

USE OF AMBIENT VIBRATIONS IN UNDERSTANDING LOCAL SITE EFFECTS AT BROADBAND SEISMIC STATIONS OF THE HELLENIC UNIFIED SEISMOLOGICAL NETWORK (HUSN)

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Abstract

The evaluation of ambient seismic noise at the Hellenic Unified Seismic Network (HUSN) stations is investigated in this study. Ambient vibration recordings combined with the horizontal to vertical (H/V) spectral ratio technique helps in characterizing local site effects. This technique was applied at 17 sites ambient noise measurements. We selected a number of 1-hr waveform segments during day and night for summer and winter. For each site the H/V spectral ratio was calculated and the results were combined with geological and geophysical information. The goal was to show the network performance as far as the station quality and noise level at each site concerns in order to provide possible structural improvements, seismic station relocations or to detecting operational problems.

Keywords: *H/V ratio, noise, seismic stations.*

Περίληψη

Η παρούσα εργασία ασχολείται με την εκτίμηση και αξιολόγηση του σεισμικού θορύβου στους σεισμολογικούς σταθμούς του Ελληνικού Ενοποιημένου Σεισμολογικού Δικτύου (Ε.Ε.Σ.Δ). Η τεχνική που χρησιμοποιήθηκε για τη μέθοδο εκτίμησης των τοπικών εδαφικών συνθηκών αφορά το φασματικό λόγο της οριζόντιας προς την κατακόρυφη συνιστώσα καταγραφών εδαφικού θορύβου (Horizontal-to-Vertical Spectral Ratio ή HVSR). Η μέθοδος αυτή εφαρμόστηκε σε ένα δείγμα 17 σεισμολογικών σταθμών του ενιαίου σεισμολογικού δικτύου. Χρησιμοποιήθηκαν κυματομορφές διάρκειας μίας ώρας και οι οποίες αφορούσαν καταγραφές κατά τη διάρκεια της νύχτας, της ημέρας για το χειμώνα και για το καλοκαίρι. Για κάθε καταγραφή υπολογίστηκε ο φασματικός λόγος της οριζόντιας προς την κατακόρυφη συνιστώσα εδαφικού θορύβου και έγινε μία προσπάθεια εκτίμησης των αποτελεσμάτων σε συνδυασμό με γεωλογικές και γεωφυσικές πληροφορίες. Ο στόχος είναι να γίνει μια προσπάθεια επανεκτίμησης της σωστής λειτουργίας των σεισμολογικών σταθμών του δικτύου και με τον έλεγχο των επιπέδων θορύβου για κάθε σταθμό του δείγματός μας να παραχθούν πιθανές βελτιώσεις σε τυχόν λειτουργικά προβλήματα των σταθμών ή ακόμη και τοποθέτηση των σταθμών σε άλλη θέση.

Λέξεις κλειδιά: *σεισμολογικοί σταθμοί, φασματικός λόγος, εδαφικός θόρυβος.*

1. Introduction

An important precondition for the correct interpretation of seismic signals and the development of seismological research is the quality of seismic observations. Primarily this is achieved by the use of accurate and high quality instrumentation. In the last 15 years high performance seismological instruments have been developed and became available to the seismological community. Gradually, old short-period sensors have been replaced by new broadband ones, able to cover a very high range of frequencies.

Secondly, the quality of the data is controlled by local conditions, installation quality and ambient noise influence. To assure a good station performance it is important to estimate local site effects for each existing station or during a new site selection.

Complete modernisation of the Hellenic Unified Seismological Network (HUSN), has been accomplished in 2007. Modern digital equipment have been installed in all existing stations of the four national seismological networks (network codes: HL, HT, HP, HA), while more new stations have been installed, ameliorating the regional seismological coverage. Furthermore the real-time exchange of data between these networks, as well as with other networks from surrounding countries, has facilitated the every day event detection and analysis procedures. Today HUSN consists of 149 seismological stations. Even though a large number of these stations behavior has been investigated, in this study we only present a sample of 17 stations (Fig. 1) for which the installation quality in relation with local geology (Table 1) and possible interactions with physical or human related noise sources has been thoroughly examined.



