	40,7078N	30,3970E	0,94	4,46
ac13_u01	40,7080N	30,4047E	1,01	3,68
ad02_r01	40,7994N	30,4186E	0,25	5,78
ad02_u01	40,8061N	30,4102E	0,49	4,27
ad03_u01	40,7922N	30,4090E	0,25	3,11
ad04_u01	40,7853N	30,4122E	0,90	3,24
ad04_u02	40,7877N	30,4113E	0,85	3,20
ad04_u03	40,7806N	30,4114E	0,22	3,10
ad05_u01_yen	40,7765N	30,4110E	0,20	2,58
ad05_u02	40,7811N	30,4175E	0,30	2,53
ad05_u03	40,7744N	30,4156E	0,85	3,57
ad06_u01	40,7628N	30,4148E	0,87	3,99
ad06_u02	40,7714N	30,4098E	0,91	3,64
ad06_u03	40,7695N	30,4149E	0,88	4,58
ad06_u04	40,7630N	30,4166E	0,93	4,22
ad06_u05	40,7643N	30,4102E	0,30	3,05
ad06_u06	40,7681N	30,4131E	0,21	2,57
ad07_c01	40,7582N	30,4123E	1,08	4,75
ad07_c02	40,7618N	30,4084E	0,68	3,66
ad07_u01	40,7526N	30,4124E	1,74	5,49
ad07_u02	40,7542N	30,4167E	1,40	4,06
ad07_u03	40,7610N	30,4185E	0,85	3,99
ad07_u04	40,7543N	30,4070E	5,73	5,67
ad07_u05	40,7596N	30,4132E	0,94	4,71
ad07_u06	40,7607N	30,4167E	0,78	4,36
ad07_u07	40,7571N	30,4111E	1,49	4,40
ad07_u08	40,7566N	30,4187E	1,06	6,18
ad08_c01_adc	40,7534N	30,4114E	2,26	5,36
ad08_c02	40,7488N	30,4118E	0,90	5,76
ad08_c03	40,7509N	30,4075E	4,33	6,87
ad08_c04	40,7505N	30,4081E	2,90	10,26
ad08_c05	40,7532N	30,4096E		

Station	Latitude	Longitude	freq[Hz]	amp
ad08_c06	40,7504N	30,4124E	1,56	4,49
ad08_c07	40,7489N	30,4193E	1,43	5,36
ad08_u01	40,7488N	30,4102E	1,21	5,34
ad09_u01	40,7436N	30,4098E	1,05	7,37
ad09_u02	40,7454N	30,4132E	0,27	5,23
ad10_c01	40,7285N	30,4156E	0,93	6,22
ad10_u01	40,7353N	30,4186E	0,94	6,03
ad11_c01	40,7219N	30,4097E	0,92	6,80
ad12_c01	40,7130N	30,4103E	0,92	5,70
ae02_r01	40,8034N	30,4280E	0,40	4,55
ae03_r01	40,7936N	30,4242E	0,21	4,29
ae03_r02	40,7904N	30,4309E	0,26	3,20
ae03_u01	40,7945N	30,4266E	0,30	3,67
ae04_c01_adu	40,7869N	30,4192E	0,24	3,58
ae04_u01	40,7848N	30,4268E	0,27	3,00
ae04_u02	40,7843N	30,4225E	0,20	3,42
ae05_u01	40,7756N	30,4270E	0,80	4,12
ae05_u02	40,7743N	30,4207E	0,20	2,18
ae05_u03	40,7791N	30,4214E	0,21	2,69
ae06_u01	40,7691N	30,4187E	0,20	3,58
ae07_u01	40,7581N	30,4240E	0,90	5,97
ae07_u02	40,7545N	30,4203E	1,09	5,91
ae08_u01	40,7507N	30,4214E	1,59	5,44
ae08_u02	40,7516N	30,4196E	1,06	6,73
ae08_u03	40,7529N	30,4259E	0,95	1,93
af02_c01	40,8028N	30,4349E	0,47	4,16
af04_u01	40,7884N	30,4369E	0,76	5,12
af05_u01	40,7785N	30,4374E	0,87	4,60
aw10_r01	40,7279N	30,3344E	0,72	5,31
aw11_r01	40,7209N	30,3349E	0,33	7,77
aw12_r01	40,7165N	30,3320E	0,33	5,25
aw12_r02	40,7123N	30,3295E	1,16	4,70
ax11_c01	40,7232N	30,3384E	0,48	4,75
ax11_r01	40,7222N	30,3439E	0,40	5,77
ax11_r02	40,7273N	30,3476E	0,61	5,50
ax12_r01	40,7147N	30,3415E	0,68	4,44
ax12_r02	40,7124N	30,3408E	1,14	4,21
ax12_r03	40,7135N	30,3416E	0,66	2,92
ay10_c01	40,7318N	30,3547E	1,82	3,59
ay10_c02	40,7295N	30,3575E	0,76	3,56

Station	**Latitude**	**Longitude**	**freq[Hz]**	**amp**
ad08_c06	40,7504N	30,4124E	1,56	4,49
ad08_c07	40,7489N	30,4193E	1,43	5,36
ad08_u01	40,7488N	30,4102E	1,21	5,34
ad09_u01	40,7436N	30,4098E	1,05	7,37
ad09_u02	40,7454N	30,4132E	0,27	5,23
ad10_c01	40,7285N	30,4156E	0,93	6,22
ad10_u01	40,7353N	30,4186E	0,94	6,03
ad11_c01	40,7219N	30,4097E	0,92	6,80
ad12_c01	40,7130N	30,4103E	0,92	5,70
ae02_r01	40,8034N	30,4280E	0,40	4,55
ae03_r01	40,7936N	30,4242E	0,21	4,29
ae03_r02	40,7904N	30,4309E	0,26	3,20
ae03_u01	40,7945N	30,4266E	0,30	3,67
ae04_c01_adu	40,7869N	30,4192E	0,24	3,58
ae04_u01	40,7848N	30,4268E	0,27	3,00
ae04_u02	40,7843N	30,4225E	0,20	3,42
ae05_u01	40,7756N	30,4270E	0,80	4,12
ae05_u02	40,7743N	30,4207E	0,20	2,18
ae05_u03	40,7791N	30,4214E	0,21	2,69
ae06_u01	40,7691N	30,4187E	0,20	3,58
ae07_u01	40,7581N	30,4240E	0,90	5,97
ae07_u02	40,7545N	30,4203E	1,09	5,91
ae08_u01	40,7507N	30,4214E	1,59	5,44
ae08_u02	40,7516N	30,4196E	1,06	6,73
ae08_u03	40,7529N	30,4259E	0,95	1,93
af02_c01	40,8028N	30,4349E	0,47	4,16
af04_u01	40,7884N	30,4369E	0,76	5,12
af05_u01	40,7785N	30,4374E	0,87	4,60
aw10_r01	40,7279N	30,3344E	0,72	5,31
aw11_r01	40,7209N	30,3349E	0,33	7,77
aw12_r01	40,7165N	30,3320E	0,33	5,25
aw12_r02	40,7123N	30,3295E	1,16	4,70
ax11_c01	40,7232N	30,3384E	0,48	4,75
ax11_r01	40,7222N	30,3439E	0,40	5,77
ax11_r02	40,7273N	30,3476E	0,61	5,50
ax12_r01	40,7147N	30,3415E	0,68	4,44
ax12_r02	40,7124N	30,3408E	1,14	4,21
ax12_r03	40,7135N	30,3416E	0,66	2,92
ay10_c01	40,7318N	30,3547E	1,82	3,59
ay10_c02	40,7295N	30,3575E	0,76	3,56

Station	Latitude	Longitude	freq[Hz]	amp
ay10_c03	40,7285N	30,3509E	0,58	5,79
ay11_c01	40,7208N	30,3544E	0,34	7,11
ay11_c02	40,7255N	30,3546E	0,47	5,81
ay11_c03	40,7208N	30,3603E	0,34	5,95
ay12_r01	40,7165N	30,3535E	0,40	5,23
ay13_c01	40,7051N	30,3592E	n/a	n/a
az10_c01	40,7299N	30,3664E	0,81	6,43
az10_c02	40,7326N	30,3622E	2,15	3,72
az10_c03_01	40,7334N	30,3726E	1,33	6,10
az10_c04	40,7318N	30,3675E	1,63	4,12
az10_c05	40,7303N	30,3618E	0,90	5,36
az10_c06	40,7281N	30,3673E	0,67	5,29
az10_r01	40,7341N	30,3682E	n/a	n/a
az11_c01	40,7221N	30,3663E	0,35	6,91
az12_c01	40,7102N	30,3626E	n/a	n/a
az13_u01	40,7047N	30,3710E	1,30	7,06
az14_u01	40,6987N	30,3667E	1,51	4,39

