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Research paper

Soil amplification factors at the seismographic network stations sites in morocco from seismic ambient noise

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Abstract

Knowledge of the soil response to seismic activity allows to better incorporate the constraints of seismic risk reduction. The experimental methods employed to determine site effects seek to obtain seismic amplification parameters by means of measuring earthquakes or seismic background noise. In this work, we present the main set of results of the microtremor data analysis based on the horizontal-to-vertical (H/V) spectral ratio technique at broadband seismic stations in order to get the fundamental site frequency (f0) and its associated amplitude of ground motion (A0). These stations were deployed in different structural domains: Rif, Middle, High and Anti Atlas Mountains. This study was carried out using the Nakamura technique, based on the measurements of background noise at each measurement site. Nakamura's method makes it possible to evaluate the effect of the superficial layers on the seismic signal. The f0 (H\V) values were used in the calculation of bedrock depth at measured sites. The thickness of unconsolidated sediments at the investigated sites was determined. The parameters obtained in this work allowed us to highlight a set of distribution figures of fundamental frequency (f0), amplification (A0) (H/V) and soft sediments thickness throughout the location of study and to show the agreement with geological setting.

Keywords: *H\V Spectral Ratio; Amplification Factor; Frequency Wavenumber; Thickness of Sediments.*

1. Introduction

The work presented here is the H/V method, which is a passive method that uses three-component measurements of ambient seismic noise (e.g., microtremors induced by wind, ocean waves, anthropogenic activity, etc.). In opposition to active shallow seismic techniques (e.g., reflection, refraction or multi-channel surface-wave), which use an artificial seismic source such as hammer blow, weight drop or an explosive charge to obtain a seismic response from the subsurface.
In order to obtain the distribution of fundamental frequency and lower limit of amplification factors in the uppermost 30 m layer in site of interest, microtremor surveys may be the best choice for this purpose. In the current research, the H/V ratio technique, which was proposed by [1], is applied to estimate the site response from microtremor records at the study sites. Nakamura hypothesized that the vertical component of ambient seismic noise is relatively uninfluenced by the sediments, and can therefore be used to remove the source effects from the horizontal components. In other words, the H/V ratio is the ratio between the Fourier spectra of the horizontal and vertical components of seismic noise.

$$H/V\ (\omega) = \left\{\left[S^2(\omega)_{NS} + S^2(\omega)_{EW}\right] / 2S^2(\omega)_V\right\}^{1/2} \qquad (1)$$

Where the terms [S(ω)NS and S(ω)EW] and [S(ω)V] are the ration of the horizontal and vertical spectra of the ambient seismic noise respectively and ω is the angular frequency.

The H/V ratio is an adequate estimation of the site response to S waves, providing reliable estimates about resonant frequencies, this suggestion of Nakamura is confirmed by several authors such as [2] and [3], they conclude that these ratios are much more stable than the raw noise spectra. In the present research, the recorded background noise was used to distinguish the subsurface sediment amplification in investigated areas. The main target of this study is to exhibit the subsurface characteristics of soil layers. The spectral ratio analysis of the horizontal and vertical components of the ambient seismic noise determines the resonance frequency. The H/V method has been used to estimate unconsolidated sediment thickness, map the bedrock surface, and infer fault locations (e.g., [4], [5] and [6]), and as method to predict site response to earthquake seismicity by miscrozonation studies (e.g. [1], [7] and [8]). The seismic resonance frequency, frn, of the n mode that is related to sediment thickness Z can be determined from the relation:

$$F_{rn} = (2n+1)(V_s / 4Z) \qquad (2)$$

Where Vs is the average shear-wave velocity in meters per second (m/s) of the sediment layer overlying bedrock, Z is given in meters, and frn is given in hertz (Hz) [4]. The fundamental resonance frequency, fr0, is given when n=0 and higher-order modes of the resonance frequency are given by n≥1. The relation between sediment thickness, Z, and resonance frequency can be given by:

$$Z = a f_{r0}^{\ b} \qquad (3)$$

The coefficients a and b are determined from non-linear regression of f_{r0} data acquired at sites where Z is known (e.g., adjacent to boreholes), and among the advantages of equation (3) is that explicit measurement of Vs is not required. The [4] and [6] have published equations linking sediment thickness to resonance frequency as function of correlation with drilling in Germany. [4] found that the values of fitting parameters a and b equal to 96 and -1.388 respectively while [6] estimated the values of a and b equal to 108 and -1.551 respectively.

[9] developed a MATLAB Program to perform a nonlinear regression fit of equation (3) with 95% confidence bounds and the following parameters obtained for many sites in Egypt. Where a and b are equal to 90 and -1.45.

In order to characterize the performance of the broadband stations deployed on Moroccan territory, this study is an extend of previous work of [10] [11] to detect operational problems, the study bellow should be useful for the next location of seismic stations of scientific institutes in the Moroccan territory in the future and optimize the distribution of local stations. We presented a 3D model of distribution of Thickness and frequencies fundamentals for permanent and temporary seismic networks in Morocco.

The seismic action used for the dimensioning of the structures depends on the seismotectonic context of the site of implantation of the structure which makes it possible to define the regional hazard, but also of the geotechnical context which makes it possible to define the local hazard. If the regional hazard is defined by the legislator, or by specific studies in the case of special risk structures, the local hazard, in turn, depends on the local characterization of the dynamic behavior of the sites that can induce significant modifications of the site seismic action.

