

RELATIVE SITE AMPLIFICATION FACTORS USING THE CODA WAVES
FROM LOCAL EARTHQUAKES RECORDED BY THE SEISMOLOGICAL NETWORK
OF THE GEOPHYSICAL LABORATORY OF THE UNIVERSITY OF THESSALONIKI

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A B S T R A C T

The goal of the present paper is to determine the relative site amplification factors at the recording stations of the telemetric seismological network, operated by the Geophysical Laboratory of the University of Thessaloniki at northern Greece. For this purpose the properties of coda waves were used by applying the single S to S back-scattering model. We used data of local earthquakes occurred during the period 1983-1989 and recorded by the eight stations of the network. Spectral ratios of coda amplitudes have been calculated for lapse times between 30 sec and 60 sec and for frequencies of 1.5, 3.0, 6.0 and 12.0 Hz. The average site amplification relative to the mean of all stations is calculated. All of the stations show no or very low amplification and a stability over all frequencies.

ΣΧΕΤΙΚΟΙ ΠΑΡΑΓΟΝΤΕΣ ΕΝΙΣΧΥΣΗΣ ΤΩΝ ΣΕΙΣΜΙΚΩΝ ΚΥΜΑΤΩΝ ΜΕ ΤΗ ΧΡΗΣΗ
ΤΩΝ ΚΥΜΑΤΩΝ ΟΥΡΑΣ ΤΟΠΙΚΩΝ ΣΕΙΣΜΩΝ ΓΙΑ ΤΟ ΣΕΙΣΜΟΛΟΓΙΚΟ ΔΙΚΤΥΟ
ΤΟΥ ΕΡΓΑΣΤΗΡΙΟΥ ΓΕΩΦΥΣΙΚΗΣ ΤΟΥ Α.Π.Θ.

Χατζηδημητρίου, Π.Μ.

Π Ε Ρ Ι Λ Η Ψ Η

Σκοπός της παρούσας εργασίας είναι ο υπολογισμός των σχετικών παραγόντων ενίσχυσης των σεισμικών κυμάτων για τους σεισμολογικούς σταθμούς του τηλεμετρικού δικτύου του Εργαστηρίου Γεωφυσικής του Α.Π.Θ. Για το σκοπό αυτό, χρησιμοποιούνται οι ιδιότητες των σεισμικών κυμάτων ουράς με την εφαρμογή του μοντέλου της απλής οπισθοσκέδασης των εγκάρσιων κυμάτων. Χρησιμοποιήθηκαν δεδομένα σεισμών που έγιναν κατά τη χρονική περίοδο 1983-1989 και καταγράφηκαν από τους οκτώ σταθμούς του δικτύου που λειτουργούσαν εκείνη τη χρονική περίοδο. Από τους λόγους των πλατών των κυμάτων ουράς, για χρόνους μεταξύ 30 και 60 sec από το χρόνο γένεσης του σεισμού και για συχνότητες 1.5, 3.0, 6.0 και 12.0 Hz υπολογίστηκε ο σχετικός παράγοντας ενίσχυσης κάθε σταθμού σε σχέση με το μέσο όρο όλων των σταθμών. Οι σταθμοί του δικτύου χαρακτηρίζονται από καθόλου ή πολύ μικρή σχετική ενίσχυση και η συμπεριφορά τους είναι σταθερή για όλες τις συχνότητες.

INTRODUCTION

The geological characteristics of the upper layers beneath the seismological station affect the spectral shape of the recorded seismic waves. This effect, particularly known in the strong motion seismology, is called "site effect", (Aki, 1988; 1991). Traditionally, direct waves were used for the estimation of the site effects (eg. Borchardt, 1970; Tucker et al., 1984). By comparing the results from direct S waves and coda waves Tsujura (1978) and Tucker and King (1984) showed that the site effects computed by using S and coda waves were very close and also that using coda waves more stable estimates of site amplification can be obtained. Since coda waves are considered to be composed of backscattered waves coming from many heterogeneities surrounding the source and receiver, the result is an average over all directions and furthermore, the separation of source, path and site effects is much simpler for coda waves than for S waves. Since then, site specific amplification factors using weak motion data from S wave coda have been successfully determined at sites of complex geology (Phillips and Aki, 1986; Mayeda et al., 1991; Su et al., 1992; Koyanagi et al., 1992).

However, the question of whether weak motion amplification scales linearly with strong motion is still under investigation. Recently, Chin and Aki (1991) using strong motion records obtained from the 1989 Loma Prieta earthquake found that a non linear effect of sediment sites existed above a threshold acceleration of 0.1 to 0.3 g.

