Directionally Effect Observation in Topographical Site-Effects at Feden-Sema Range (Guelma-Northern Algeria) from Ambient Vibration

Khalissa Layadi [1*], *Yacine Mohamed* Tebbouche[2], *Redouane* Chimouni[1], *Ahmed* Saadi[1] and *Hamoud* Beldjoudi[1]

[1]Astronomy, Astrophysics and Geophysics Research Center, Algeria
[2] University of Sciences and Technology Houari Boumediene, Algiers, Algeria

Abstract. The Eocene Feden-Sema Range is a topographical structure located in the complex area of Mechtat El-Ababsia (Guelma) characterized by topographical site effects from an experimental investigation using earthquake and ambient vibration. The structure has its maximum orientation toward the south and a half-circular shape. To study the directionality effects caused by this structure, two profiles of ambient vibration measurements were carried out on the maximum axe and through the range of 12 points. The analysis of the horizontal over vertical spectral ratio indicated that the fundamental frequency, f0, of the topographical structure is constant and around 3.0 Hz in all measurement points. The ambient vibration analysis in the 0.1–20 Hz frequency domain showed that f0 is strongly related to the polarization or directionality, where the maximum amplification is obtained at 45° azimuth from the north with an amplitude of 3.5 times compared to 0° at 2.5 times. The obtained result is of great importance in showing that the topographical site effects are not free from the directionality influence in the ground motion, which must be taken into consideration in the case of building construction orientation.

1 Introduction

The characterization of the site effects of the broad-band stations of the Algerian Digital Seismic Network (ADSN) showed that some of them installed on topographic surfaces (mountain, range, hill, etc.) are not free from amplification in the high-frequency domain (>1 Hz) [1]. The directionality effects in these stations are existing and perpendicular to the main axe of the topographic structures. Furthermore, the fundamental frequency peak of the topographic site effects is constant regardless of the elevation of Eocene, Mesozoic, and Paleozoic structures (massifs and ranges). For the Miocene hills, the topographic site effects are combined with the lithological ones, and to separate between them, [1] found that the H/V of ambient noise technique [2] helps to distinguish topographic-lithological site effects, where the lithological site effects vary inversely with elevation. The thick sediment layer corresponds to the highest elevation with low frequency amplification (< 1 Hz) observed previously in the Chéliff [3, 4, 5, 6] and Mitidja [7] basins for flat sediment layers. Also, the directionality effect can help with landslide region limitation (e.g., [8]).

Considering seismic events in site response determination at a station installed in Bouzaréah Massif (ABZH) of Paleozoic metamorphosed limestone, the topographic site effects depended on the azimuth, presenting a change in the frequency peak [9]. In the present study, we consider a case from [1], the Feden Sema range (Guelma; Fig. 1), to analyze the relationship between the directional and seismic motion energy from eleven ambient noise recordings distributed on its surface (Fig. 1).

2 Geological and topographical setting

The Feden Sema range is a Lower Eocene topographical structure from the complex area of Oulad Dhan Missif (Guelma). It consists of limestone, limestone-marl, and clay [1]. According to “Agence Nationale des Ressources Hydrauliques” (ANRH) drillings, this thin layer of Lower Eocene (40 m) overlays a thicker layer of Upper Cretaceous (760 m) than the Lower Cretaceous. The maximum and minimum elevations of this range are 1003 and 670 m, respectively, from the north to the south (Fig. 1). The major axe of the range is curved, oriented toward the south, with a 1.5-kilometer width from the east to the west. In seismic anisotropic analysis, [10] showed that in this region, seismic wave propagation has a NE-SW favorite or fast orientation.

* Corresponding author: author@email.org

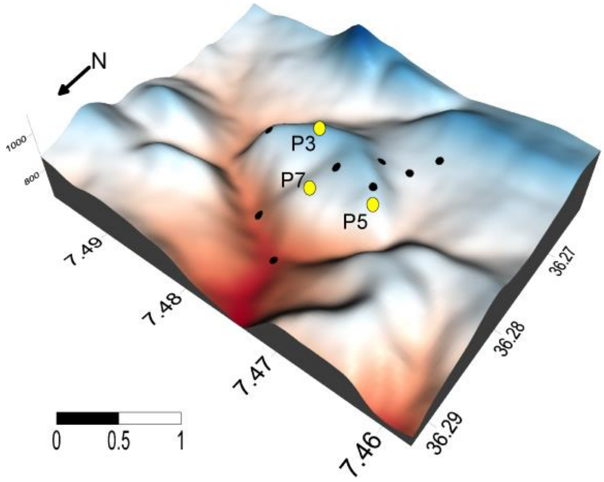

Fig. 1. 3D Feden Sema topographical range structure. The black-filled circles are the ambient noise point measurements. The three yellow-named ones are the points considered by the directionality analysis: P3, P5, and P7.