Traditional geotechnical tests provide information on lithology and soil resistance to the right of soundings, but do not allow to characterize their seismic behavior at the site scale. Geophysical measurements provide access to the dynamic behavior of soils at particular points (Cross Hole) or along specific profiles (SASW). With these methods, the generalization and multiplication of point or profile information is necessary to develop seismic microzoning. This implies the implementation of important means.

Methods based on background noise recordings and H/V treatment make it possible to characterize the resonance frequency of the subsoil surface layers and provide information characteristic of their behavior with respect to seismic movements. Depending on the available tests, the frequency gives access to either the thickness of the surface layers or to the speed of the shear waves (Vs). The major advantage of this technique is that it is economical in terms of both means and time, which allows its rapid deployment over large areas, on which meshes adapted to map the frequencies of a site can be realized. In addition to the spot tests, the frequency mapping makes it possible to judge the homogeneity of the seismic behavior of a site and to deduce a mapping of the thicknesses or speeds of the shear waves.

This paper presents a case of application of the H/V method at 23 seismic broadband stations deployed in three heterogynous domain of Morocco. The objective is to characterize the thickness of the superficial sedimentary formations over Moroccan country in order to highlight variations of these thicknesses that may correspond to the different geological structures.

We follow the variations of the thickness from North to South of Morocco. The study area covers practically the north of Morocco, namely the Rifain belt, central Morocco, the Atlasic and Meseta chains and finally the Anti-Atlas in the South. This study area is characterized by a seismotectonic complexity, despite the fact that Morocco has a moderate seismic activity since it is located at the extreme north-west of Africa (Fig. 1), where the African plate collides with the European plate and the reconciliation rate is about 0.5 cm/year on average in the Strait of Gibraltar, we collected data for four years (2011-2014), from our network contains 23 permanent and temporary stations.

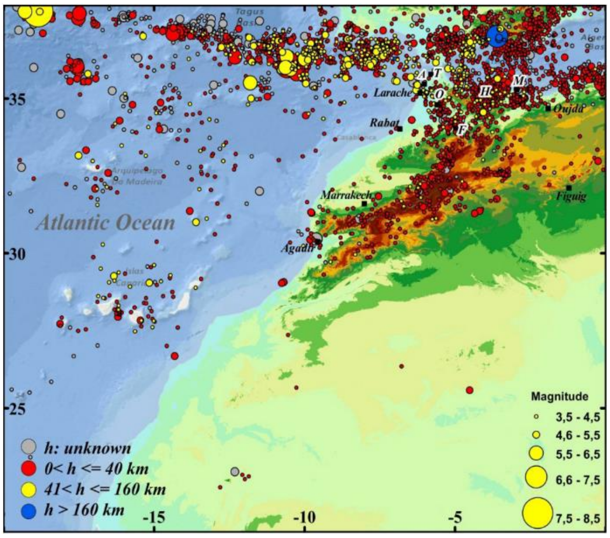


Fig. 1: Seismicity Map of Morocco for the Period between 1901 and 2010 [12].

2. Geological setting

The examination of the structural map of NW Africa allows to locate Morocco with four large regions which are in fact also structural domains (Fig. 2) [13].

Rif: It is a recent assembly line, formed with the Tertiary sector. She belongs to the alpine chains, which result, from the Africa-Eurasia collision and more precisely with the chain Rifo-tellienne from North Africa. This chain consists of immigrant units carted on the margin of the Africa plate.

Atlases: Middle Atlas and High Atlas, are part of the Atlasic chain, formed in the Tertiary, these intra-continental chains are located in the African continent extends to Tunisia and constitutes the deformed tectonic foreland of the chain Rifo-tellienne. The meso-cenozoic sediments, autochthon, are faulted and folded.

Meseta: regions of plains, plates, hills. Tabular meso-cenozoic grounds constitute the cover of a Paleozoic base folded, metamorphized and granitized during the formation of the Hercynian chain. This Hercynian base appears in "buttonholes". We distinguish Western Meseta and Eastern Meseta separated by the Middle Atlas.

Southern Morocco: This is the Saharan domain whose limit corresponds to the South Atlas fault. We distinguish the Anti-Atlas mountainous region south of Haut Atlas resulting from a recent extensive anticlinal folding and, beyond, the Sahara proper, a region of vast plains and desert plateaus. This domain is characterized by a Precambrian basement (Archean and Proterozoic) deformed by orogenesis eburnian and pan-African and covered by a Paleozoic cover weakly deformed during the Hercynian Orogeny. Mesocenozoic cover, little thick, is tabular (hamadas).

All these areas are characterized by the presence of mountain ranges, the recent chains of the Alpine cycle and the old, eroded, Hercynian and Precambrian cycles [15].