Figure 1 - Seismological stations used in present study.

Table 1 - Seismological stations specifications.

Station	Latitude	Longitude	Elevation	Digitizer	Sensor	Geology
AGG	39.021	22.336	625	Trident	CMG-3ESP/100	Diabas-Dolerite MESOZOIC
APE	37.073	25.523	608	PS6-SC	STS-2/N	Mica Schist PRE-PERMIAN
ATH	37.974	23.718	93	DR24	STS-2	Mica Schist-Limestone CENOMANIAN
FNA	40.782	21.384	806	HRD24	CMG-3ESP/100	Gneiss NEOGENE-QUATERNARY
GVD	34.839	24.087	170	PS6-SC	STS-2N	Limestone JURASSIC- CRETACEOUS
HORT	40.598	23.1	933	Trident	CMG-3ESP/100	Gneiss Schist NEO-PALEOZOIC- MESOZOIC
IACM	35.306	25.071	45	PS6-SC	STS-2	Conglomerates PLEISTOCENE
KARP	35.547	27.161	524	PS6-SC	STS-2	Flysch UPPER EOCENE
KLV	38.044	22.15	758	PS6-SC	STS-2	Limestone UPPER CRETACEOUS
LIT	40.103	22.489	558	Trident	CMG-3ESP/100	Crystalline limestone TRIASSIC
OUR	40.333	23.979	117	Trident	CMG-3ESP/100	Granodiorite MESOZOIC
PRK	39.246	26.265	130	EDR-209	STS-2	Igneous Breccia PLEISTOCENE
SIGR	39.211	25.855	90	Trident	CMG-3ESP/100	Volcanic Breccias NEOGENE
SOH	40.821	23.356	670	Taurus	Trillium 120P	Aluminaceous Gneiss PALEOZOIC
THE	40.632	22.963	132	Trident	CMG-3ESP/100	Schistous Gneiss PALEOZOIC
VLS	38.177	20.589	402	DR24	Trillium 120P	Alluvium QUATERNARY
ZKR	35.115	26.217	270	PS6-SC	STS-2N	Limestones-Δολομίτες CRETACEOUS

2. Method and Data

2.1. H/V method

The spectral analysis of ambient noise using the H/V (Horizontal-to-vertical Spectral Ratio or HVSR) technique is examined in this paper. The method is a convenient way to reliably evaluate site effects; it is a low cost method and contributes to seismic risk mitigation in urban environments. Ambient noise is low amplitude soil vibrations generated by natural disturbances such as weather conditions (temperature, wind, rain etc.), transients (traffic, steps, cars, etc.), industrial noise, etc.

The HVSR technique is well known as “Nakamura technique” and it was initially proposed from Nogoshi and Iragashi (1971) and Nakamura (1989). According to them the spectral ratio of horizontal to vertical component of ambient noise usually shows a peak, which indicates the fundamental frequency of the investigated site. The reliability of this method has been studied both numerically and experimentally. Several researchers (among which Field and Jacob, 1993; Lachet and Bard, 1994; Lermo and Chávez-García, 1994a) have theoretically supported the H/V spectral ratio technique through numerical simulations showing that synthetics obtained by randomly distributed near surface sources lead to H/V spectral ratios sharply peaked around the fundamental S-wave frequency, whenever the surface layers exhibit a sharp impedance contrast with the

underlying stiffer formations. A large number of observational studies have been performed to experimentally establish the credibility of the method (Ohta *et al.*, 1978; Mucciarelli, 1998; Rodriguez and Midorikawa, 2002 among others). Recently, a European project the so-called SESAME (Site EffectS assessment techniques using AMbient Excitations) studies the site effects assessment techniques using ambient variations and investigates the experimental aspects that influence the stability of ambient noise measurements (Atakan *et al.*, 2004; Duval *et al.*, 2004). In Greece site effects assessment has been attempted analysing ambient noise measurements. Several tests and evaluation of noise recordings that were performed in selected sites in the downtown of the city Thessaloniki (Northern Greece) (Panou *et al.*, 2005a, b) examine the ability and reliability of the H/V spectral ratio technique.