7.2 H/V Ratios in Adapzarı

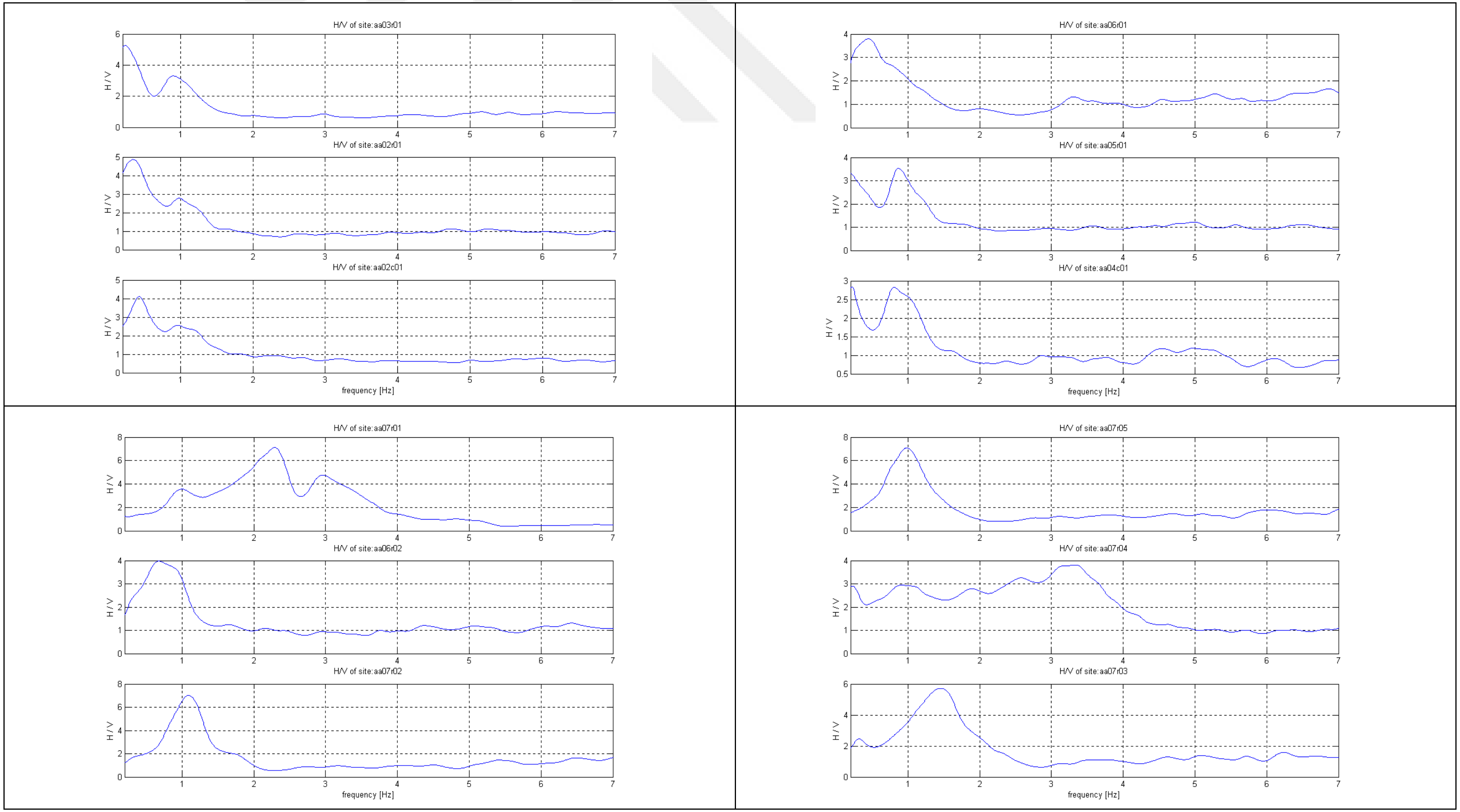


Figure 7-1 H / V of site: aa02r01 to aa07r05

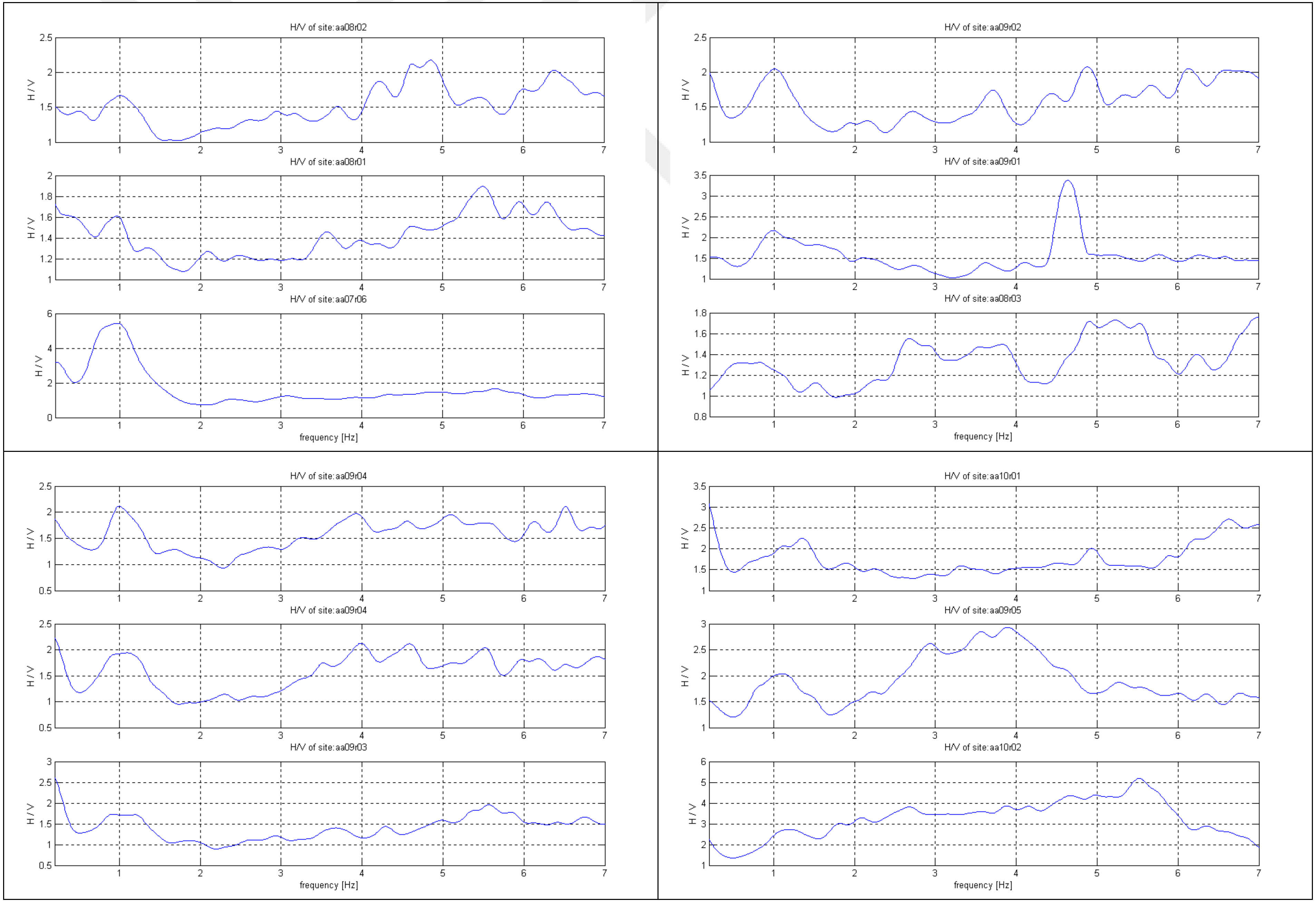


Figure 7-2 H/V of site: aa07r06 to aa10r02

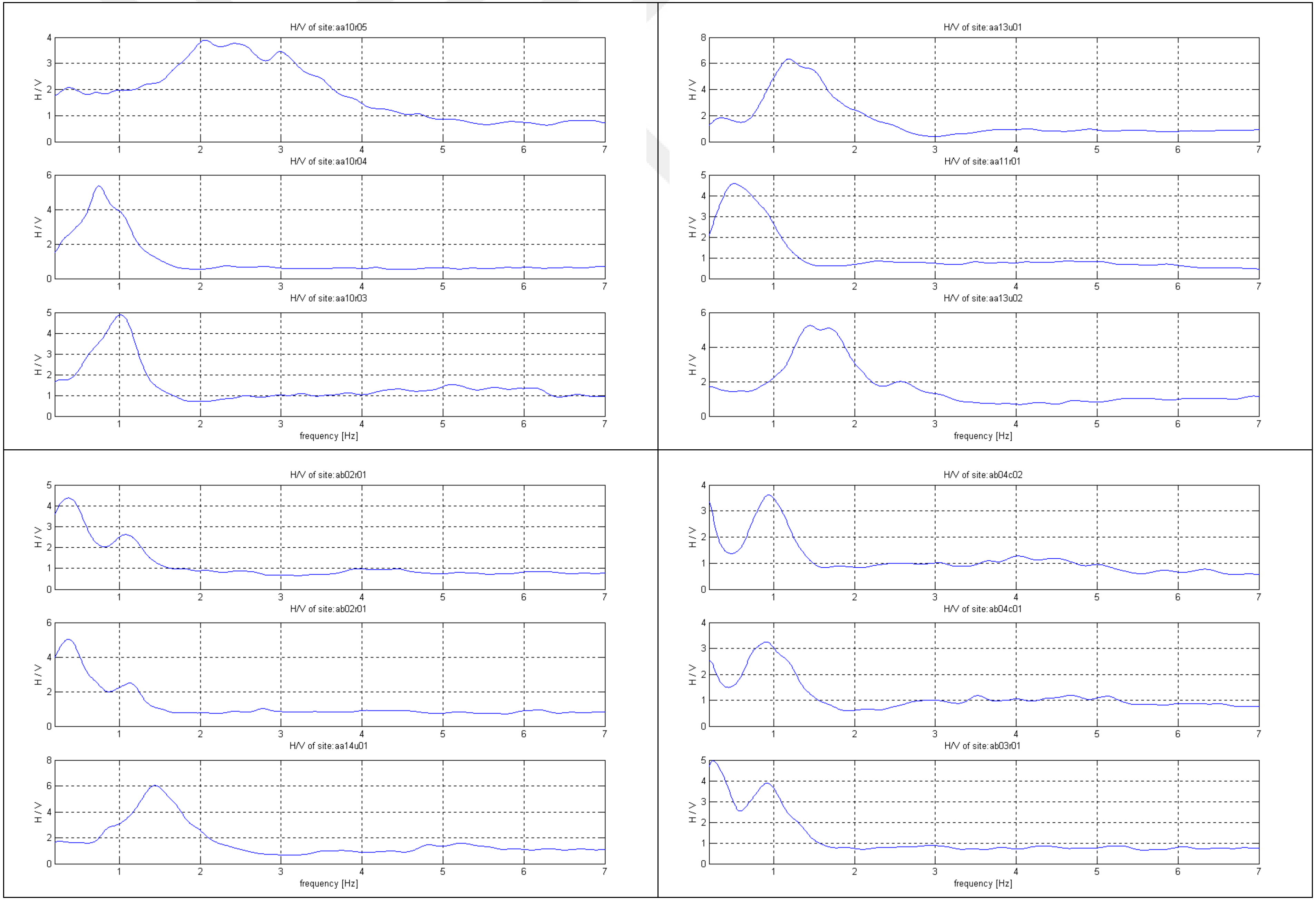