3. Method

To analyze the directional effects in the Fedan Sema range, we considered eleven ambient noise measurements of two profiles where the points were distributed on the major axe and across the structure (Fig. 1), each lasting 30 minutes. [1] showed that the variation of the fundamental frequency, f_0, of the measurement points is very narrow, between 2 and 3 Hz of topographic site origin (Fig. 2). According to [11], this category of site response is named “typical topographic site effects”. In the following, we detailed the steps of directionally effects computation considering only three points, P3, P5, and P7 (Fig. 1 and 2).

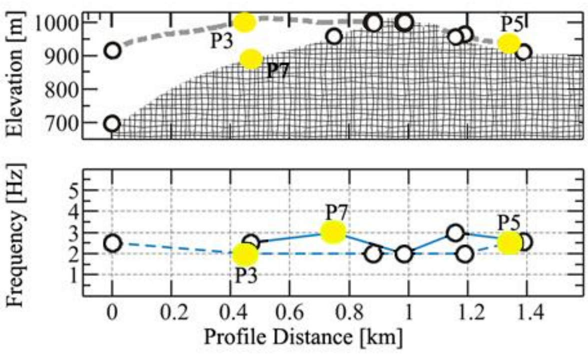

Fig. 2: Fundamental frequency variation (bottom) of the two ambient noise measurement profiles across the Feden Sema range (Fig. 1) and on its major axis (grey dashed line) (top) (modified from [1]).

3.1 Signal Energy Directionality

The energy variation of the horizontal ambient noise signal recording of P3, P5, and P7 with azimuth from 0 to 180° was calculated from the amplitude spectrum in the 1–10 Hz frequency domain using GEOSY software. Individual window of 25 sec of NS and EW components of each point were transformed into amplitude spectrum using FFT smoothed by 30 b-value of Konno-Omachi smoothing [12]. The obtained results of individual windows were averaged for global horizontal components. In the rotation, a step of 10° in 0-180° was used.

3.2 H/V Rotate

To analyze the relationship of the fundamental frequency, f_0 (Fig. 2), variation with the azimuth from 0-180°, we considered the ambient noise recordings in the H/V technique [2] from 0.4 to 20 Hz using the same processing in Section 3.1 of the present study.

3.3 Covariance Matrix Method

To obtain a better resolution of the directivity angle, we performed a direct estimation of the polarization angle using the covariance matrix method [13] which consists of determining the polarization angles directly from of the three components of a ground motion signal. This analysis, which is carried out in the time domain, involves the calculation of the covariance matrix obtained from a three-component signal.

First, the signals are filtered by a band-pass filter taking into account the frequency bands where the previous spectral analysis revealed a significant and interesting amplification pattern (2-3 Hz; Fig. 2). Subsequently, the processing was applied to the three components of the signals in the time domain, using a floating window whose length is adapted depending on the case, thus obtaining the direction of the maximum polarization for each time window.

4 Results and Discussion

The obtained results for the directionality effects analysis of topographic site effects in the Feden Sema range are plotted in Fig. 3 for signal energy in horizontal direction, H/V-rotate in Fig. 4, and the polarization angle using the covariance matrix method of P3, P5, and P7 measurement points in Fig. 5.

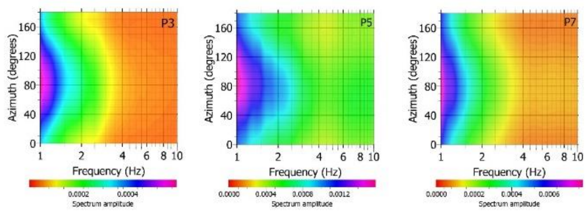

Fig.3: Energy of horizontal ambient noise signal recordings of P3, P5, and P7 measurement points (Fig. 1) variation with azimuth from 0 to 180° in 1-10 Hz. The horizontal color bar is the amplitude spectrum.

The energy of the signal showed a diminution with frequency from 1 to 10 Hz (Fig. 3). Less than 1.5 Hz and around 80°, the amplitude spectrum revealed maximum values for the three points. Also, starting from this azimuth, 80°, to high and low ones, the diminution of the energy with the frequency is not linear but is a parabolic variation. Very well known that noise energy decreases with frequency [14]. But for the case of directionality, a very strong concentration is obtained between 40° and 120° with a parabolic decrease. The compression between points showed that the P5 site is the strongest, which may be related to the time recording or local topographical conditions [15].