It is highly recommended that prior to planning a measurement campaign on ambient vibrations, a local geological survey, especially on Quaternary deposits, should be performed. Interpretation of the H/V results will be greatly enhanced when combined with geological, geophysical and geotechnical information.

In order to investigate the HUSN stability and performance and the seismological sites installation quality and noise level, 17 sites of ambient noise measurements were used in this study. The software used to analyze noise recordings was GEOPSY (GEOPhysical Signal database for noise array processing) (www.geopsy.org). The noise recordings are classified into two time categories (morning (12:00-13:00) and night (00:00-01:00)) to study the diurnal variation and in order to examine the seasonal variation, samples from winter and summer have been used. All waveform samples for every seismological site are referred to the same hour and day. Using the module 'H/V' of the Geopsy software the following parameters were applied to our data:

- Enable the anti-triggering process on raw signal.
- The window length was defined to be greater than 50-60sec
- The smoothing type: Kono and Ohmachi ($b=40$)
- The frequency range from 0.50Hz to 10Hz.
- The short term average (STA) and the long term average (LTA) set equal to 1.0s and 30.0s respectively. (STA/LTA:0.20-2.50)
- Windows selection was either automatic or manual with a minimum number of 20 windows for the results to be acceptable.

The average noise H/V spectral ratios of each category (time and season) as a function of frequency are given in figure 3.

2.2. Data

Digital seismic data from 3-component broadband seismometers at 100 sps have been used for the analysis. Technical specifications of seismological stations are shown in Table 1. A mixture of seismic sensor types were used in present study, including Streckheisen STS-2, 3ESP (100 s), 3ESPC (60 s), Nanometrics Trillium 120P (120 s), all of them within wide frequency ranges from 0.001 to 50-100Hz.

Four distinct data sets (Table 2) have been used to investigate seasonal and diurnal variations and to verify stable station behaviour not depending on temporary problems.

The frequency window used was of 0.5-10 Hz (Fig 2). The selection of this frequency range was based on the frequencies of seismic signals enregistered and analyzed for regional events. As we can see on Figure 2, where 10 month (01/01/2015-31/10/2015) events are plot, the big majority of them are located within the frequencies from 0.2 to 10 Hz.

Table 2 - Data sets used in this study for seasonal and diurnal analysis.

	SUMMER 01/07/2014	WINTER 01/01/2014
NIGHT 00:00-01:00	S1	W1
DAY 12:00-13:00 GMT	S2	W2

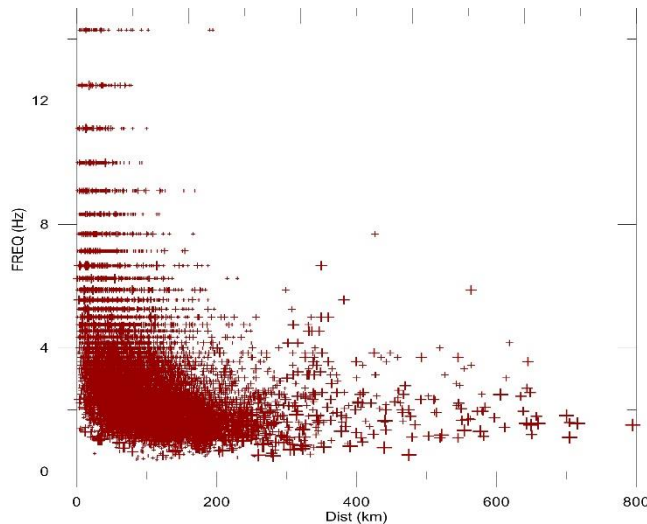


Figure 2 - Frequency distribution for regional events (0-800 km of epicentral distance) as it results from the bulletin of year 2015. The window frequency of seismic signal is of 0.5-10Hz.