Figure 7-3 H/V of site: aa10r03 to ab04c02

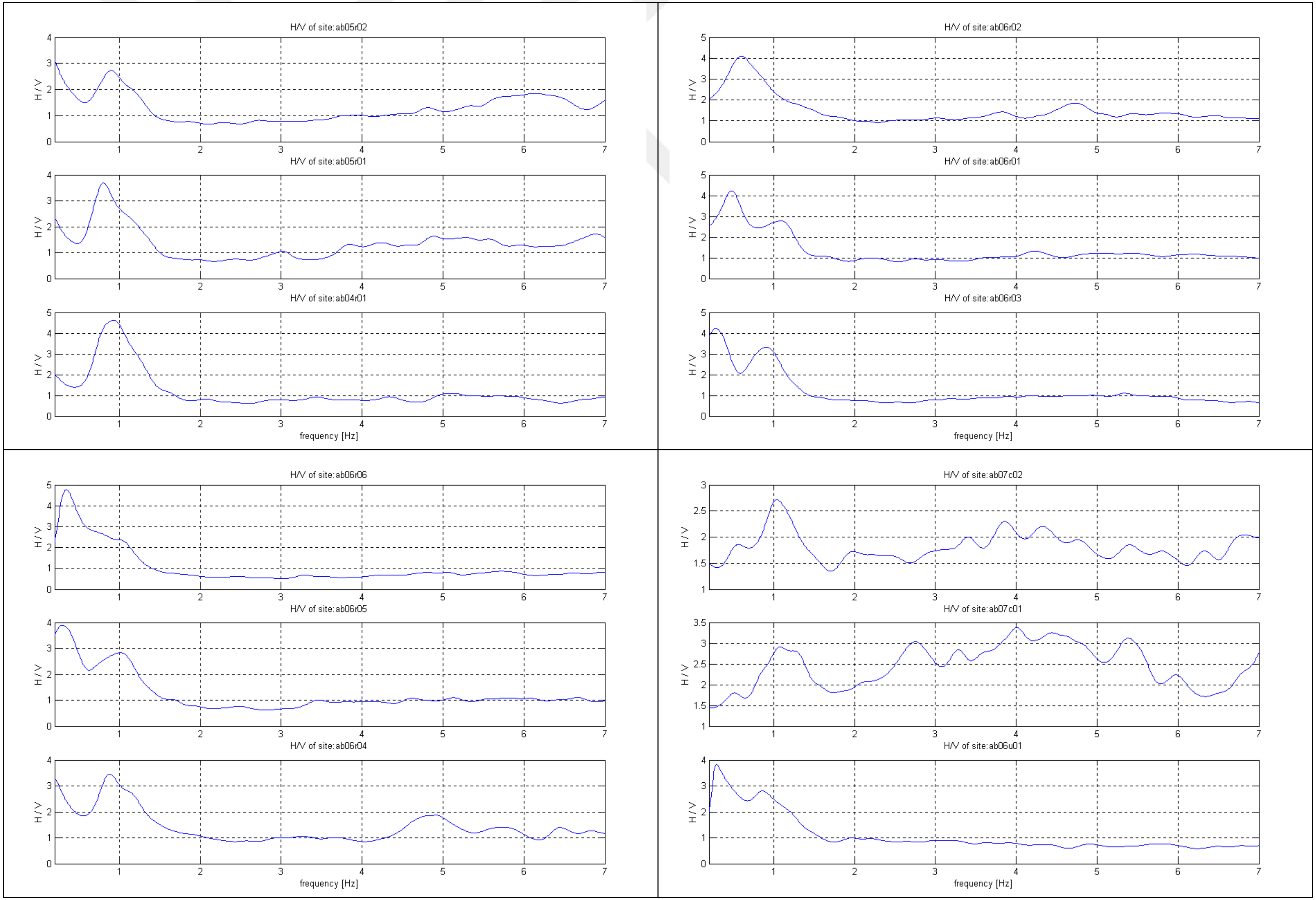


Figure 7-4 H/V of site: ab04r01 to ab07c02

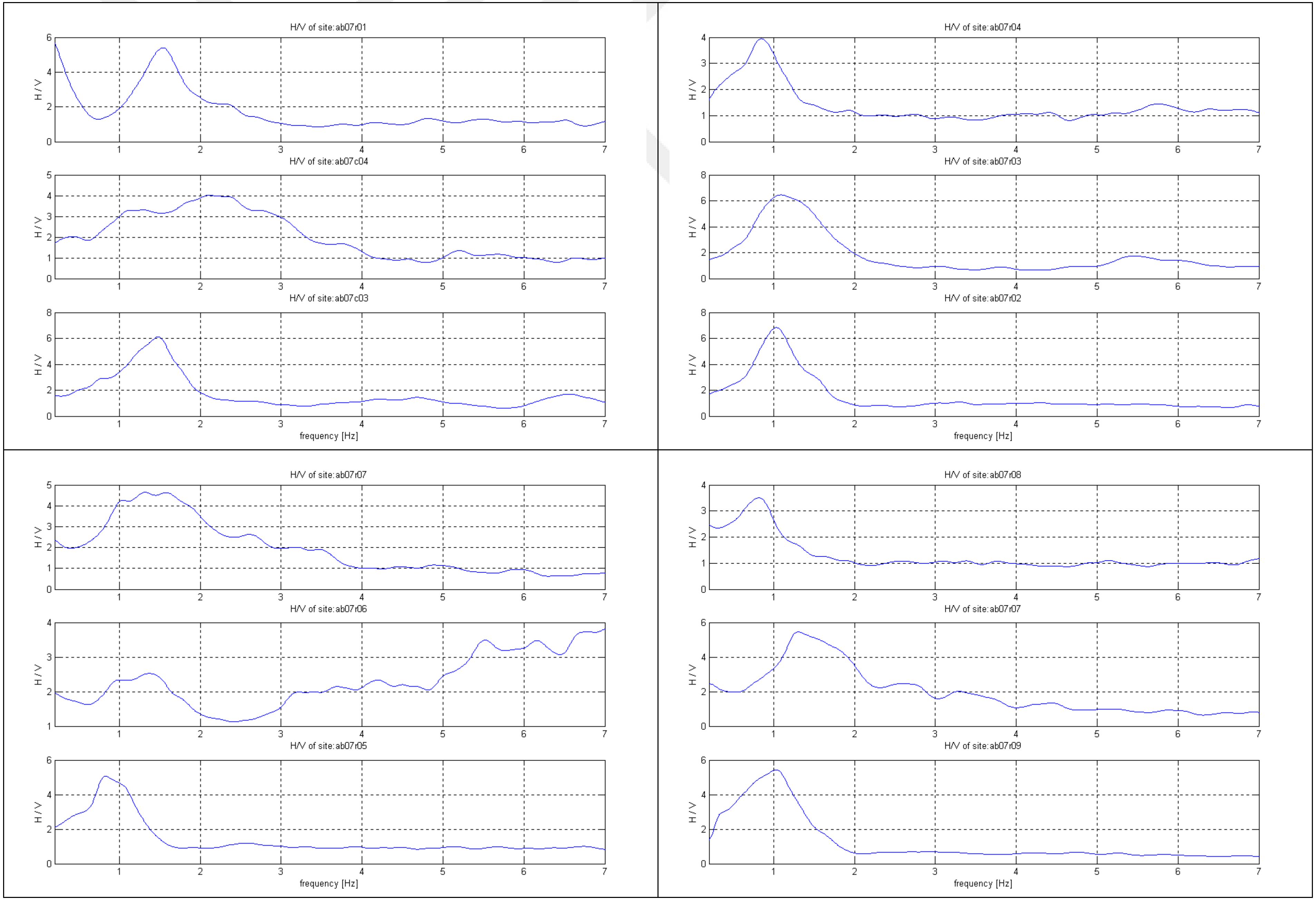


Figure 7-5 H/V of site: ab07c03 to ab07r09