3. Data and methods

[1] Introduced a method based on the calculation of H/V spectral ratios between horizontal and vertical components at the studied site. Although the theory behind this technique is still debated, [15] and [16] have shown that it allows to determine the fundamental resonant frequency, related to a resonance 1D or 2D. On the other hand, they have also demonstrated that the amplitude of the H/V peaks does not correspond to the amplification determined by the technique of the site/reference spectral ratios. Several explanations have been proposed to understand, in the case of 1D resonances, the correspondence between the peak frequency of the H/V curve (f_{HV}) and the fundamental frequency (f_0). [17] and [18] showed that, depending on the speed contrast between bedrock and sedi-

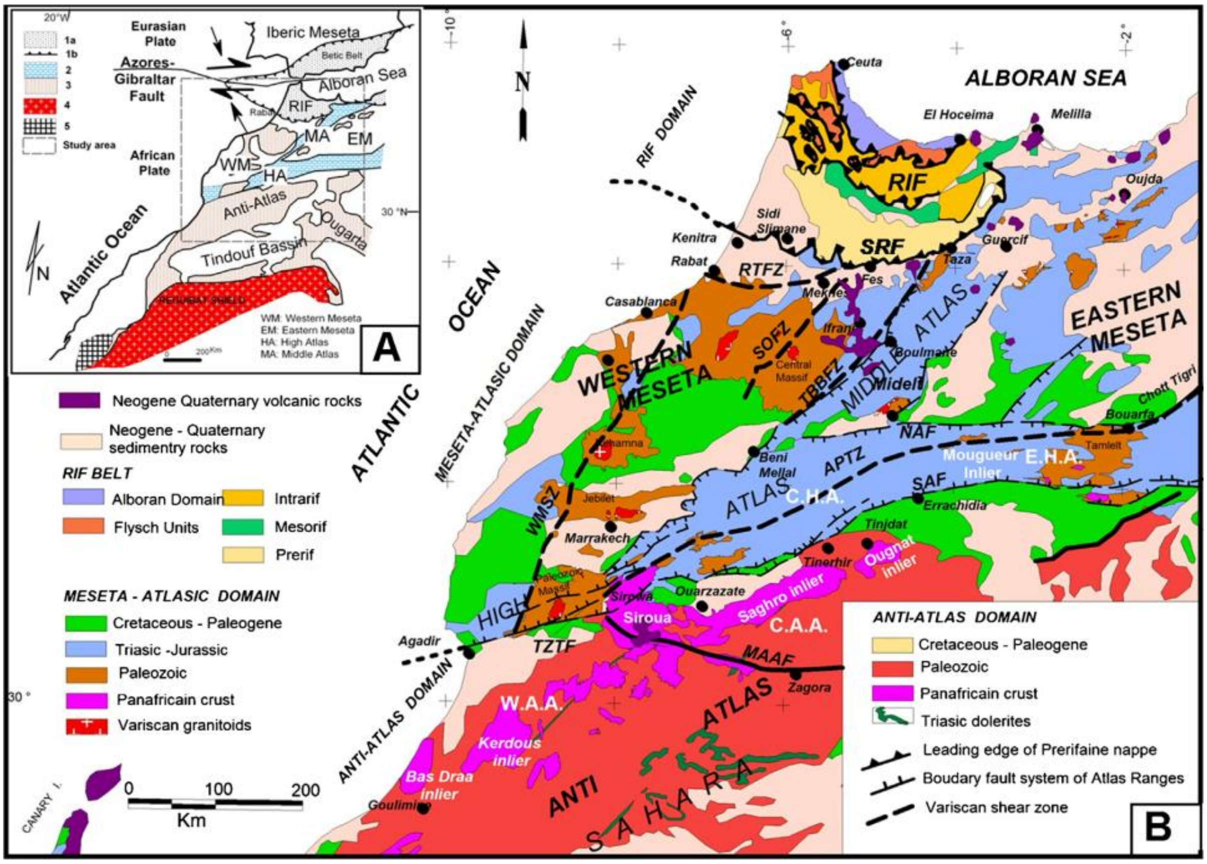


Fig. 2: (a) Tectonic units in Morocco (left); (b) The main geological formations in the study area (right) [13].