3. Results

In Fig.3, comparison of the averages H/V spectral ratio (± 1 standard deviation) for the 17 examined sites for diurnal and for seasonal analysis, is presented. It is apparent that in terms of stability almost all sites exhibit stable response during day/night and summer/winter, but the HORT station. For the latter the H/V spectral ratio appears a clear peak only during the summer time (day and night) around 3Hz that is most probably due to industrial noise.

The majority of the investigate sites (stations: AGG, ATH, FNA, HORT, KLV, PRK, SIGR, SOH, THE, VLS, ZKR) present a flat H/V spectral ratio with amplitude level less than 2, indication of “rock” site conditions. In fact, surface geology taken from the IGME geologic maps (1:50.000 scales) supports such a site characterization both in terms of mechanical geologic properties and geologic age (Table 1). The station IACM shows a clear fundamental frequency $f_0 \approx 0.8$ Hz, and a corresponding amplitude 8 for all examined time periods summer/winter as well as day/night. This station is installed on conglomerates of Pleistocene overlain older and harder geologic formations. Also it is located close to a water treatment facility (Evangelidis and Melis, 2012). The rest of the stations (APE, GVD, KARP, LIT, OUR) although they are installed to rock conditions from geologic point of view (maps 1:50.000) with geologic age older than Eocene (>40million years), they show amplified H/V spectral ratio with amplitude >2 , for frequencies greater than about 4Hz. Such high frequency amplification may be due to a weathered layer overlain hard rock formation. However, it is difficult to conclude about the reason of such a high frequency amplification based only on surface geology (maps 1:50.00). In-situ geophysical/geotechnical prospecting could shed light on this issue. Finally, the GVD station appears a fundamental frequency at intermediate frequency range