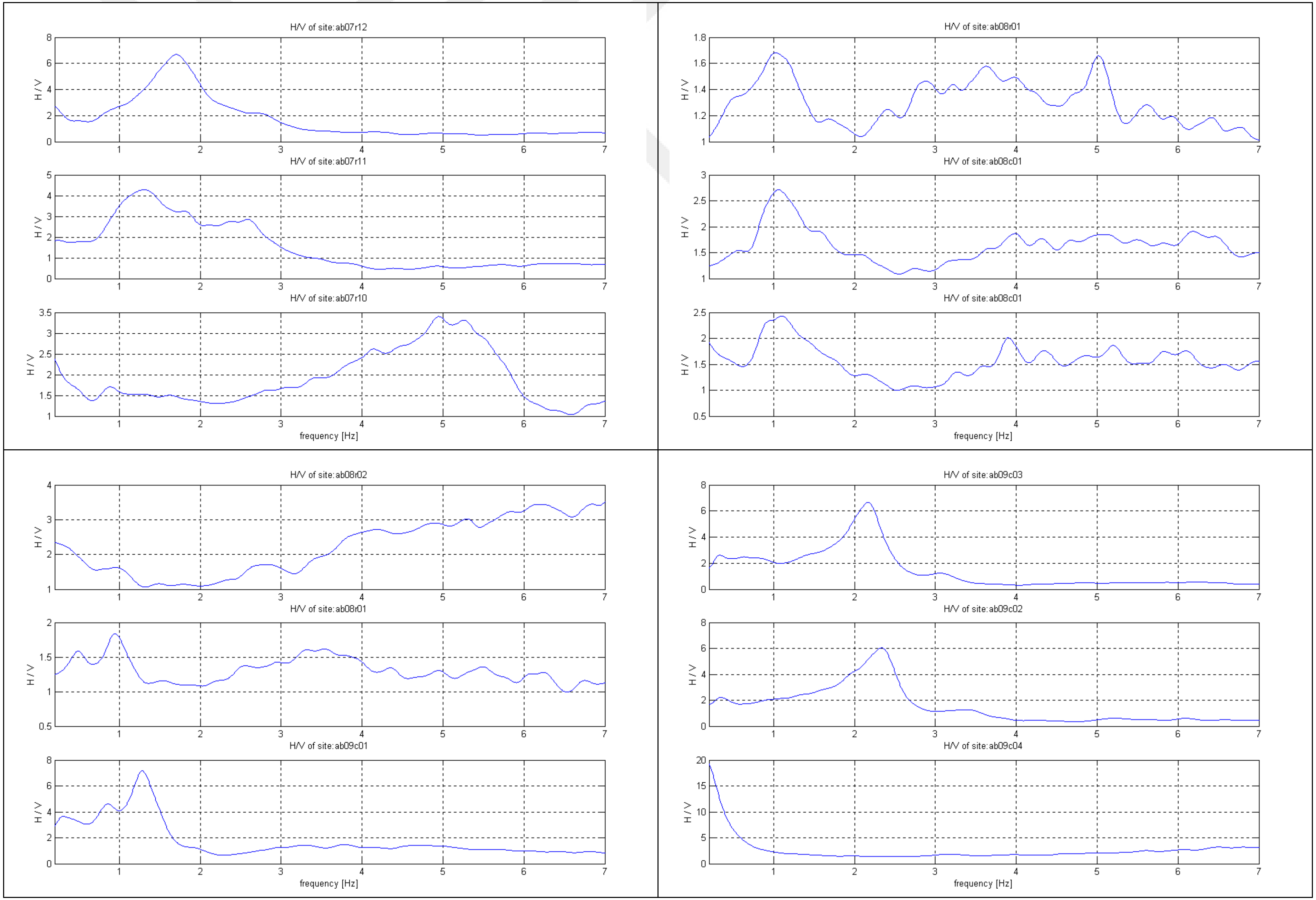


Figure 7-6 H/V of site: ab07r10 to ab09c04

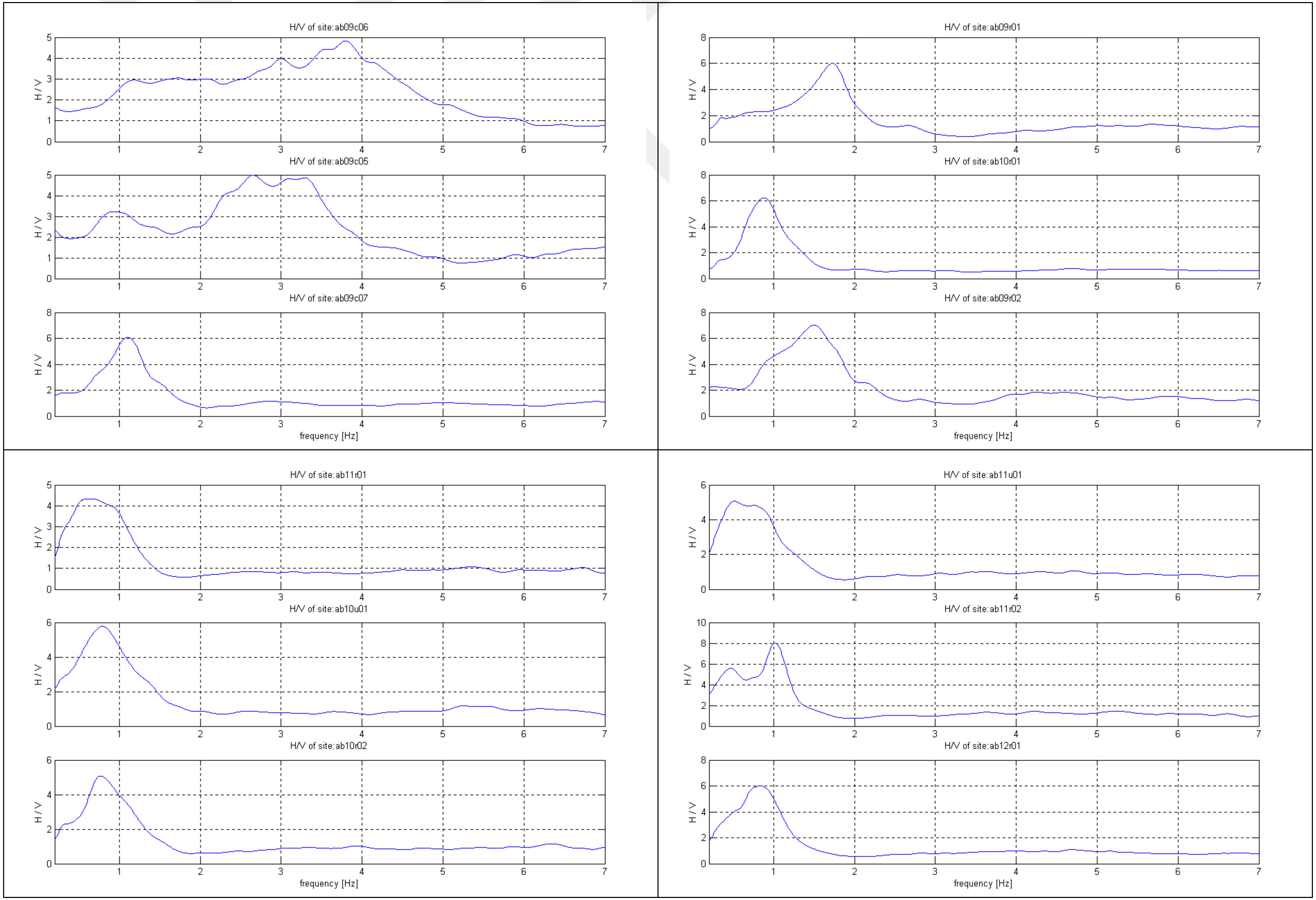


Figure 7-7 H/V of site: ab09c05 to ab12r01

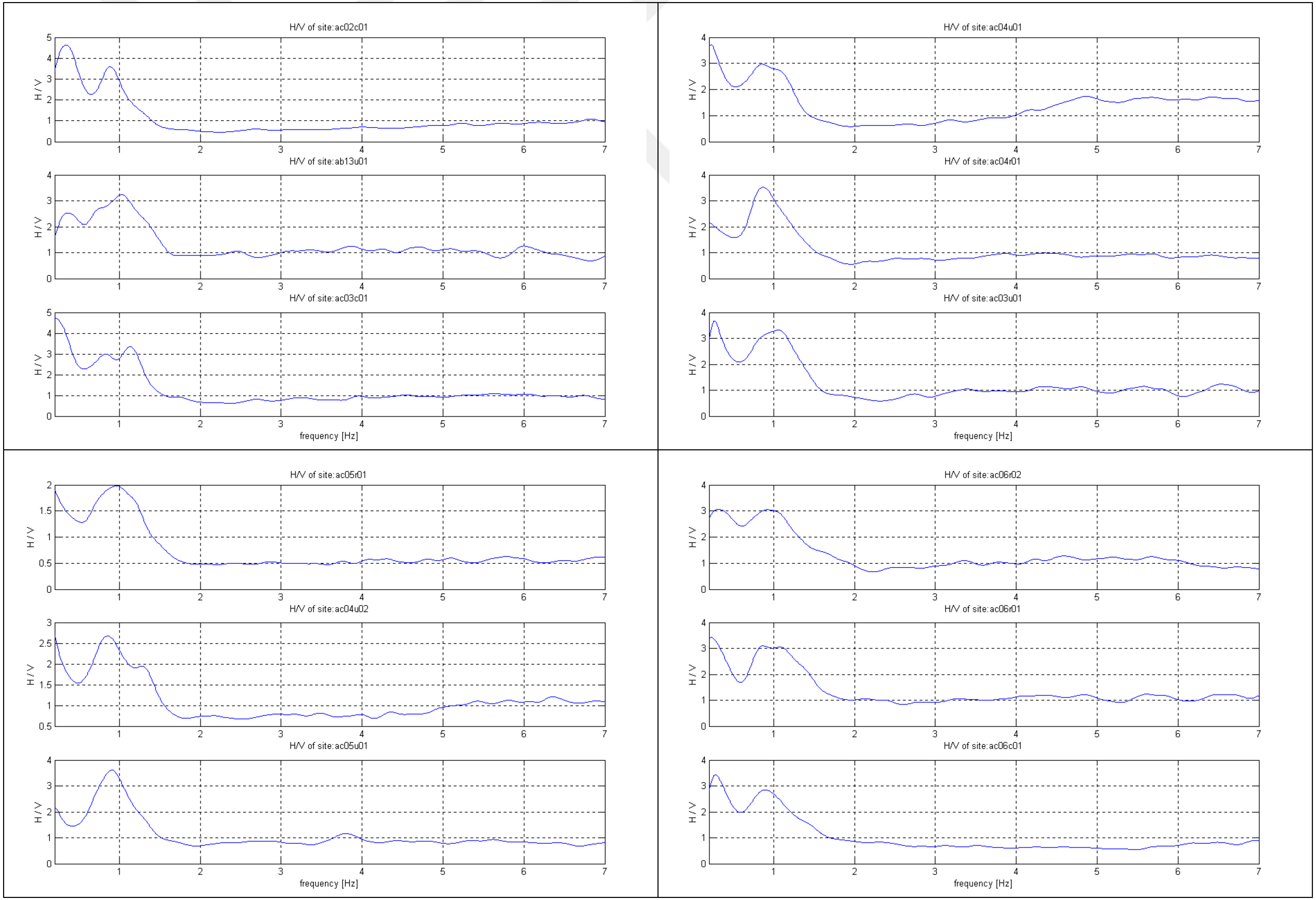


Figure 7-8 H/V of site: ab13u01 to ac06r01