Stations	Sensor type	Digitizer type	Communication	Lat(°)	Long(°)	Altitude (meter)	F_0 H\V (Hz)	A_0 Amplitude H\V	Our Thickness 2017	Thickness A Ibs-von 1996	Thickness B Parolai 2002
ALHU	Trillium 120	Taurus	Flash disk	35.213	-3.890	63.0	7.8681	4.5602	4.521	5.480	4.405
M001	Trillium 120	Taurus	Flash disk	33.929	-6.756	192.0	6.6716	5.3393	5.7426	6.890	5.689
NKM	Trillium 120	Taurus	Flash disk	35.447	-5.410	423.0	1.3611	1.7585	57.5575	62.579	66.952
M004	Trillium 120	Taurus	Flash disk	34.791	-6.249	119.0	6.5199	1.6685	5.9374	7.114	5.896
TAF	Trillium 120	Taurus	Flash disk	34.810	-2.411	854.0	2.2179	1.2265	28.3548	31.776	31.396
M012	Trillium 120	Taurus	Flash disk	34.730	-5.434	227.0	6.4718	2.3644	6.0014	7.187	5.964
M013	Trillium 120	Taurus	Flash disk	34.610	-4.414	537.0	1.7207	2.2813	40.9704	45.197	46.542
AVE	STS-2	Quanterra Q330	Satellite	33.298	-7.413	230.0	0.7173	2.8488	145.7056	152.250	180.814
IFR	STS-2	Quanterra Q330	Internet	33.516	-5.127	1630.0	6.7223	2.6031	5.6799	6.818	5.623
M015	Trillium 120	Taurus	Flash disk	33.984	-3.035	1079.0	5.9683	3.7062	6.7493	8.042	6.762
M017	Trillium 120	Taurus	Flash disk	33.698	-5.990	657.0	0.9617	1.5778	95.2434	101.347	114.744
M018	Trillium 120	Taurus	Flash disk	33.622	-4.448	1090.0	5.9920	3.1153	6.7106	7.998	6.721
M202	Trillium 120	Taurus	Flash disk	32.922	-5.513	1443.5	2.9833	3.3649	18.4473	21.057	19.823
M206	Trillium 120	Taurus	Flash disk	32.801	-6.578	748.9	2.9481	4.6330	18.7675	21.407	20.191
M215	Trillium 120	Taurus	Flash disk	32.046	-7.449	518.8	1.4618	1.9750	51.8985	56.677	59.935
M208	Trillium 120	Taurus	Flash disk	29.578	-10.03	114.5	11.468	2.9052	2.6179	3.248	2.455
M210	Trillium 120	Taurus	Flash disk	32.354	-4.082	1432.7	9.0595	2.0333	3.685	4.506	3.540
M218	Trillium 120	Taurus	Flash disk	31.547	-5.551	1403.0	0.6607	1.8489	164.1483	170.650	205.398
MM07	Trillium 120	Taurus	Flash disk	30.258	-5.608	731.0	12.667	1.4736	2.2664	2.830	2.104
MM08	Trillium 120	Taurus	Flash disk	31.025	-6.492	1278.0	2.4985	2.7212	23.8565	26.933	26.099
MM10	Trillium 120	Taurus	Flash disk	30.529	-7.928	1058.0	12.265	3.0238	2.3749	2.959	2.212
MM14	Trillium 120	Taurus	Flash disk	30.042	-9.169	774.0	8.5221	1.5219	4.0267	4.905	3.892

Table 1: Network stations (ALHU, AVE, IFR, NKM, TAF, M004 and M001, ALHU, AVE, IFR, NKM, TAF, M004, M001, M215, M218, MM07, MM08, MM10, MM14, MM15 and M012) distributed in the all Moroccan area. (Rif with green color) (Atlas and Meseta with blue color) (Anti Atlas with black color)

ment fill and depending on the position of the noise sources (in the bedrock or in the sediments, far or near). The H/V peak can be explained by the S-wave resonance, the ellipticity of the Rayleigh fundamental mode, and / or the Airy phase of the fundamental mode of Love. Moreover, in the case of 2D resonances, the peaks of the H/V curves calculated individually on the axial and perpendicular components to the valley correspond to the resonant frequencies of the modes SH_0 and SV_0 respectively. However, [19] found, that the 2D resonances, of the site/reference spectral ratio technique was more efficient than the H/V method. In this paper, we calculate H/V ratios using Sesarray's Geopsy software [20].

In this work, we calculate soil amplification factors at 23 seismic broadband stations deployed in three heterogynous domains of Morocco (Table 1). The largest amount of the data were provided by the temporary Topo-Iberia and Morocco array experiment (19 stations, blue and red polygons), type Nanometrics Trillium 120P and taurus dataloggers which continuously records data sampled at rate of 100 samples/sec (Fig. 3). Additionally, we analyze data from two permanent stations from seismic network of scientific institute, type and Quanterra Q330 dataloggers which also saves data continuously at the same rate. We calculate the Thickness from the resonance frequency obtained in the H/V method giving by: $Z = a f_{r0}^{b}$ with three methods: [4], [6] and [9]. The H/V curves are calculated in five steps:

1) Cutting the signals of each of the three components into time windows. The length of these signals are generally adapted to each frequency. In addition, a triggering algorithm can be used to ignore windows containing transient signals.
2) Calculation and smoothing of the Fourier spectra of the three components of each of the windows. The technique used for smoothing is proposed by [8].
3) Calculation of the quadratic mean of the horizontal components for each window.
4) Calculation of the H/V ratio for each of the windows.
5) Calculation of the mean and the standard deviation of the H/V curve.