The purpose of the present paper is to estimate the site amplification factors by means of coda waves, for the eight stations of the telemetered seismologic network operated by the Geophysical Laboratory of the University of Thessaloniki (Fig.1). These stations, which are Sohoh (SOH), Serres (SRS), Ouranoupolis (OUR), Litochoron (LIT), Griva (GRG), Paliourion (PAIG), Kentriko (KNT), and Thessaloniki (THE), started their operation in 1981 while in 1989 four more stations have been installed but which are not studied in the present work.

METHOD APPLIED

Assuming that the local earthquake coda is composed of single backscattered S waves Aki and Chouet (1975) have shown that the amplitude spectrum, $A_c(\omega, t)$, of the coda at times greater than twice the S wave travel time can be expressed as

$$A_c(\omega, t) = S_o(\omega) \cdot R(\omega) \cdot t^{-1} \cdot \exp\left(-\frac{bt}{2}\right) \quad (1)$$

where t is the lapse time after twice the S wave travel time measured from the origin. $S_o(\omega)$ is a term that describes the source as a function of angular frequency, ω , and $R(\omega)$ is the site term. $b=2\pi f/Q$ is the coda attenuation coefficient and Q is the coda Q , which is independent of the location of source or the recording site. This equation shows that the effects of source, site and path can be isolated by taking spectral ratios of coda amplitude (Phillips and Aki, 1986; Mayeda et al., 1991;

Su et al., 1992). To determine relative site amplification between two stations, the same event must be recorded at both sites at the same lapse time. By taking the ratio of coda spectra, according to relation (1), both source and path effects are eliminated and thus the ratio depends only on the local site amplification of the two stations.

Implicit in the elimination of the path effect is the assumption that the shape of the coda decay curve

$t^{-1} \exp(-\frac{bt}{2})$ is common to all stations. However, recent studies

(Steck et al., 1989; Mayeda et al., 1991) have shown cases where the coda Q determined from the early coda was strongly dependent on the geology of the site. In these cases, in order to overcome this violation of the single scattering model data from larger lapse times must be used. For the area which is studied in the present study Hatzidimitriou (1993) has estimated mean coda Q values for different lapse times. It was found that these coda Q values are very much dependent on the lapse time used for lapse times less than about 30 sec. Therefore in the present study in order to avoid the influence of the lapse time on the early coda we restricted to times greater than 30 sec.

DATA AND ANALYSIS

The data used in the present study come from local earthquakes recorded by the telemetric network, located at northern Greece, which is operated by the Geophysical Laboratory of the University of Thessaloniki. The network started its operation in 1981 and the data we used cover the period 1983-1989. During that time the network had eight stations each one equipped with one vertical and two horizontal of 1Hz natural frequency (S-13 Teledyne Geotech) seismometers. The signals from all stations are transmitted via telephone lines to the central station of Thessaloniki, digitized at 50 samples/second and the detected events are stored on magnetic tapes by a PDP 11/34 (Skordilis, 1985). Off-line P and S wave phase picking is made for each event on a daily basis and the earthquake parameters are determined using the HYPO71 computer program (Lee and Lahr, 1975), while the magnitudes of the earthquakes are determined from the signal duration. All the stations are calibrated every year and therefore their frequency response is accurately known.

The seismograms of all the well located events (more than one thousand earthquakes) were visually examined to check whether there were any recording problems such as noise, saturation, missed recordings, overlapping (a second earthquake at the coda of the first one) or early cut off (the seismogram recording was terminated too early to have well developed coda waves). In this way 317 events were finally selected for further analysis. In Figure (1) we show the epicenters of these earthquakes (circles) and the seismological stations (black triangles). The local magnitudes of these events are between 1.0 to 4.5, while the focal depths are all less than 20 km.

For the present study only the vertical components of the seismograms have been used. The Fourier amplitude spectrum, $F(\omega)$,

was computed at lapse times 30, 40, 50 and 60 sec all of which are after twice the S wave travel time. The window lengths were 512 points for frequency 1.5 Hz, 256 points for 3.0 Hz and 128 points for frequencies 6.0 and 12 Hz. $F(\omega)$ was corrected for instrument gain and averaged over octave frequency bands centered at 1.5, 3.0, 6.0 and 12.0 Hz. The Fourier amplitude spectrum of the noise before the P-wave arrival for the same time windows was calculated, corrected for the instrument gain, averaged over the same frequency band and then subtracted from the corrected coda amplitude.