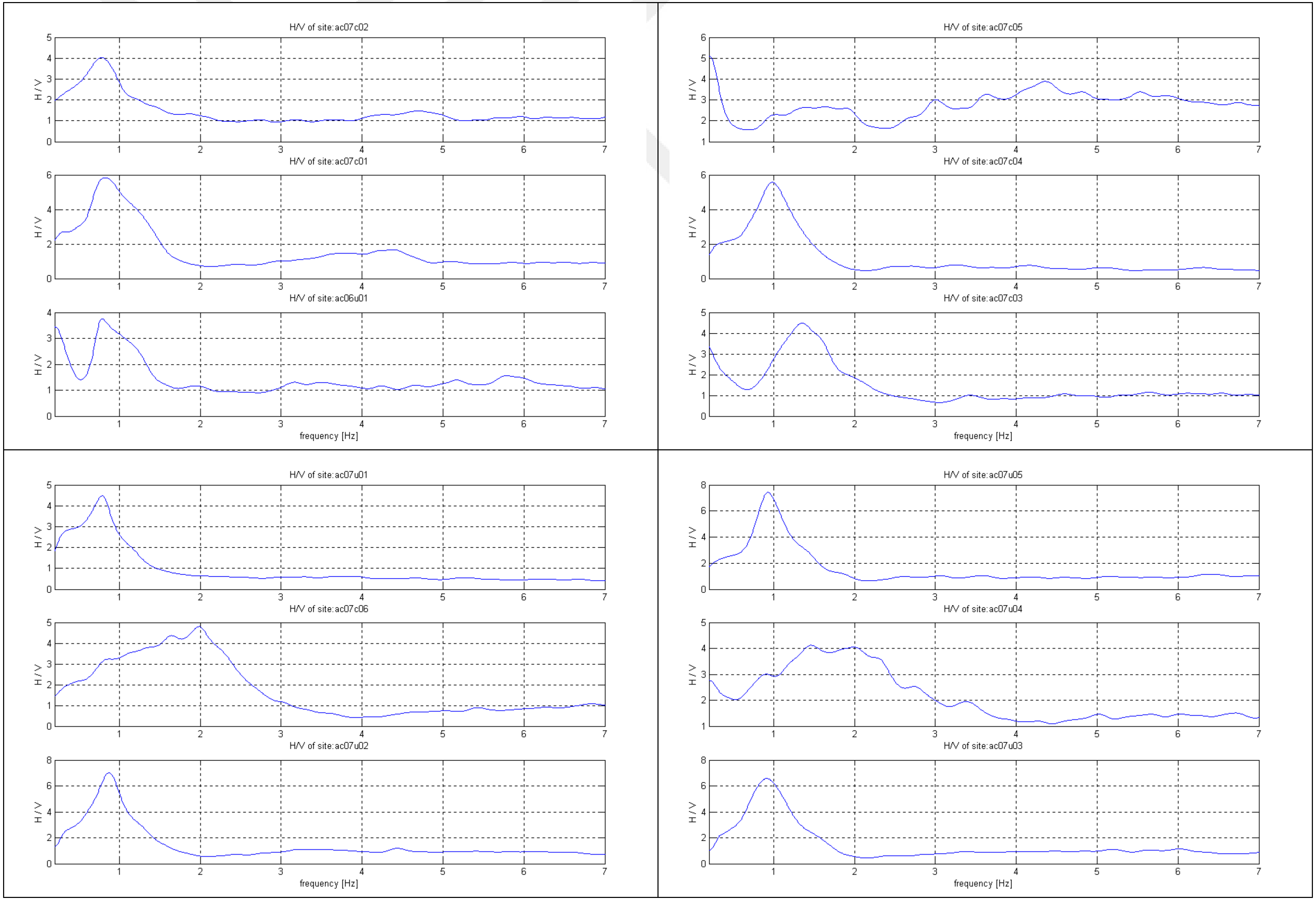


Figure 7-9 H/V of site: ac06u01 to ac07u05

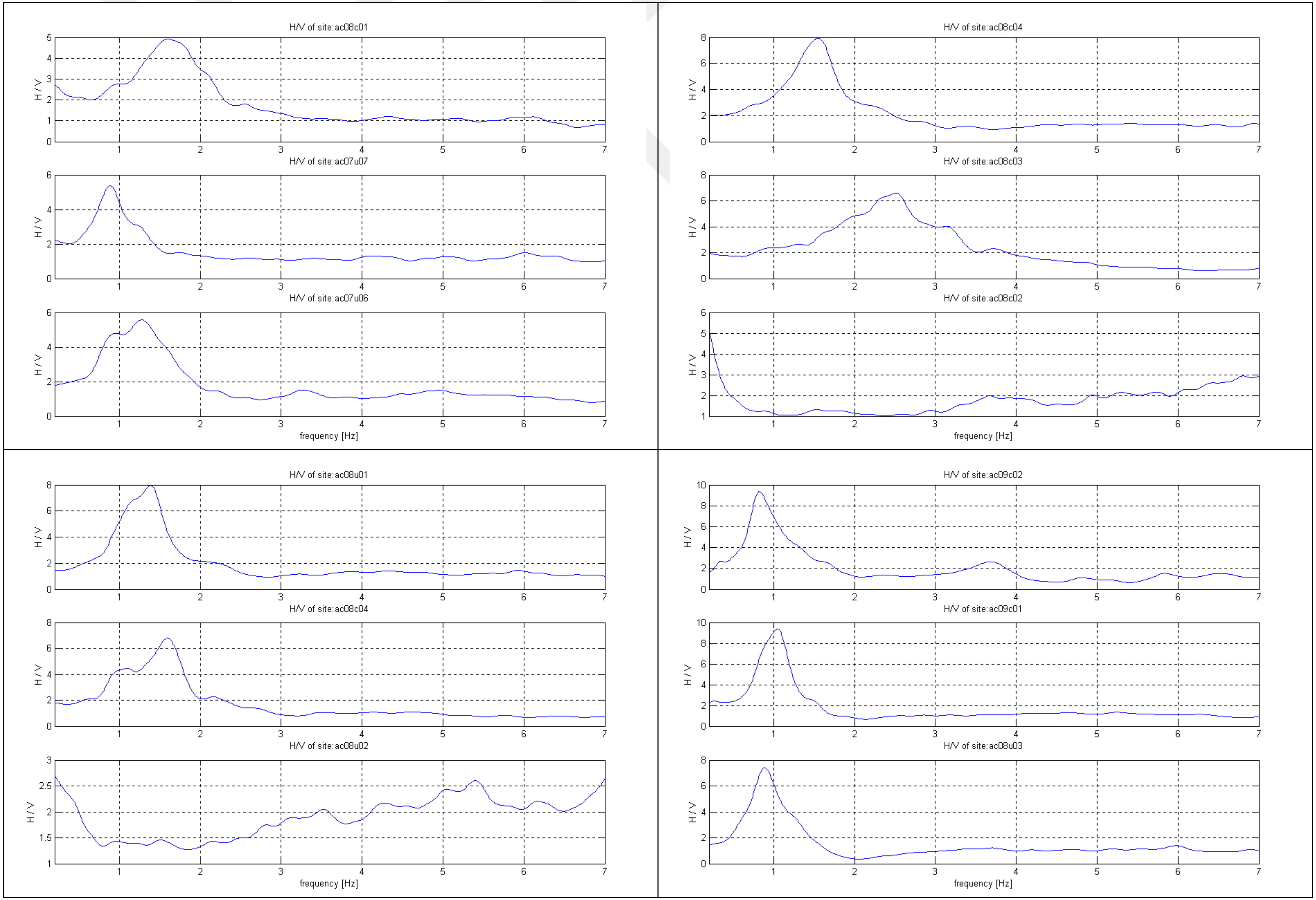


Figure 7-10 H/V of site: ac07u06 to ac09c02

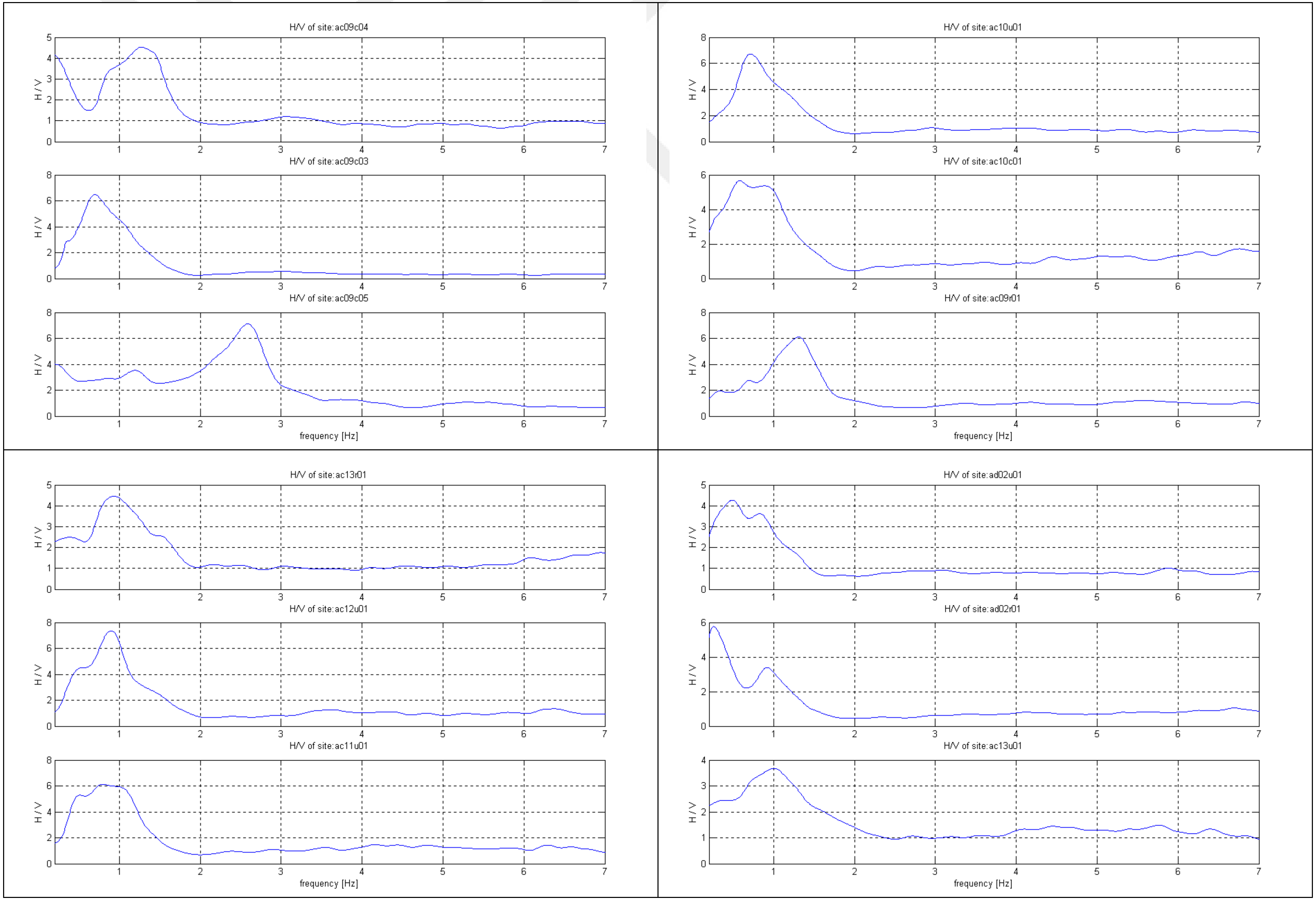


Figure 7-11 H/V of site: ac09c03 to ad02u01