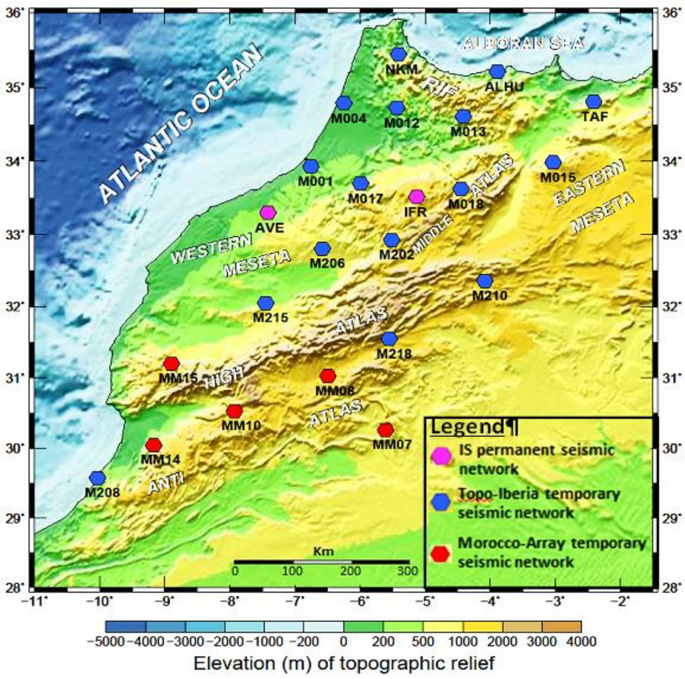


Fig. 3: Distribution of 23 temporary and permanent broadband stations in Moroccan country; the color scale displays relative hypsometry. Two permanent Stations of the Scientific Institute were installed in the Averroes and Ifrane observatories (Pink). Sixteen ICJTA temporary stations were located in different regions, within the project Topo-Iberia and cover the north and center of the country (Red). The IFG installed the other five stations in the south as part of Morocco array project (Blue).

The interpretation of the H/V peaks in terms of fundamental resonance is based on reliability criteria of the H/V curve and peak clarity. These two criteria were defined during the SESAME project [21], with the aim of helping to make a decision on the reliability of the results of the method. The data is established on the number of wave cycles for each frequency in each of the time windows, the total number of cycles at this frequency and the standard deviation of the H/V peak amplitude. The criterion of clarity aims to verify that the frequency of the H/V peak can be interpreted as the fundamental frequency. It is also based on the amplitude of the peak, its width as well as the standard deviations of its frequency and amplitude.

4. Results and discussions

Two categories of soil amplification are distinguished by the near-surface layers due to the site effect:

- The first is related to the shape of the local topography, for the sites located on the ridges of mountains or hills, the seismic waves are focused because of the characteristics of convexity.
- The second is the site effect associated with the displacement of seismic waves in the soft material underlying the rock. This category of site effect occurs in valleys recently filled with sediments. In order to illustrate the phenomenon of amplification, we present in the following figures (Fig. 4, Fig. 5, and Fig. 6) the distribution of the amplification factors on the various geological zones of Morocco. The values of the fundamental frequency of the site (f_0) vary mainly according to the geological composition; we can distinguish three types of curves according to their form, which clearly identifies three deferent zones:
- Type 1: broad peaks with a high fundamental frequency f_0 greater than 10 Hz in the Anti Atlas zone, with similar amplitude or different amplitude in the vicinity of 8.5 Hz and 12.5 Hz. These typologies can be attributed to thin layers with low thickness and volcanic substratum lies at a depth between 2 and 3 meters.
- The thickness of the crust increases in the middle of the high Atlases and decreases towards the south and the Anti Atlas, with the two stations MM08 and M218 where we find the deepest point to be 161m of thickness, and from the station MM08 where the transition to the lowest thicknesses in the Anti-Atlas between MM10 and MM07 (Fig. 6)
- Type 2: In the middle, in the area of the Atlas, the crustal thickness shows less variation, varies between 5 and 6m and lower than that of the Meseta domain where the thicknesses are higher between 20 and 100m (Table 1) and the most deep is detecting at the AVE station (145m deep). Although the location of the station does not cover the whole area and the highest altitudes, several Stations are located in the middle and others towards the East and West extremities (IFR stations, M018, M017 and M202) (Fig. 5) near the main channel. The results of this study are consistent with the hypothesis of lack of crustal root under the Atlas chain, [22] [23] [24]. In order to ensure the conclusions we need other measurement stations in this area since there are several gaps in the location of the stations (for example, in East South East IFR and M018 stations) should do not exceed 100 km and coincide with the areas where the surrounding stations give a relatively consistent picture. So, future studies will have to test the hypothesis of lateral homogeneity emerging from these results. Meanwhile, the crustal thickness measurements reported in this study indicate the presence of three fundamentally different domains reflecting different geodynamic developments.
- Type 3: For the type that characterizes the Rif's area, we propose two alternative interpretations: for the three neighboring stations (ALHU, M013 and TAF) in the central area of the Rif belt (Fig. 4), the signals show two pulses of similar amplitude M013 and TAF with equal fundamental frequencies. These pulses have a certain change if one goes up on the ALHU station. For the western part of the Rif we find the stations NKM M012 and M004, to associate with amplitudes and depth varies in the same way as before, the thickness increases if we go up to the extremities (NKM). the M012 and M013 stations are placed in an area that coincides with a range of abnormal GPS speeds within the Rif [25] and [26] which can be modeled by a small plot of basal traction in this area [27] supposed to represent delamination and backtracking of the lithospheric mantle [28] [29]. We associate the second impulse with such a subcrustal structure. A detailed interpretation of this presumed mantle conversion is beyond the scope of this article and the methodology.