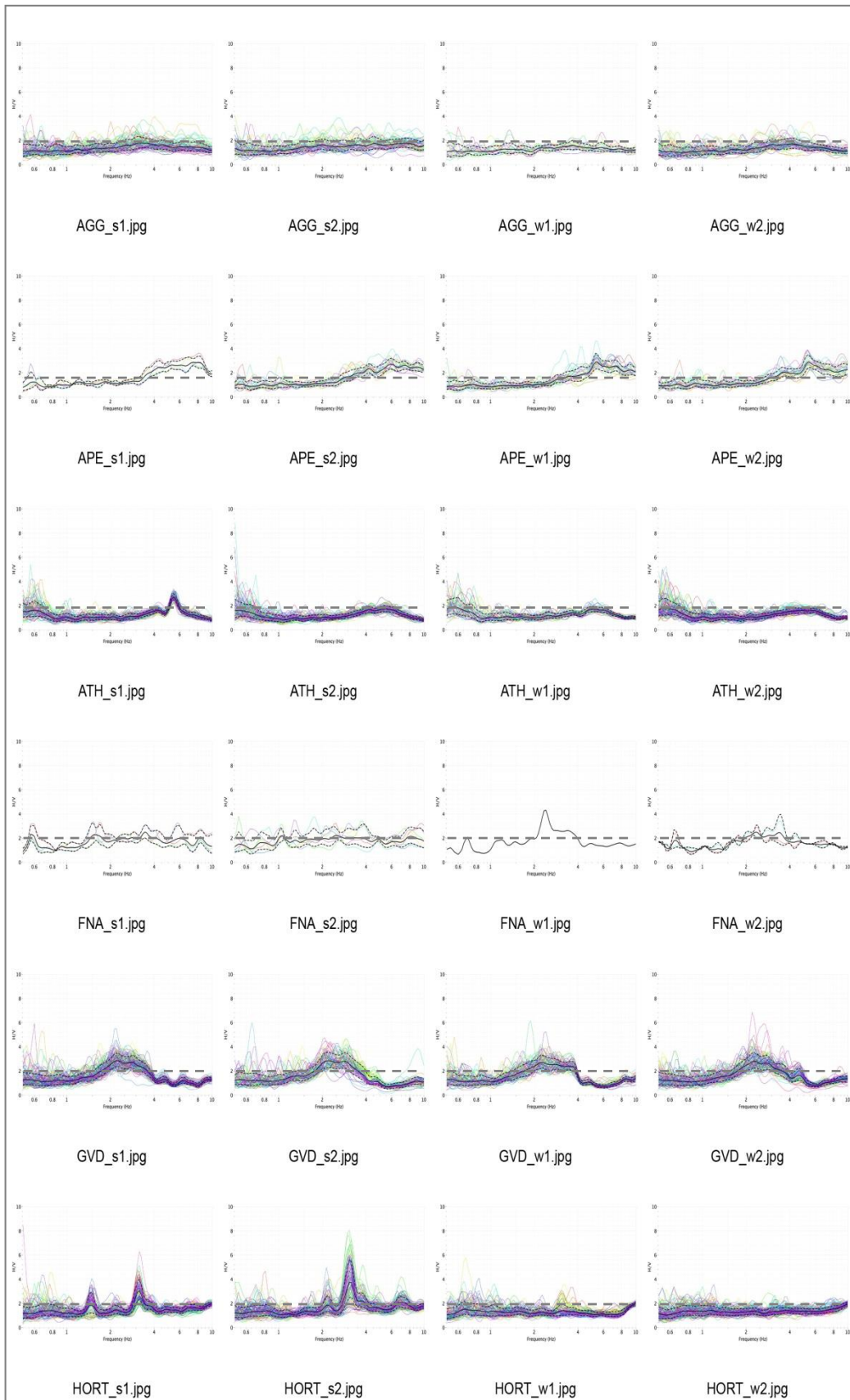
($f_0 \approx 2.5\text{Hz}$) although surface geology is described as limestone of Cretaceous and one would expect flat H/V spectral ratio curve.

