Evidences of directional soil response comportment

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Abstract

In recent years, the importance of considering other peaks than the predominant in the soil response has been revendicated. One possible explanation for some of these secondary peaks in the soil response is the presence of strong lateral variations in the geology of the area. Specifically, the existence of paleochannels and streams in the city of Barcelona has been associated with the appearance of some of these double peaks. This work stems from the idea that it is reasonable that a linear structure such as a paleochannel or stream produces a directionality in the response of the site and therefore the directional peak does only affect the structures in this specific direction. On the other hand, the peak produced by the half-space outside the stream may also present a certain degree of directionality that influences the behavior of the structures.

To study this possible phenomenon, we have chosen an area close to the border between Barcelona and L'Hospitalet de Llobregat, and, analyzed 11 ambient noise Horizontal to Vertical Spectral Ratio (HVSR) soil response measurements of 40 minutes length and applying circular statistics to the results. The results show clear indications of this directional behavior of the response peaks.

1 Introduction

The existence of lots of places were the soil response shows an HV shape with more than one peak suggest a complex structure of the soil response further a classical view with only one resonance peak (Caselles et al., 2010). Moreover, the soil response in some places shacked by some earthquake has evidenced complex amplification (Finn et al., 1993). This fact could be important for earthquake engineering considering that the structures response to a shake dependent, sometime, on directional effects (Pinzon et al., 2021). The existence of complex or double peaks in soil response seems to be related, in some cases, with strong geological lateral changes (Matsushima et al., 2014; Stanko et al., 2016) or with the presence of paleochannels (Santos-Asunsao et al., 2016; Salinas et al., 2014). Meanwhile other seems to be related with vertical complex geology (De Monaco et al., 2013). If a lateral geological change is the responsible of the double peaks seems to be logical that in the interregional zone one of the peaks are produced by the wave propagation in a zone and the other is produced in the other one. These is the fact found in Kyoto by Matsushima et al. (2014) where then higher resonance peak only appears in the west direction. In Kyoto the geological change is produced by the existence of a North-South fault with an average dip of about 10º at a deep from 250 to 420 meters. The case of lateral geological variations produced by paleochannels is different. In paleochannels case, the expected geological changes are shallow, they are produced by the filling of the rivers eroded by the water flow. Moreover, inside the paleochannels water flows, so the soil response has to be different than dried zones. In some places, as in Barcelona, some of this paleochannels are very narrow (few meters width) while others have some tens of meters. The different geological ambient could produce differences in the kind of soil response. In Kyoto the directionality is very clear, the low frequency peak only appears in the north-south direction while the high frequency peak appears in both directions. While the results obtained in Barcelona show great variability. Some paleochannels produce high variation in peak frequency but no double-peaks appears, whereas other paleochannels produce a double peak of the HV site response. To properly study one of these zones with double peak soil response we carried out extensively soil response measurements in a place located in the border between Barcelona city and L'Hospitalet de Llobregat. In this zone we have performed 11 ambient noise HV soil response measurements of 40 minutes length.

The long measurement time was chosen to be able to apply statistical methods to the directional H_θ/V results of each of the individual windows. We applied circular statistical methods to the direction of the maximum of the H_θ/V of each individual window. Circular statistics is a particular case of statistic applied to periodical events or angular. That is, circular statistics is the branch of statistics that study cyclical variables. In circular statistics there are tests and tests of hypotheses that allow us to infer if the samples are directed and if two samples are directed at different angles. Some of these tests has been used to found evidences of soil response directionality in some places of Barcelona city.

2 Materials and methods

2.1 Localitzation and measurements

Topographically, Barcelona is encircled by Collserola Montagne range and Mediterranean Sea. This fact produces the existence of a large number of creeks in the upper part of the city that joint as they approach the coast, forming streams. In the upper part of the city the creeks are very small with few meters' width, meanwhile in the lower part of the city the creek beds could have tens of meters. We have chosen a place in the border between Barcelona city and L'Hospitalet de Llobregat were two little creeks of the upper part of the city joint to form one important scream head of the Hospitalet city.