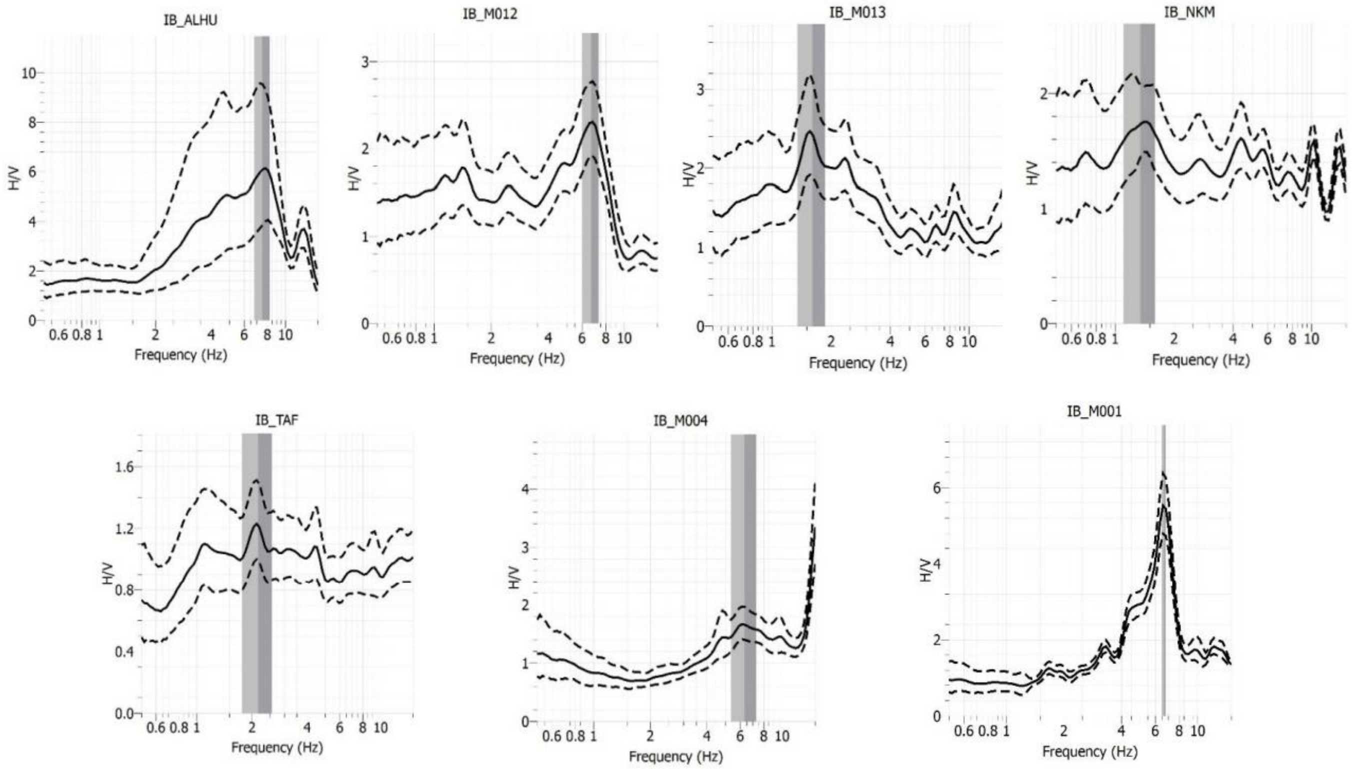


Fig. 4: H/V spectral ratios for the sites network stations of the Rif (ALHU, M012, M013, NKM, TAF, M004 and M001) in the investigated area. The mean curves are represented as continuous lines, while the dashed lines define the one-standard deviation intervals around the mean curves. The couloured curves represent the number of the time windows used for each site.