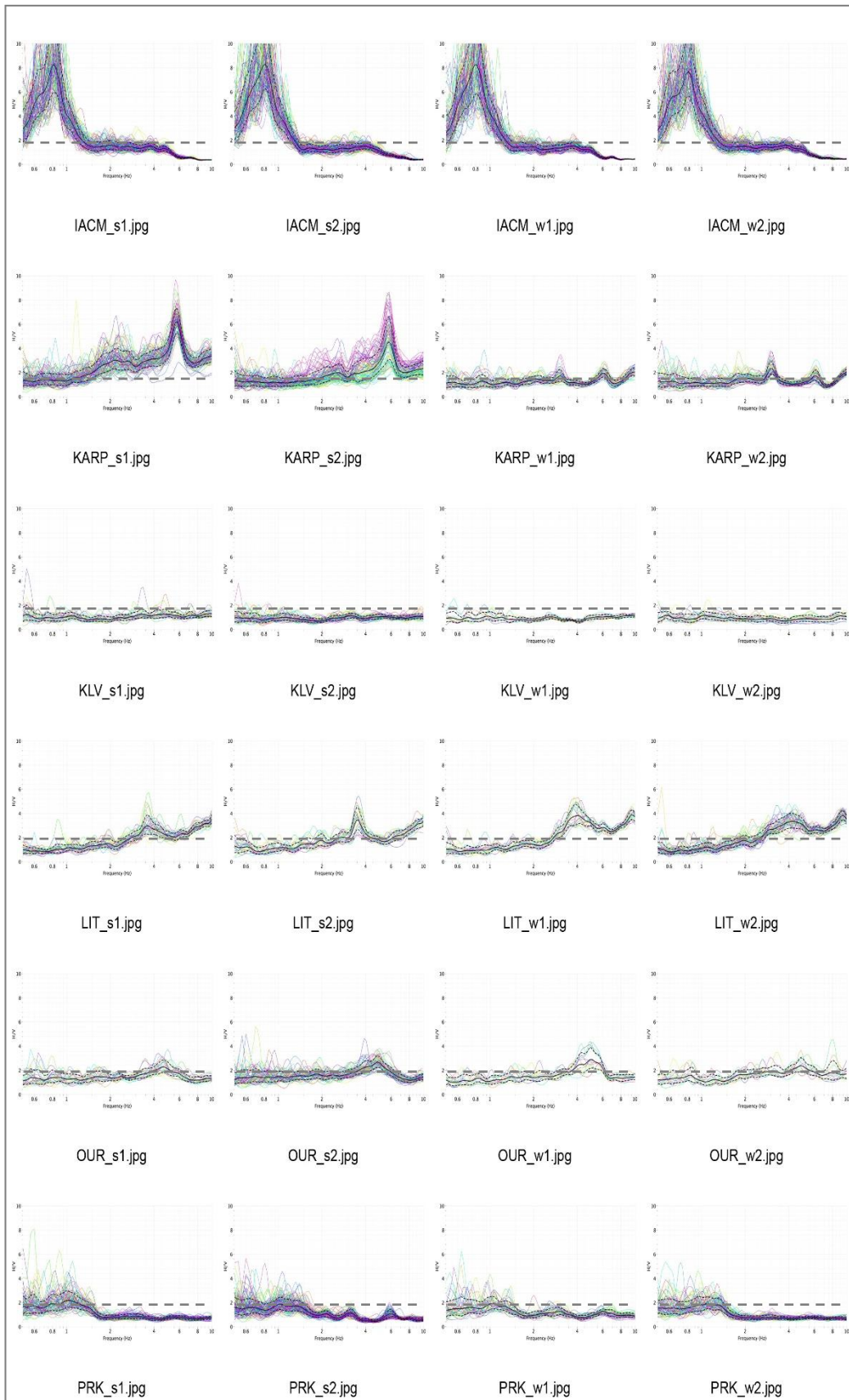
4. Discussion and Conclusions

Seismological stations are usually installed on rock site conditions, of low noise, with high shear wave velocity ($V_s > 800\text{m/sec}$) in order to avoid influence of site effects on recorded seismic ground motion. Magnitude estimation based on amplitude, duration or spectral analyses, should not involve site amplification since these parameters may be significantly affected by near surface geology effects. For this reason it is of high importance to check if the station site has the potential of amplifying ground motion and in which frequency range. The H/V spectral ratio method based on ambient noise is a fast, easy to perform and low cost method in order to investigate a seismograph station site for any possible site effect on seismic ground motion.

The aforementioned H/V spectral ratio method applied to a subset of seventeen seismograph stations in Greece showed amplification higher than 2 in seven cases within the examined frequency range, $0.5\text{Hz} \leq f \leq 10\text{Hz}$. This is the frequency range where the dominant frequency of the highest Wood-Anderson amplitude appears (Fig. 2). It is well known that H/V spectral ratio amplitude may not reflect the real amplification as in standard spectral ratio (SSR) method but it its lower level amplification.

In this paper magnitude estimation based on Wood-Anderson amplitude for the seven seismograph stations that showed H/V spectral ratio amplification greater than 2 must be carefully treated and re-calculated by other methods as well in order to assure its reliability. Most probably, this approach could be performed to the rest of the Hellenic Unified Seismograph Network in order to detect all those stations suspicious of possible site amplification. In addition, using a larger data set of stations one could also compare statistically amplification of the H/V spectral ratio curves with the observed surface geology based on relevant maps 1:50.000 scale.