We performed 11 measurements of 40 minutes trying to do some inside the expected creek bed and few outside (Figure 1). First of all, we have visually selected good windows of 32 seconds long tapped by a Parsen window. So, we can hold 149 windows as maximum. After check temporal windows we visualize the H/V frequency-time history plot in order to avoid windows with spurious frequencies not detected in temporal windows. After avoid bad windows we have computed the HV curves and rejected the windows with a standard deviation more than 3 times. After this last rejection of the windows we have selected two band frequency were appears each peak. For selected windows, the program found the angle were appear each peak and visualize the $H_\theta V$ plot (HV rotate) in order to reject windows without clear peaks in each selected band. Finally, the program saves a table with the angle were the maxim of the $H_\theta V$ appears for each peak to apply circular statistic.

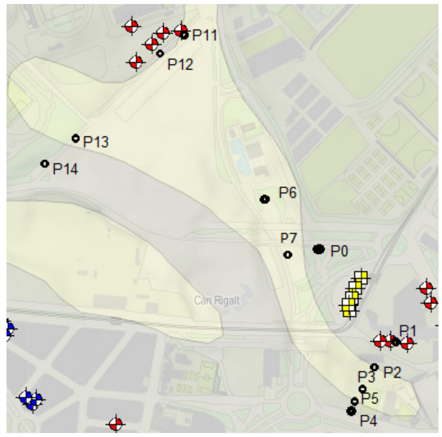

Figure 1. Localization of measurement points and surface geology. Black points: measurement places. In yellow: Pliocene. In beige: Pleistocene.

2.2 Circular statistic

Circular statistic is a special case of statistic to study cyclical variable. In fact, it is only directly applicable to cyclic variable between 0 and 360º but applying a contraction or a dilatation to the variable the new one can be studied by circular statistic. For example, the average angle is computed by:

$$\bar{\theta} = arctg\frac{\sum_{i=1}^{n} sin\theta_i}{\sum_{i=1}^{n} cos\theta_i}$$

But there are another important parameter named mean vector length (r) that it is interpreted as the concentration degree:

$$r = \frac{\sqrt{(\sum_{i=1}^{n} sin\theta_i)^2 + (\sum_{i=1}^{n} cos\theta_i)^2}}{n}$$

This parameter means that as higher it is higher is the concentration of the individual angles into the mean values. And when r is close to 0 means that angles are uniformly distributed.

Other way to check the uniformly of the distribution is to compute de circular standard desviation:

$$s = \sqrt{2(1-r)}$$

To assure that the direction of the two HV peaks of a place are statistical different, we have performed the Anderson Darling test, Kuiper's test, Watson U^2 test and, Chi-squared test. We have used the two first test to verify if a data sample is normally distributed or uniform. The last two tests were used to check if the samples associated with the two peaks of an HV signal are oriented in the same direction.

3 Results

In the upper part of the studied zone all points (P11 to P14 of figure 1) have shown double peaks in close directions (Figure 2). The low peak has a frequency between 1.31 Hz and 2.40 with clear directionality between 53º and 73º (Figure 3). Directionality are clear with circular standard deviations lest than 26º. The frequency of the higher peak ranges from 3 Hz to 5 with different directions. Points 11, 13 and 14 have a clear complementary H_θ/V pattern than low peak pattern with a mean direction between 14º and 162º (-18º) meanwhile this fact is not as clear for P12 with a mean direction of 45º. In all points, standard deviations are higher than the lower frequency peaks deviations (between 26º to 32º). All circular test performed prove the directionality of all peaks in all points and both peaks in each point have different direction.