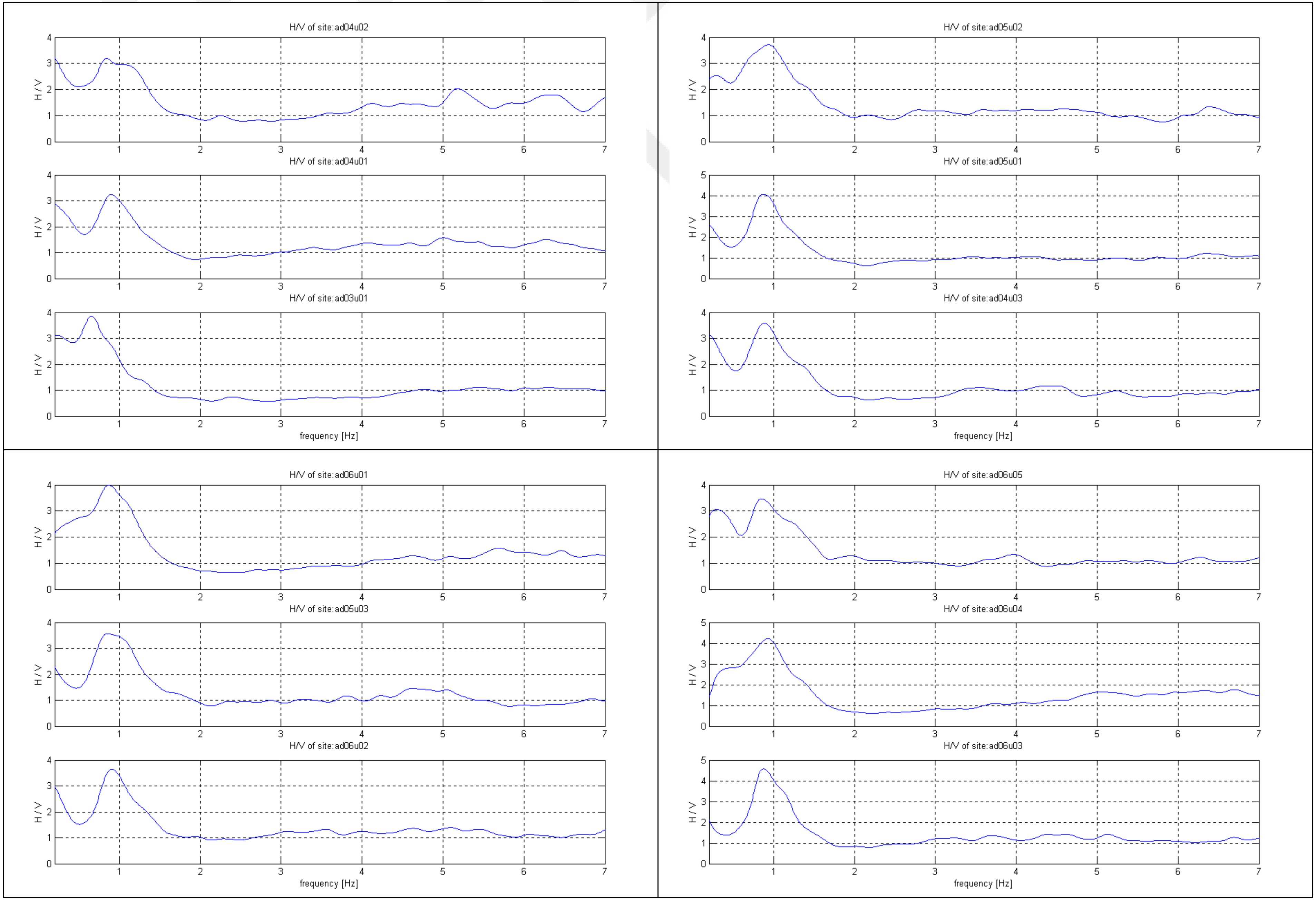


Figure 7-12 H/V of site: ad03u01 to ad06u05

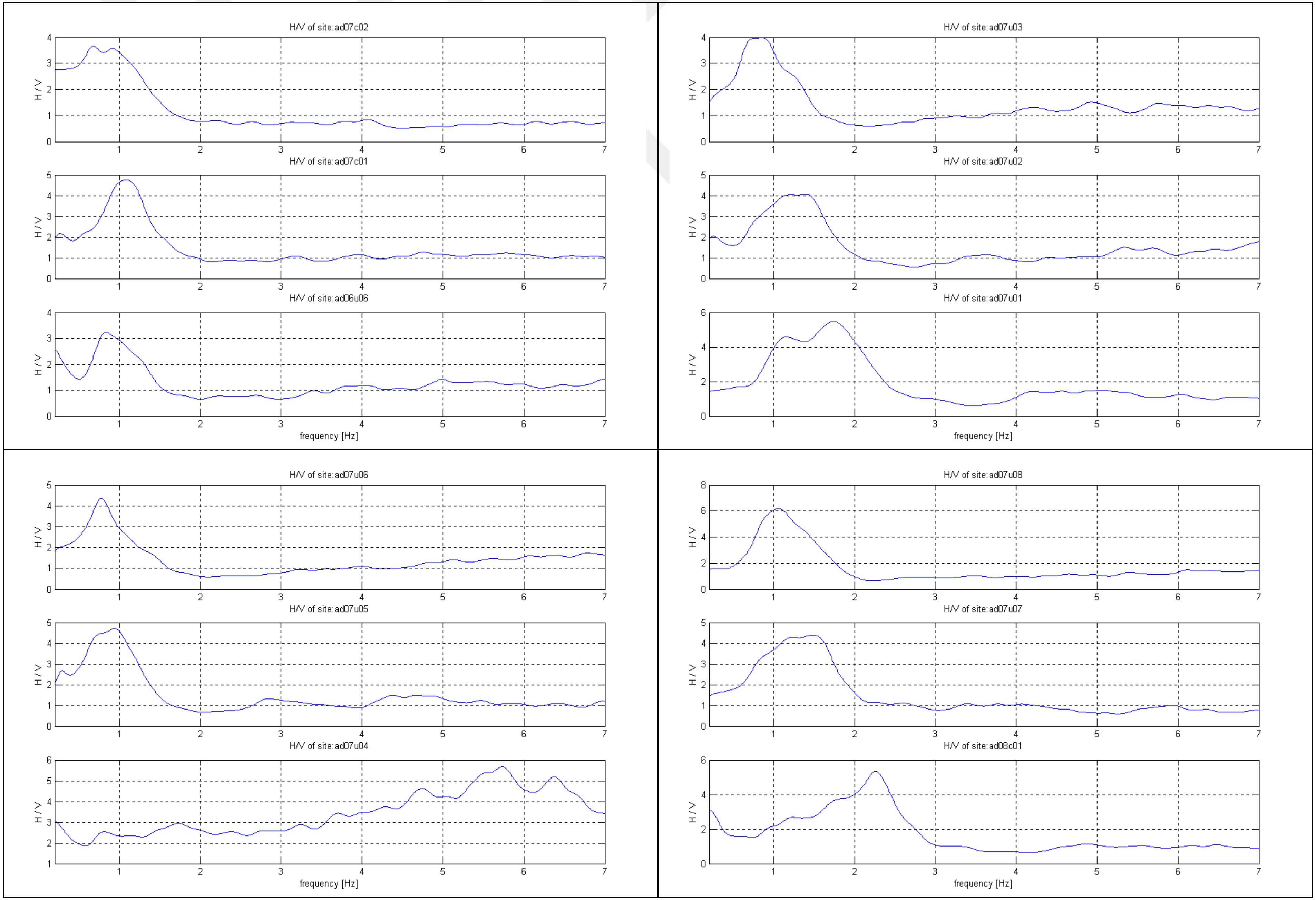


Figure 7-13 H/V of site: ad06u06 to ad08c01adc

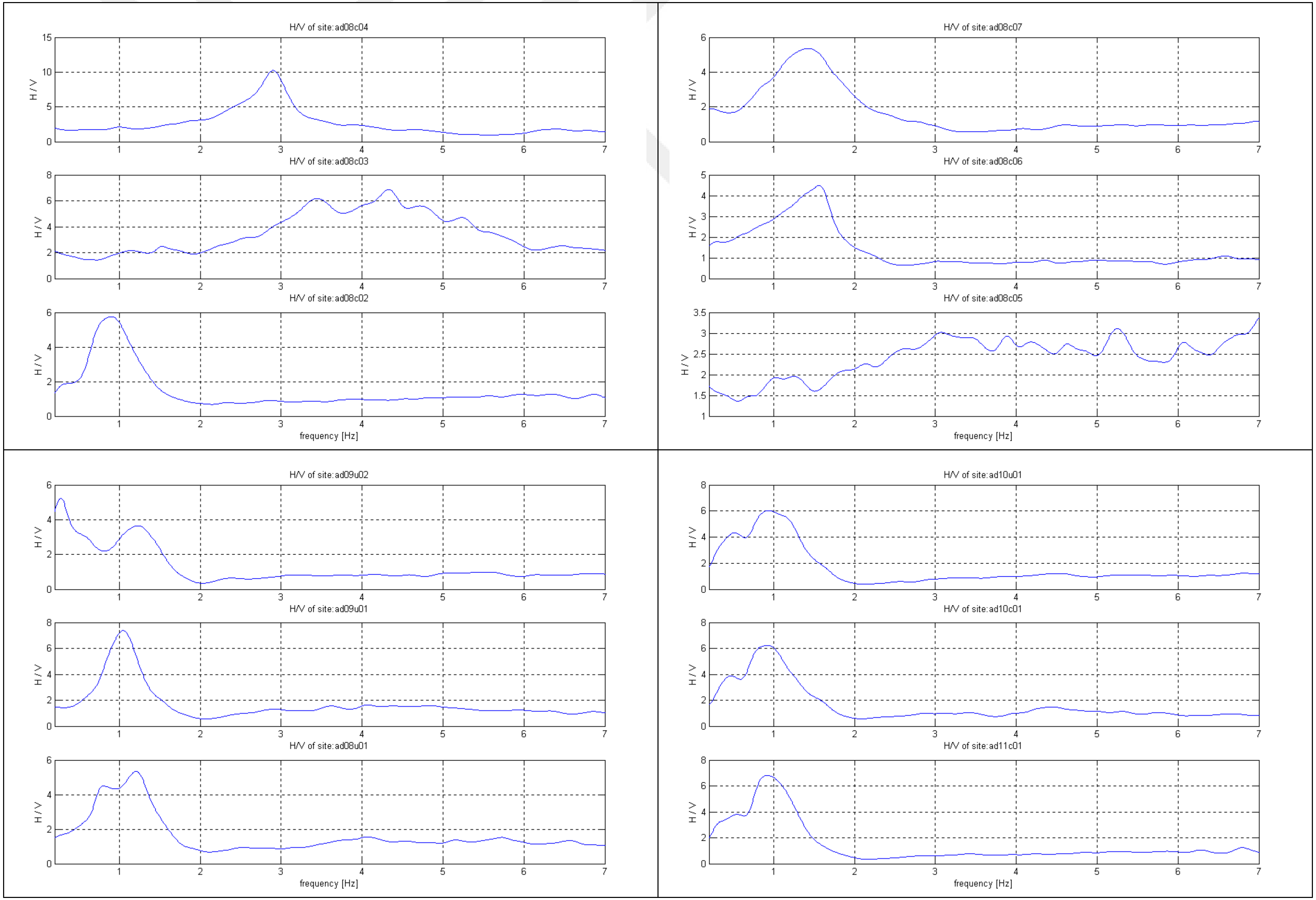


