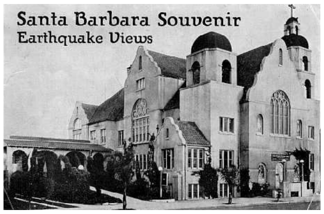

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CAN HIGH DAILY-VARIATION OF NOISE LEVEL ALTER RESULTS OF AMBIENT VIBRATION H/V TECHNIQUE?

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ABSTRACT

The ambient vibration H/V technique is often used to identify the fundamental frequency of site effect. Implemented following the right procedures from the field acquisition to the interpretation, including signal processing, (e.g. following the SESAME guidelines) this method could provide robust results. We performed the H/V technique trough a Provence (France) old valley engraved in a Cretaceous limestone bedrock and filled with Cenozoic sediments. We measured the noise over periods of 24 hours per point. During the night, a very low level of noise was recorded within the frequency band of the local site effect [2–10 Hz]. This level is one to two order of magnitude lower than during the day. We noticed that the H/V peak in the valley c an be significantly shifted from night to day. Only H/V peaks obtained during night measurements are consistent with the geology. Thus, although the H/V peak frequency is often deemed to be independent of noise level, we highly recommend to perform at least one 24-hour H/V measurement per investigated site to evaluate the daily variation of the noise (and the eventual shift of the H/V peak frequency) in order to avoid misinterpretation. Taking into account this constraint and thus, performing the measurement during the night, the H/V technique appears to be, on our case study site, not only an efficient tool to evaluate site effect frequency, but also a powerful method to “map” the depth of the bedrock.

INTRODUCTION

Today, the ambient vibration H/V technique is widely used to identify the fundamental frequency of local site effect (Nogoshi and Igarashi, 1971; Nakamura 1989; Lachet and Bard 1994). It is also used as a geophysical imagery tool to map the depth of high impedance contrast within the geological formations. Implemented following the right procedures from the field acquisition to the interpretation, including signal processing, (e.g. following the SESAME guidelines, 2004) this method could provide robust results. This method was applied in the Cadarache Nuclear Research Center (near Saint Paul lez Durance, SE of France) located across an old valley engraved in a Cretaceous limestone bedrock (Figure 1), filled with Cenozoic sediments (Guyonnet-Benaize et al.2011).

NOISE FEATURES, HIGHLIGHTING THE EMPIRICAL VARIATION IN THE H/V RESPONSE

We recorded ambient vibration during 24 hours periods at the same point. More than 200 points were measured. During the night, ambient vibrations show a very low level of noise within the frequency band of the local site effect [2 – 10 Hz]. This level is one to two order of magnitude lower than during the day. As a comparison, the noise recorded in Cadarache during the night is two to three orders of magnitude lower than the noise recorded during the night in the Grenoble city. This feature implies to take further care during the acquisition (ambient vibrations were recorded during several hours for one H/V point instead of few tens of minutes in a more “standard” configuration) and during the processing (applying the right taper to time signals before performing Fourier transform).

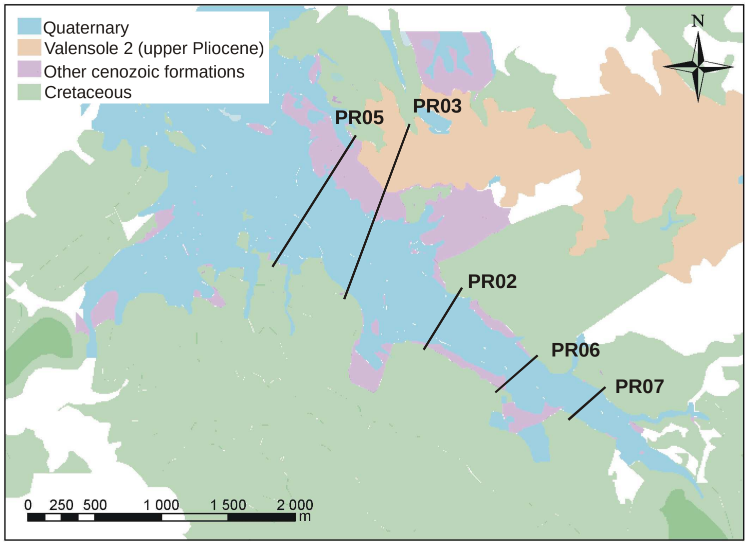

Figure 1: simplified geological map of the Cadarache Research Center and position of H/V profiles.