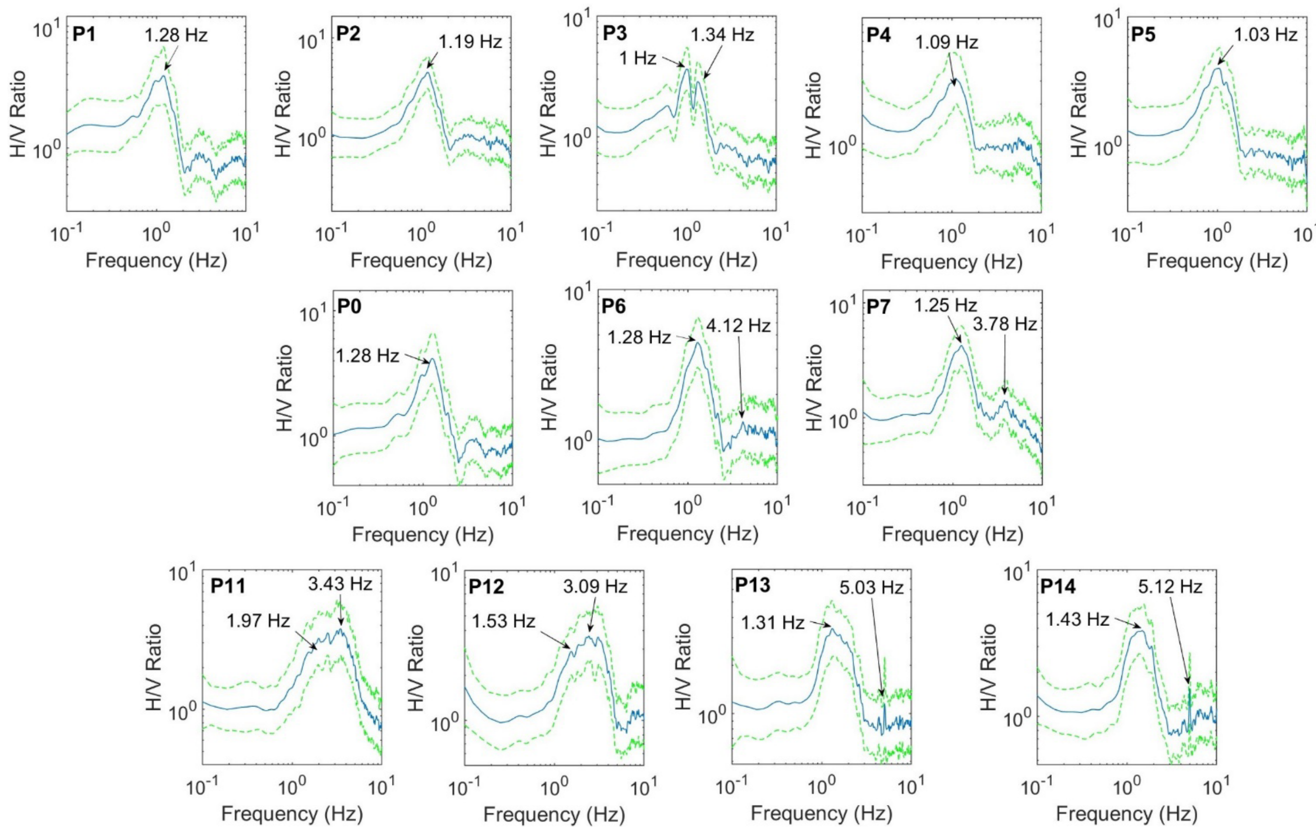

Figure 2. H/V ratio of the studied points.

In the central part of the study zone, there is the measured point P0 that only show one HV peak at a frequency of 1.28 Hz. This point is clearly out of the creek since it is 20 meters topographically over point P7. Points 6 and 7 have two HV peaks, but not as clear as upper part zone points, one at a frequency of 1.28 Hz and 1.25 respectively and another at 4.12 Hz and at 3.78 Hz respectively. Directionality have clear H_θ/V pattern complementary between low peak and high.

The down part of the studied zone shows the clear effect of the stream appearing only in point P3 a double peak with frequencies of 1.00 Hz and 1.34 meanwhile the other points have only one peak at frequencies between 1.03 Hz and 1.28. But directionality of P3 low peak and high have similar H_θ/V pattern with mean direction at about 104º and standard deviations of 25º.

The Anderson Darling test has determined that the samples associated with the peaks of all points clearly have non-Gaussian behavior. Therefore, the inference about the samples associated with all the peaks must be made with non-parametric statistics. The Kuiper test allowed us to conclude that the samples studied individually are not uniformly distributed with the tendency to concentrate in the angular plane.

Watson's U^2 and Chi-square tests as non-parametric statistical tests were used to decide whether two samples associated with the peaks of an H/V signal have the same direction. At all points, the low and high frequency peaks showed different orientations, including the P3 point peaks that have the same apparent direction.