Figure 7-14 H/V of site: ad08c02 to ad11c01

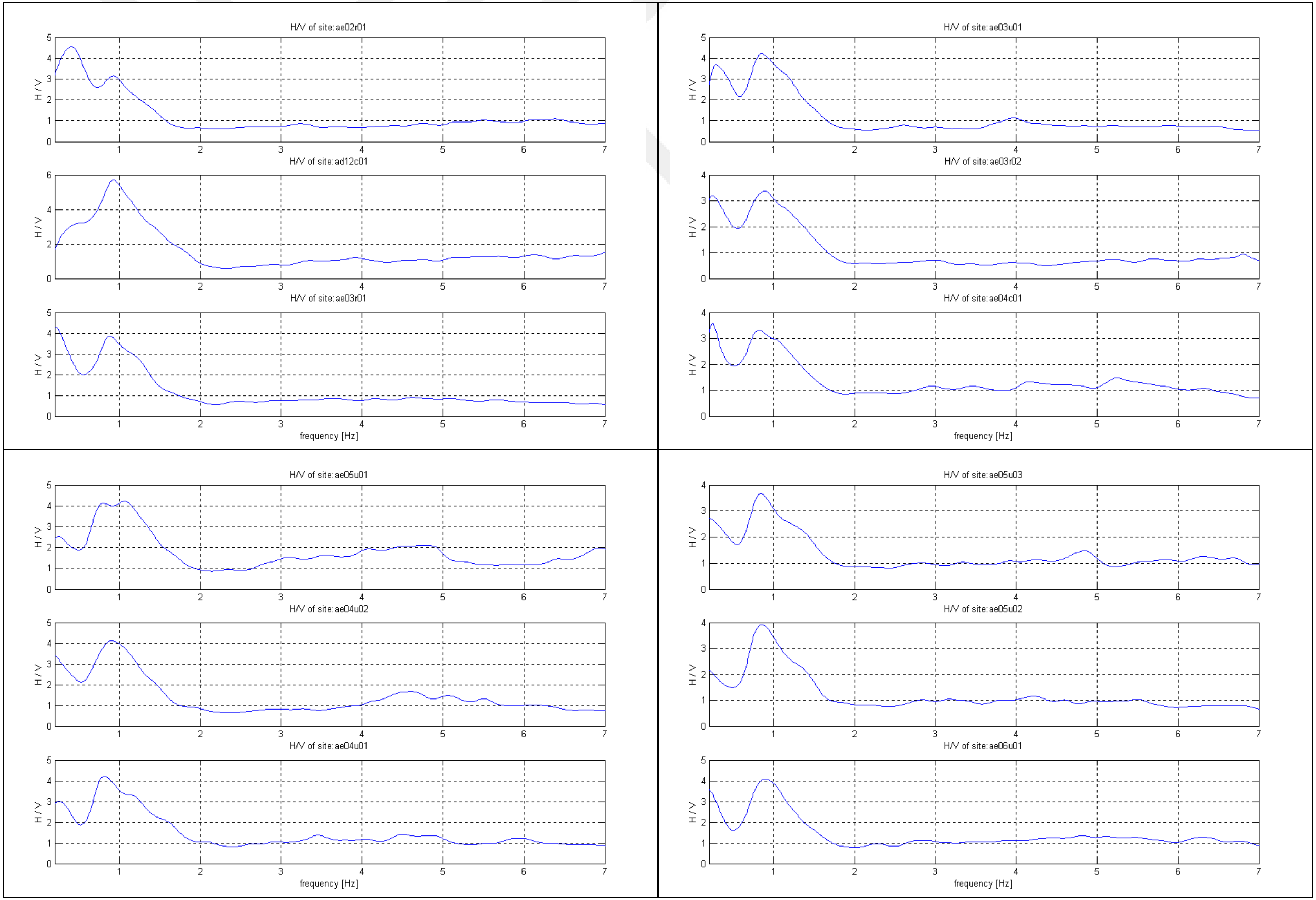


Figure 7-15 H/V of site: ad12c01 to ae06u01

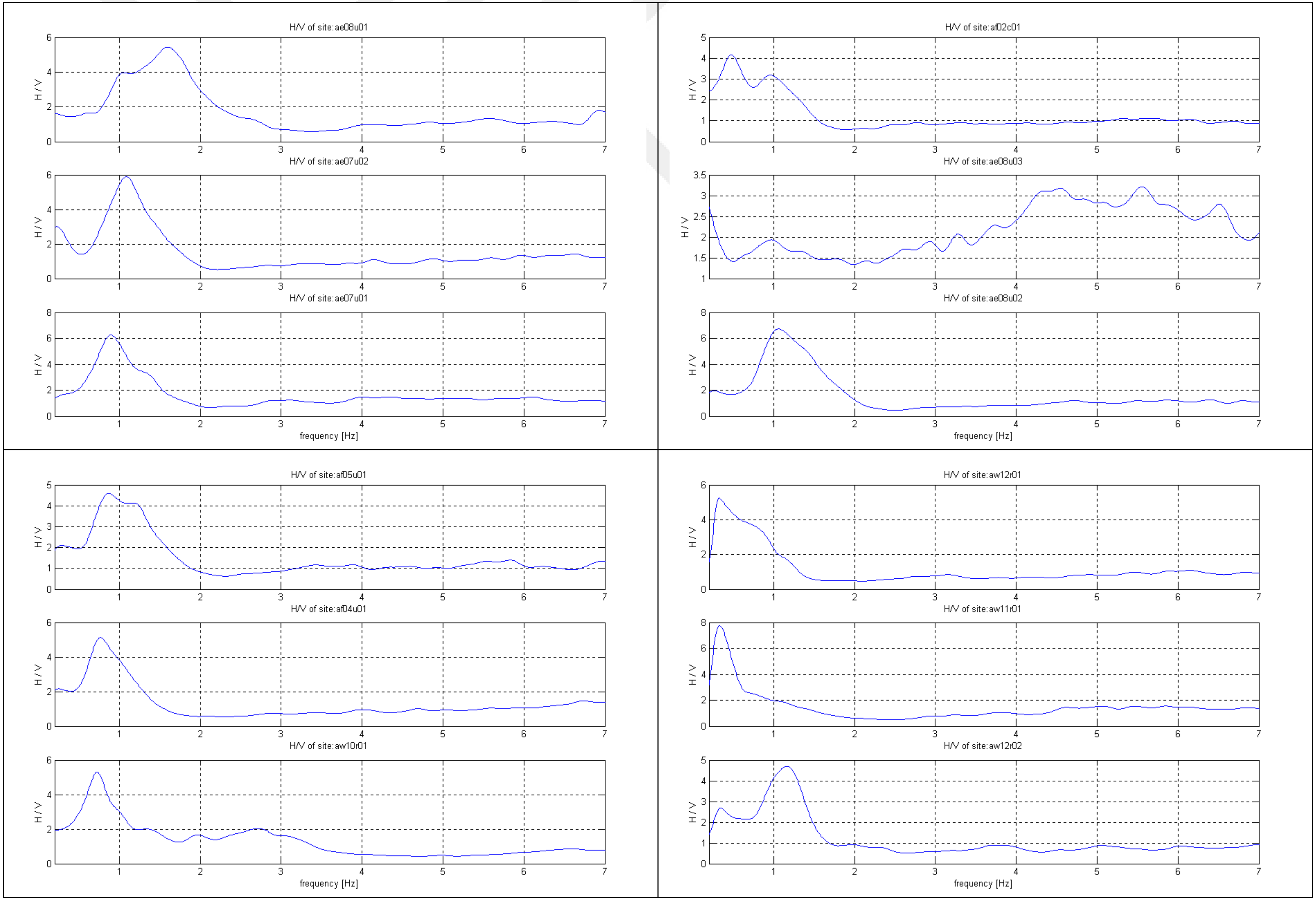


Figure 7-16 H/V of site: ae07u01 to aw12r02