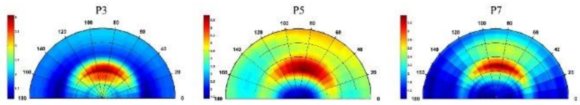

Fig. 4. H/V-rotate of P3, P5, and P7 measurement points variation with azimuth from 0 to 180° in 0.4–20 Hz. The vertical color bar is the H/V curve amplitude.

For the H/V-rotate, Fig. 4 illustrates a strong directionality near f0 in the 60 to 100° azimuth of 4, 6.5, and 3 times for P3, P5, and P7, respectively (Fig. 4). As in Fig. 3, the P5 site presents the maximum value. Higher than f0 (> 3 Hz), the amplitude variation of H/V curves at P5 and P7 sites, with frequency and azimuth, becomes more important compared to frequencies less than 1.5 Hz (blue regions). This may be related to 3D topographic site effects [15].

The last result is a rotation of H/V using the covariant matrix technique. In Fig. 5, 6 and 7, the results are more distinguished compared to the previous case in Fig. 4, for P3, P5 and P7, respectively, a favorable direction of fundamental frequency around 75° and 90°.

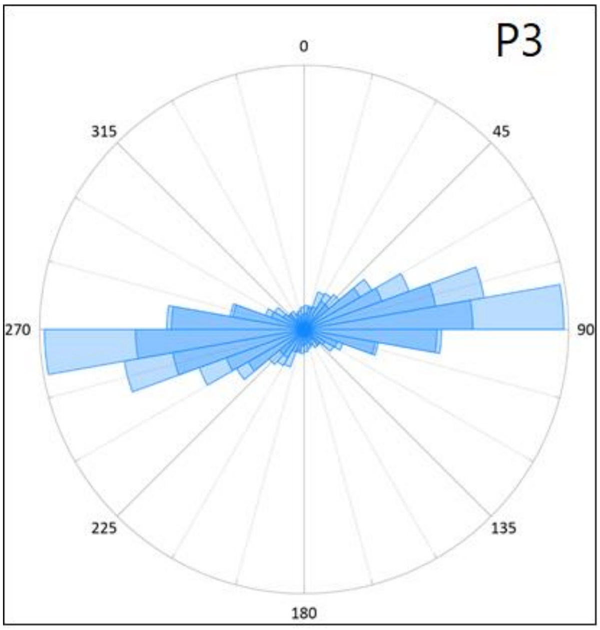

Fig. 5: Rosette diagrams showing the preferred directions at the acquisition pointP3.

5 Conclusion

From the present moderate analysis of the directionality effect in a typical topographic site effects case in one of many cases of irregular surfaces, strong dependence is observed with azimuth in the signal energy and fundamental frequency, 3 Hz, around 80°. The diminution of the signal energy in a horizontal direction has a parabolic variation with frequency and azimuth.

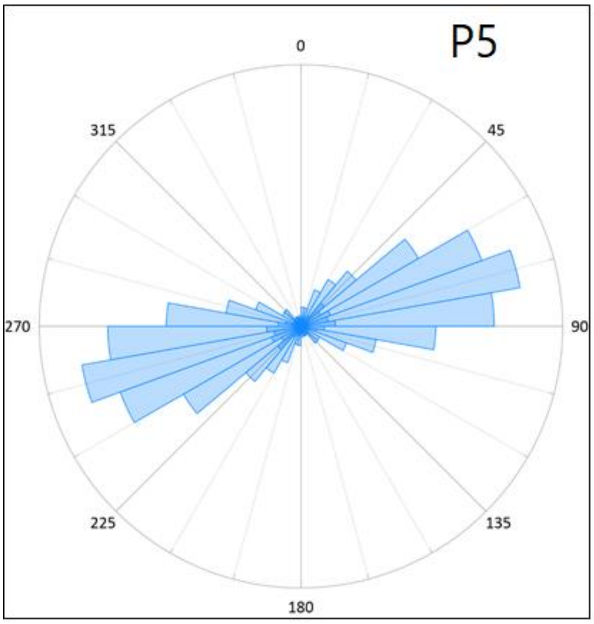

Fig. 6: Rosette diagrams showing the preferred directions at the acquisition point P5.

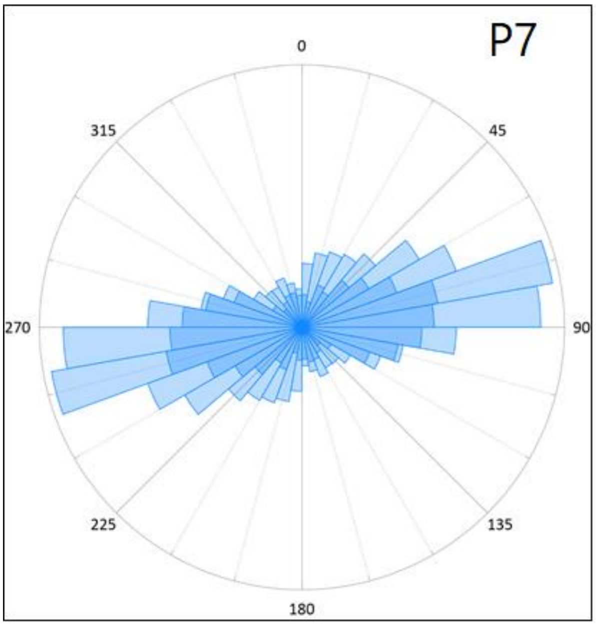

Fig. 7: Rosette diagrams showing the preferred directions at the acquisition point P7.