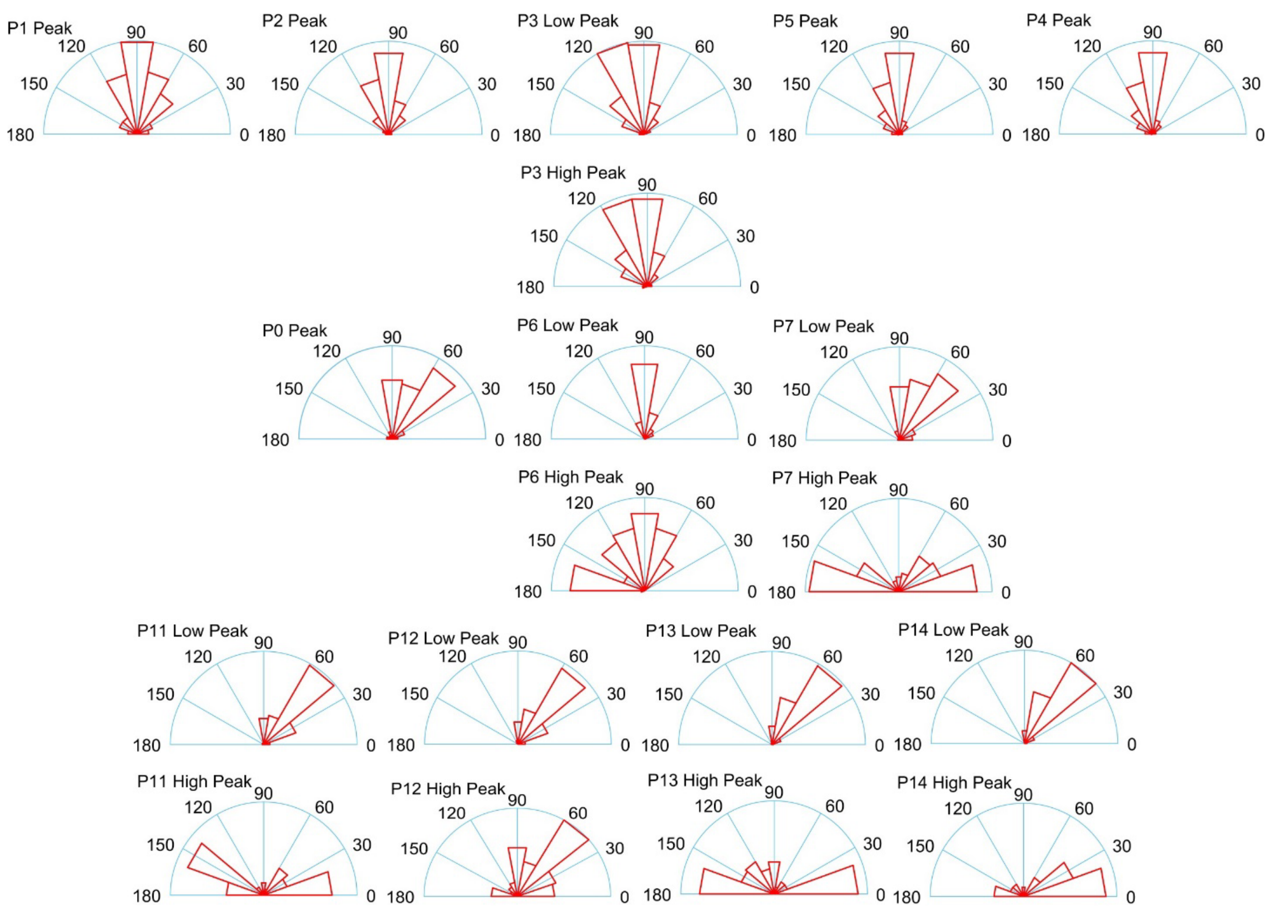

Figure 3. Rose diagrams of the peaks at each point.

4 Discussion and Conclusions

The present work has demonstrated the existence of directional effects in soil response even for lateral geological changes of small dimensions. The use of circular statistical test has been very important to assure directional effects.

In Barcelona, the existence of lots of creeks and paleochannels produce double peaks in soil response that probably present directional effects may have an important roule in earthquake engineering that is not taken into account in the studies.

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7 Author Contributions

JL and OC collected data and performed its arrangement, analyses and discussion; VS and VP contributed on discussion of the obtained results. JC contributed in data acquisition and analysis. All authors contributed to manuscript revision, and they read and approved the submitted version

8 Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.