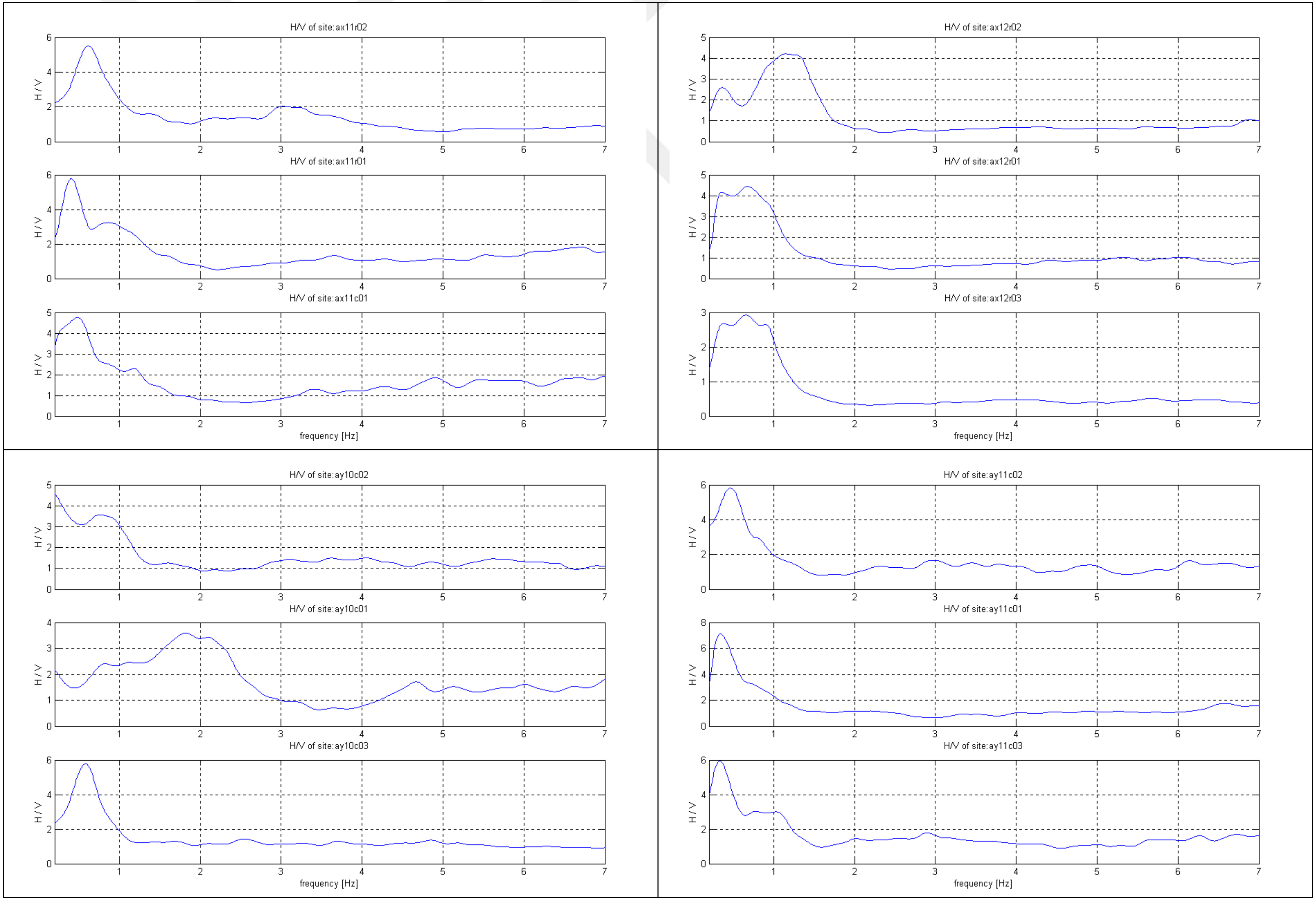


Figure 7-17 H/V of site: ax11c01 to ay11c03

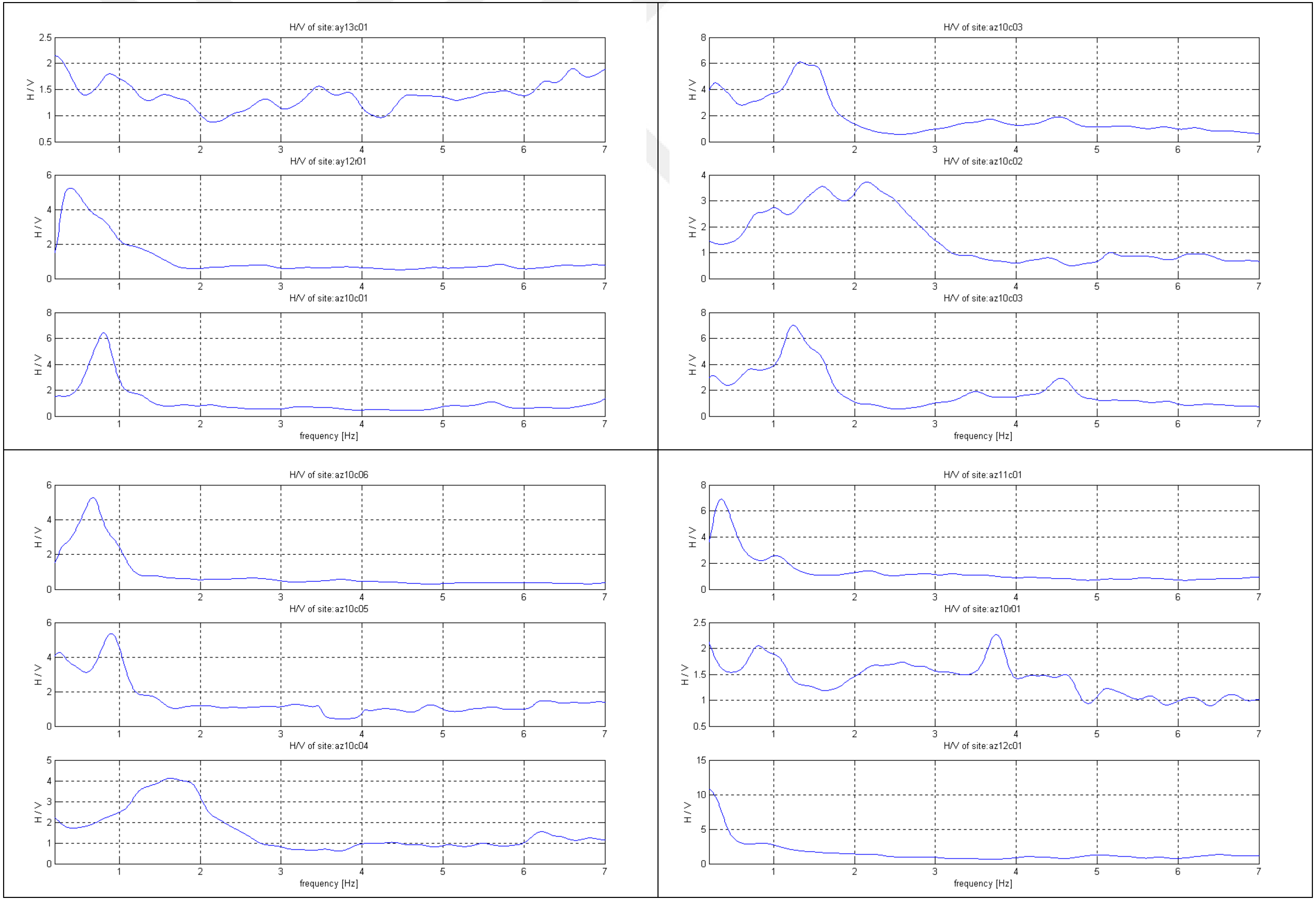


Figure 7-18 H/V of site: ay12r01 to az12c01

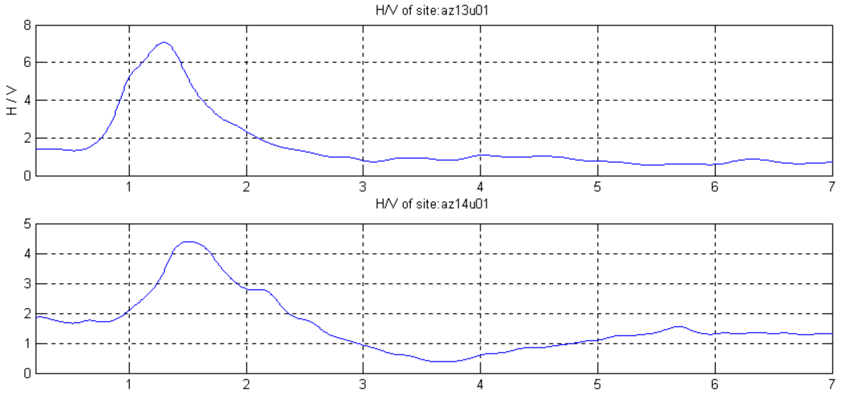


Figure 7-19 H/V of site: ay13u01 to az14u01