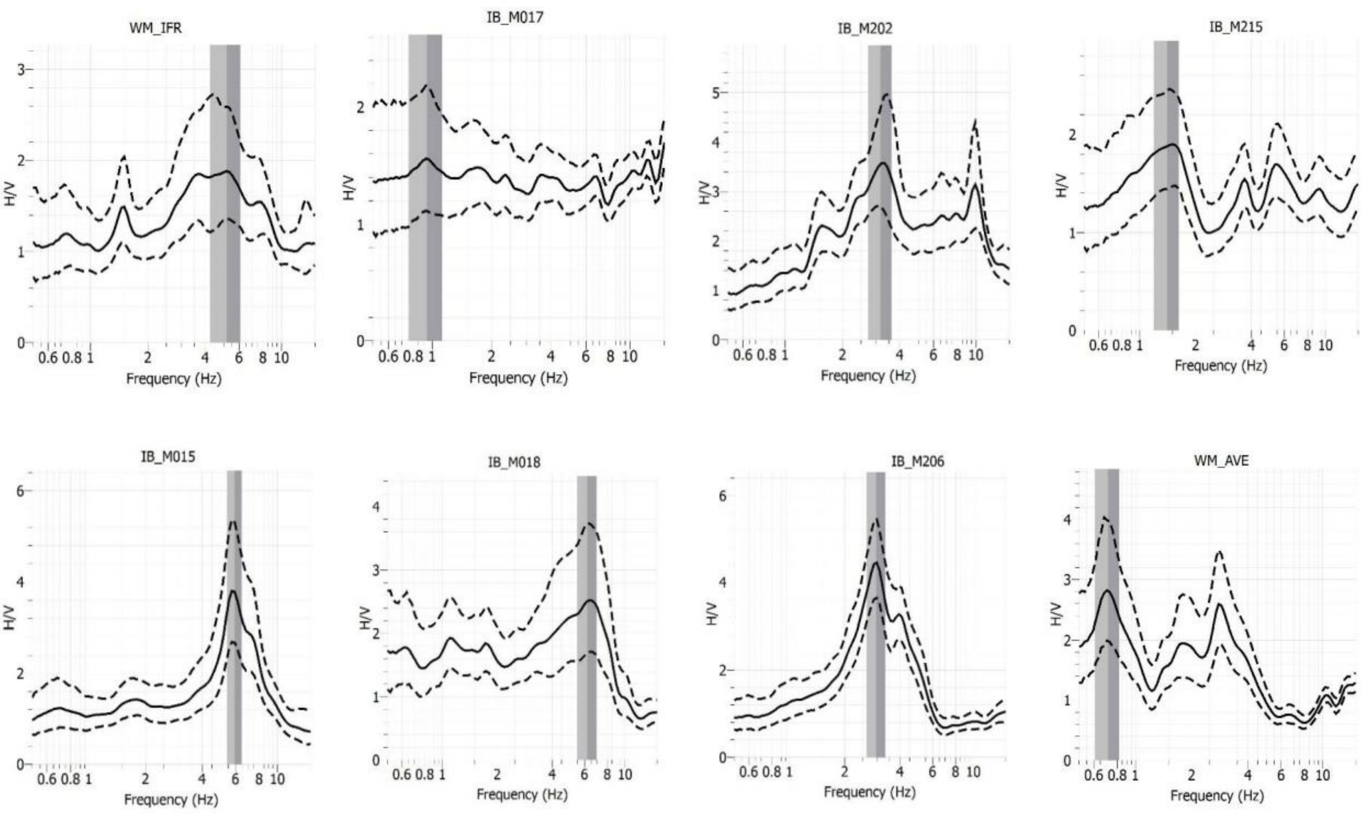


Fig. 5: H/V spectral ratios for the sites network stations of Atlas and Messeta of morocco (IFR, M017, M202, M215, M015, M018, M206 and AVE) in the investigated area. The mean curves are represented as continuous lines, while the dashed lines define the one-standard deviation intervals around the mean curves. The couloured curves represent the number of the time windows used for each site.

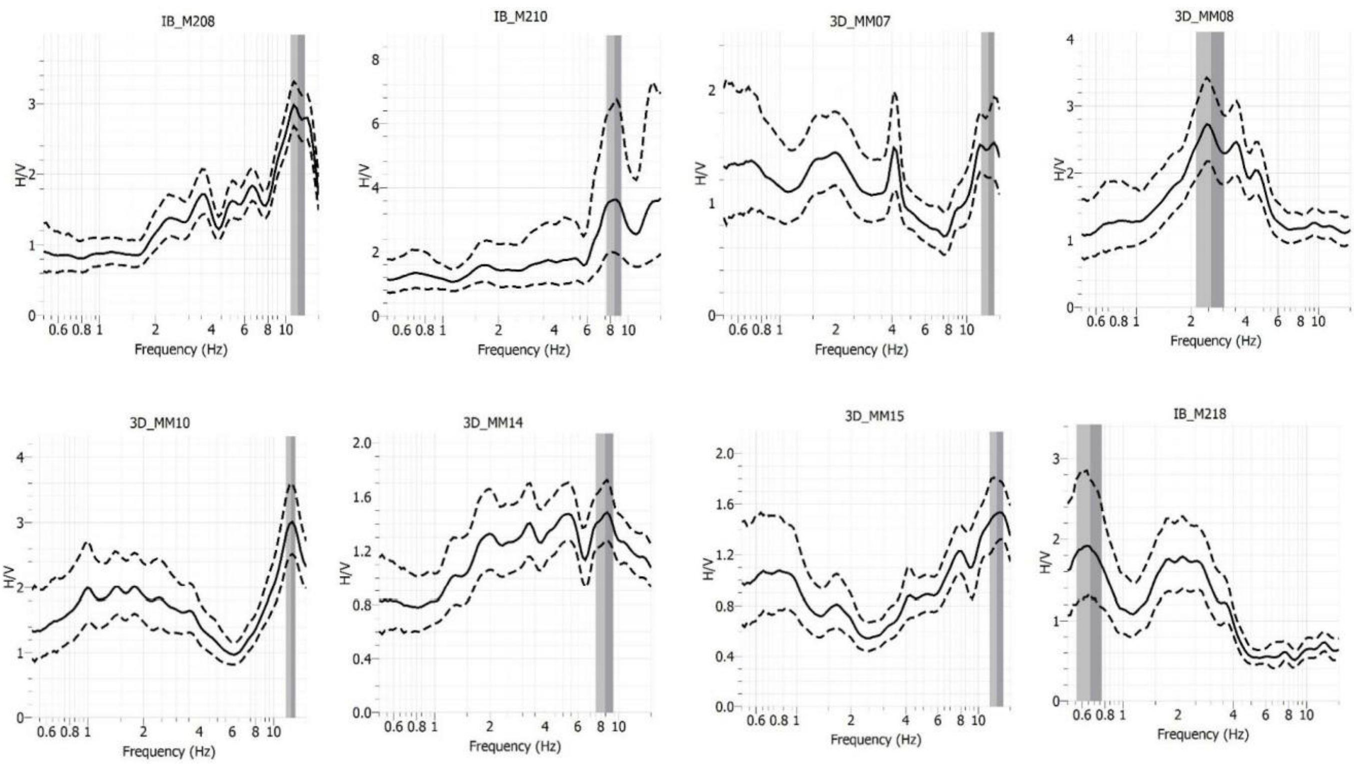
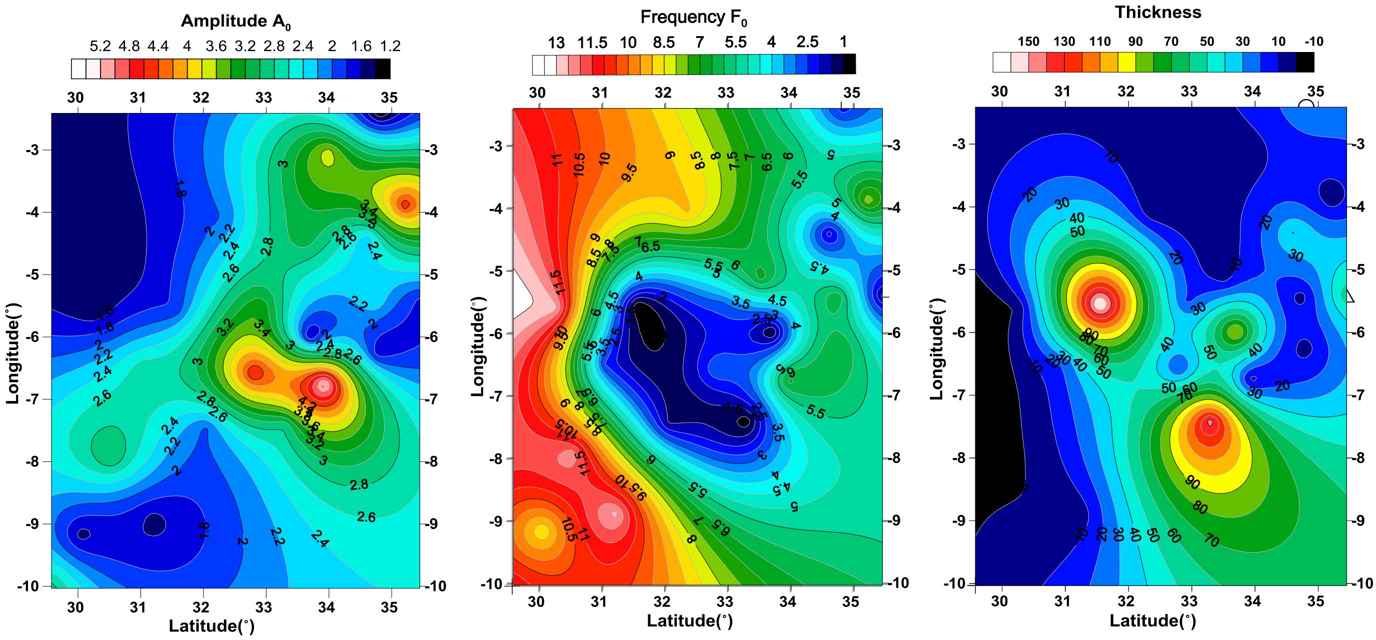