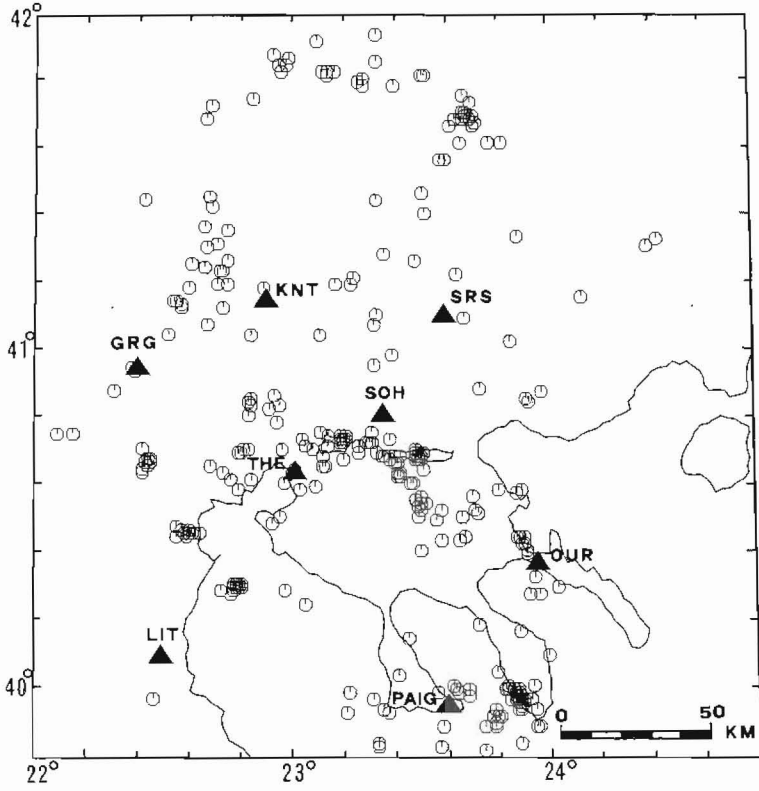


Fig.1. Map showing the stations (black triangles) and the events (open circles) used for the estimation of the relative site amplification.

RESULTS AND DISCUSSION

From the first processing of the data it was found that there were not many earthquakes which were recorded by all stations of the network so it was not possible to define one station as a "reference station". For this reason, for each earthquake and frequency we calculated the mean coda amplitude

of all the stations for each of the four lapse times and then the coda amplitude ratio for each station was calculated relative to this mean value. Then the logarithm of the average of the ratios of all four times was calculated for each station and this is the logarithmic average relative site amplification for each station.

Table 1. Logarithmic average relative site amplification values and their standard deviation for eight stations of the seismologic network operated by the Geophysical Laboratory, for frequencies of 1.5 Hz, 3.0 Hz, 6.0 Hz and 12.0 Hz. The numbers in parentheses are the number of data used for the calculation of the mean.

Station	F r e q u e n c y			
	1.5 Hz	3.0 Hz	6.0 Hz	12.0 Hz
SOH	0.01 ± 0.14 (134)	0.06 ± 0.14 (217)	0.00 ± 0.12 (135)	-0.02 ± 0.11 (158)
LIT	0.20 ± 0.22 (21)	0.17 ± 0.15 (43)	0.17 ± 0.11 (27)	0.14 ± 0.14 (7)
GRG	-0.04 ± 0.15 (101)	-0.05 ± 0.13 (150)	-0.13 ± 0.13 (116)	-0.29 ± 0.18 (60)
PAIG	0.06 ± 0.13 (41)	-0.06 ± 0.16 (92)	-0.20 ± 0.10 (76)	-0.25 ± 0.09 (51)
KNT	-0.16 ± 0.15 (91)	-0.14 ± 0.18 (221)	-0.11 ± 0.13 (198)	-0.06 ± 0.13 (192)
OUR	-0.04 ± 0.16 (53)	0.02 ± 0.15 (112)	0.14 ± 0.11 (154)	0.10 ± 0.10 (133)
SRS	0.04 ± 0.12 (108)	0.03 ± 0.11 (111)	0.04 ± 0.10 (187)	0.09 ± 0.10 (163)
THE	-0.14 ± 0.15 (55)	-0.17 ± 0.18 (92)	-0.13 ± 0.16 (73)	-0.22 ± 0.20 (46)

The values of the logarithmic average relative site amplification for four frequencies, calculated for the eight stations are given in Table 1, with their standard deviations of the mean and the number of observations used for their estimation.

In Figure 2 we show the plots of the logarithm of the average relative site amplification for each station versus frequency. Vertical bars are the standard deviations of the mean.