The authors would like to thank the Astronomy, Astrophysics, and Geophysics Research Center, CRAAG, for supplying the material for the ambient noise acquisition.

References

1. Layadi, K., Semmane, F., Yelles-Chaouche, A., Saadi, A., Chimouni, R., Haddad, O., Aïdi, C. (2023). Site characterization of Algerian broadband seismic stations using earthquake and ambient vibration data: topographic

and lithological site-effects investigation. Journal of Seismology, 27(1), 45-75.

2. Nakamura Y (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report, Railway Technical Research Institute 30: 25–30.M.
3. Layadi K, Semmane F, Yelles-Chaouche AK (2016). Site-effects investigation in the city of Chlef (formerly El-Asnam), Algeria, using earthquake and ambient vibration data. Bull Seism Soc Am 106: 2185–2196.
4. Issaadi A, Semmane F, Yelles-Chaouche A, Galiana-Merino JJ, Layadi K (2020). A shear-wave velocity model in the City of Oued-Fodda (northern Algeria) from Rayleigh wave ellipticity inversion. Appl Sci 10, 1717. https://doi.org/10.3390/app10051717.
5. Saadi A., Issaadi A., Semmane F., Yelles-Chaouche A., Galiana-Merino J.J., Layadi A., Chimouni R. 2023. 3D shear-wave velocity structure for Oran city, northwestern Algeria, from inversion of ambient vibration single-station and array measurements. Soil Dynamics and Earthquake Engineering 164, 107570.
6. Layadi K, Semmane F, Yelles-Chaouche AK (2018) S-wave velocity structure of Chlef City, Algeria, by inversion of Rayleigh wave ellipticity. Near Surf Geophys 16:328–339. https:// doi. org/ 10. 3997/ 1873-0604. 20180 11
7. Tebbouche MY, Machane D, Chabane S, Oubaiche EH, Meziani AA, Ait Benamar D. et al (2017). Imagery of the metamorphic bedrock roof of the Sahel active fault in the Sablettes (Algiers) reclaimed area by ambient vibration HVSR. Arab J Geosci 10:292. doi: 10.1007/s12517-017-3074-1
8. Tebbouche M., D. Ait Benamar, H. M. Hassan, A. P. Singh, R. Bencharif, D. Machane, A. Aghiles Meziani, Z. Nemer. 2022. Characterization of El Kherba landslide triggered by the August 07, 2020, Mw =4.9 Mila earthquake (Algeria) based on post-event feld observations and ambient noise analysis. Environmental Earth Sciences, 81:46. https://doi.org/10.1007/s12665-022-10172-8
9. Layadi K, Semmane F, Yelles-Chaouche AK (2022). Azimuth Dependence in Topographical Site Effects: Case of ABZH Broadband Station (North of Algeria). Proceedings of the 2nd Springer Conference of the Arabian Journal of Geosciences (CAJG-2): Advances in Geophysics, Tectonics and Petroleum Geosciences, 2, 217-220 Tunisia.
10. Radi Z, Chaouche AY, Guettouche S, Bokelmann G. Upper Mantle Anisotropy beneath Northern Algeria from Shear-Wave Splitting: Anisotropy beneath Northern Algeria. Ann. Geophys. Vol. 66 (2023). https://doi.org/10.4401/ag-8839
11. Massa M, Barani S. Lovati S (2014). Overview of topographic effects based on experimental observations: meaning, causes and possible interpretations. Geophys J Int 197: 1537–1550.
12. Konno K, Ohmachi T (1998). Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. Bull Seism Soc Am 88: 228–241.
13. Jurkevics, A. (1988) Polarization Analysis of Three Component Array Data. Bulletin of Seismological Society of America, 78, 1725-1743.
14. Paolucci R (2002). Amplification of earthquake ground motion by steep topographic irregularities. Earth Eng Struct Dyn 31:1831–1853.
15. Lee VW and Trifunac MD (1990). Automatic Digitization and Processing of Accelerograms Using PC. Report No. 90-03, Dept. of Civil Engrg., Univ. of Southern California.