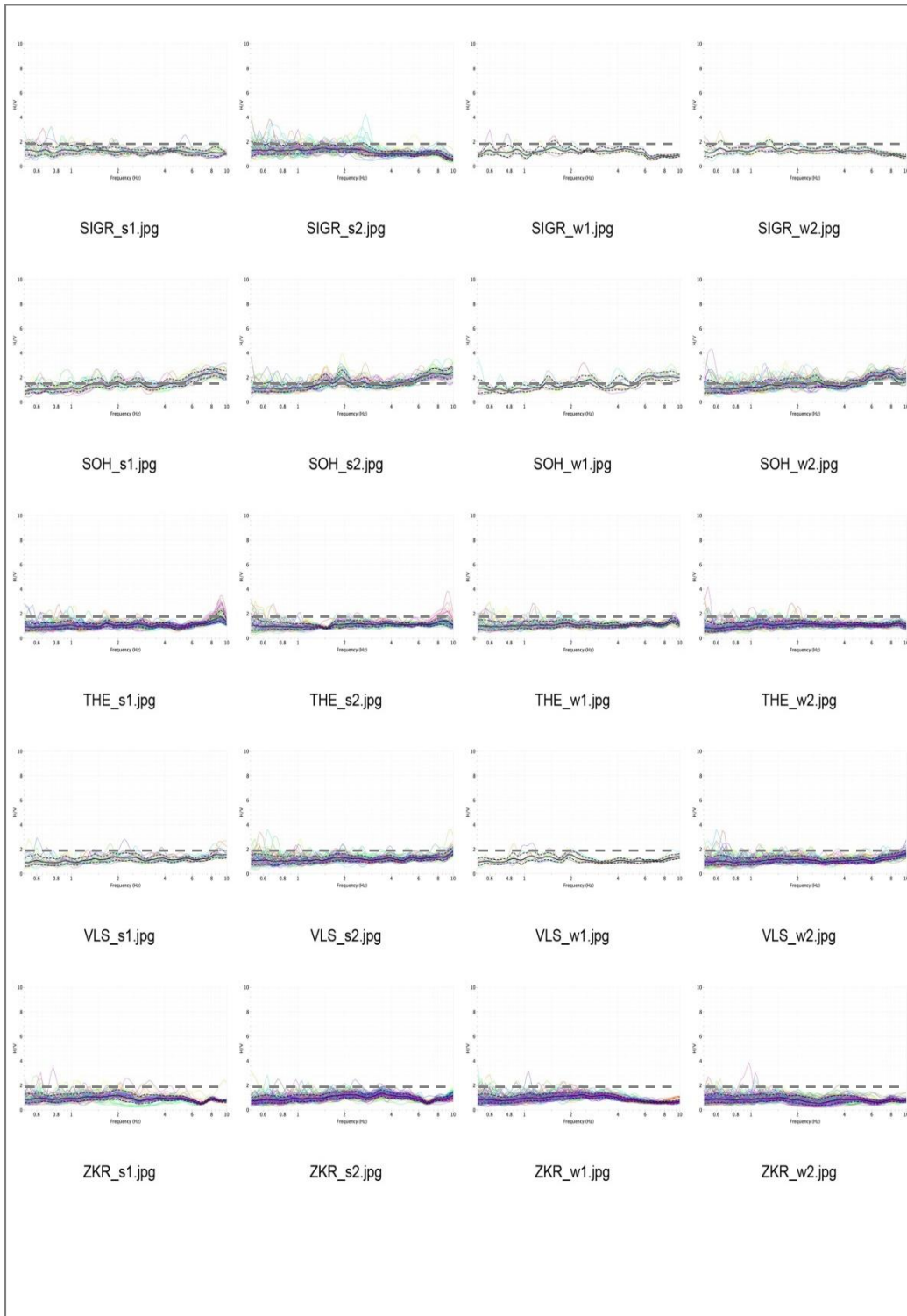


Figure 3 - Comparison of the averages H/V spectral ratio for the 17 sites for diurnal and for seasonal analysis (s1: summer-night (00:00-01:00), s2: summer-day (12:00-13:00), w1: winter-night (00:00-01:00), w2: winter-day (12:00-13:00)).

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