Two main characteristics can be obtained from figure 2. The first is that the stations show very small or not at all site amplifications with very small standard deviations. The second is that the relative site amplification for each station is stable for all frequencies, with the exception of stations GRG and PAIG who show no amplification at 1.5 and 3.0 Hz and negative

amplification at 6.0 and 12.0 Hz. Stations SOH and SRS show no amplification over all frequencies. OUR and LIT show systematically small amplifications over all frequencies while THE and KNT show small negative amplifications over all frequencies. During the installation of the network the sites of the stations have been carefully chosen in order to be on hard crystalline rocks. For that reason the small and stable site amplifications found in the present study were expected.

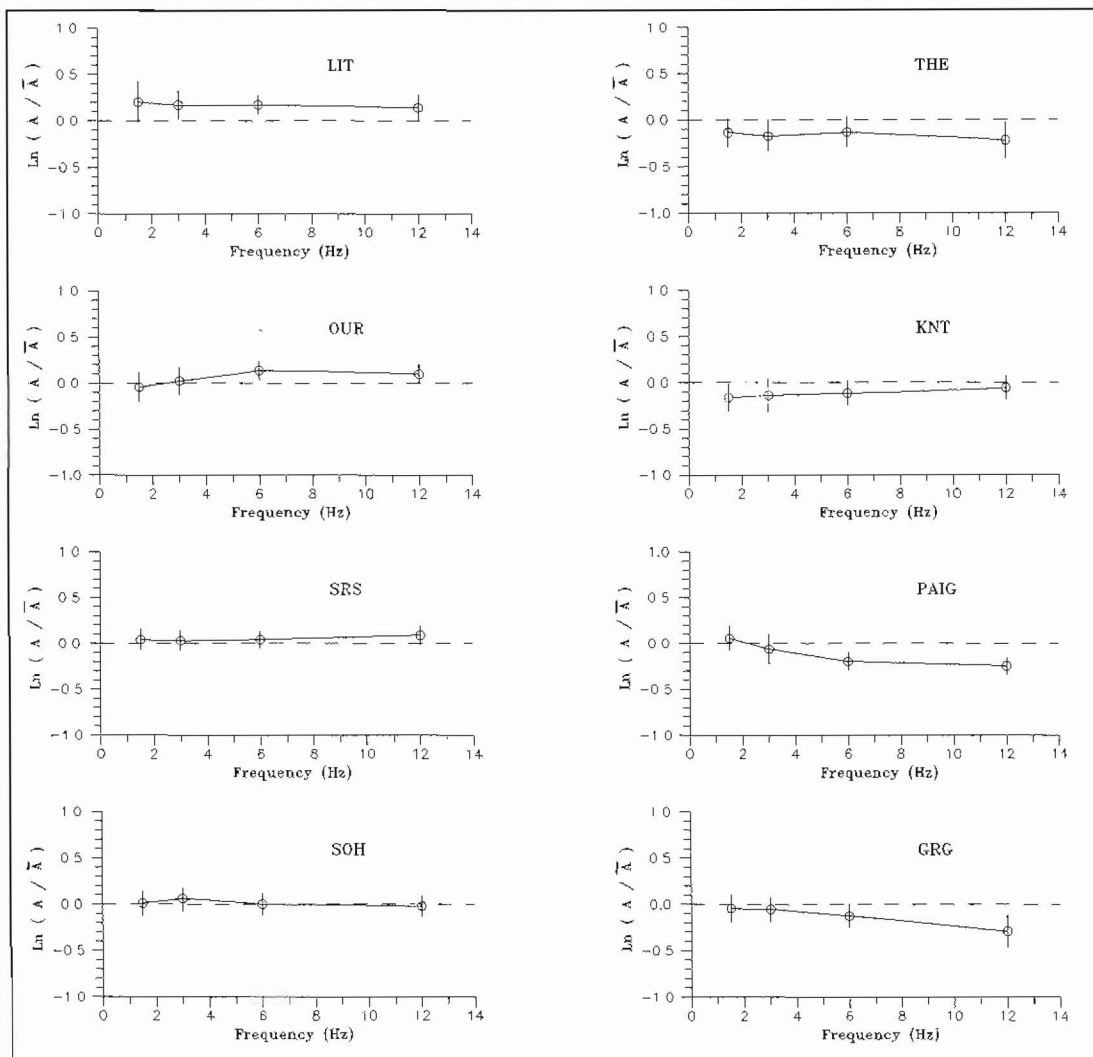


Fig.2. Frequency dependence of the logarithm of the S-wave coda average site amplification calculated relative to the mean of all eight stations. Vertical lines represent one standard deviation.

The results of the present study are in very good agreement with the results of Chavez-Garcia et al., (1990) who studied the site effects using five digital portable stations around the city of Thessaloniki, one of which was very close to the central station of Thessaloniki. They also found no significant site amplifications at the stations located on crystalline rocks.

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