Fig. 6: H/V spectral ratios for the sites network stations Anti-Atlas of Morocco (M208, M210, MM07, MM08, MM10, MM14, MM15 and M018) in the investigated area. The mean curves are represented as continuous lines, while the dashed lines define the one-standard deviation intervals around the mean curves. The couloured curves represent the number of the time windows used for each site.



(A) (B) (C)

Fig. 7: Variation from Moroccan Network Stations: A) Thickness, B) Amplitude and C) Fundamental Frequency;

To illustrate the variation of soil amplification factors across location study, Fig. 7 shows the distribution of each parameter over the study area using method of contour maps. This method is a plot of three values. The first two dimensions are the latitude and longitude coordinates, and the third dimensions is Thickness (a) Amplitude(b) and frequency (c) (Fig. 7), is represented by lines of equal value (the contour lines on the map) across the map extents. The shape of the surface is shown by the contour lines. The results show a distinct variation of soil amplification factors in the three geological zones. The deepest thickness and the highest fundamental frequency were detected in Atlas area at longitudes (33.7, 31.5) and latitudes (-7.41, -5.55). The central part of middle Atlas of Morocco is the deepest compared to the EST and Rif part, for the distribution of the fundamental frequency we note that the frequency undergoes a decrease when we start from the north towards the south of Morocco except the central part which is characterized by passes frequency (Fig. 7-c).

5. Conclusion

The realization and interpretation of a noise measurement with 23 broadband stations distributed in all Morocco and the interpretation of the H/V curves clearly identified three different main structural domains. From a geological point of view, the deepest areas are characterized by low fundamental frequencies as in the middle and high Atlas. However, for the Rif and Anti Atlas the crust is very thin, which results in moderately high frequencies.

The obtained results show that our expectations about the relationship between the geology of the field under study and the frequency of seismic noise were to the point. After four years of observation and data acquisition, we have managed to prove the existence of a strong correlation between the soil amplification parameters and the geological characteristics of Morocco.

In this vein, the study has found that the frequencies increase when the thickness of the quaternary layers decreases and vice versa. The results shown in the 2D picture of the crustal variations beneath the Moroccan country (Fig. 7), illustrate the ways in which the thickness of the soil affects the highness of seismic frequencies. To sum up, for the Atlas and foreland domains the coverage is still sparse, and future studies will have to test the assumption of lateral homogeneity emerging from our data, and to apply the H/V method on each geological area to evaluate the microzoning of each part of Morocco.

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