During the day, the level of noise is higher and is mainly due to human activity, especially the wide earthworks conducted within the framework of the future ITER (International Thermonuclear Experimental Reactor) facility building. We noticed that the H/V peak in the Cadarache valley can be significantly shifted from night to day (Figure 2). This shift is very high: from 4 Hz (day) to 7 Hz (night). The transition between the two behaviours is very sharp. Of course, this variation was not noticed for all the measuring points, but this feature occurred for 15-20% of the total of measurements. We will discuss later the cause of such a huge frequency shift.

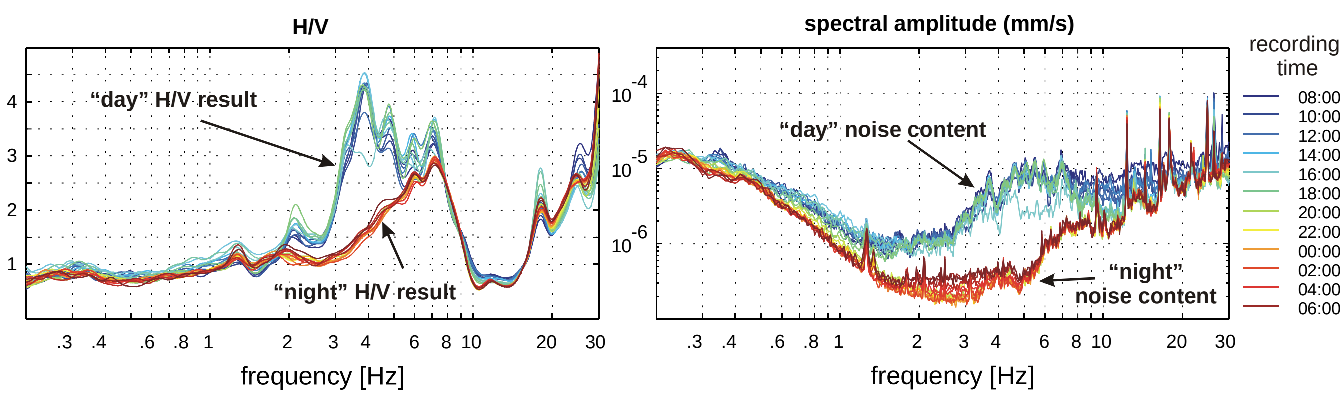

Figure 2: Variation between night and day of the H/V response and noise spectrum.

INTERPRETATION OF H/V CURVES TO MAP THE BEDROCK DEPTH

The Cadarache site gives the opportunity to use a wide geotechnical and borehole data base. On the whole site, more than 1000 geotechnical boreholes were drilled since 1960. However, the spatial distribution of these boreholes is quite heterogeneous with a high density close to nuclear facility and a sparser distribution in other areas. From one hand, we can "calibrate" the H/V interpretation in area of high borehole density. From the other hand, the H/V method is useful in the area where we do not have benefit of boreholes that reached the bedrock.

So, in order to "calibrate" the interpretation, we perform H/V measurement at the place where ~ 40 boreholes that reached the limestone bedrock were previously drilled. We clearly noticed that only H/V peaks obtained during night measurements are consistent with the geology. The Figure 3 shows the typical "typology" of H/V response we noticed on the Cadarache site: flat response on rock sites, clearly defined peak in the location where the bedrock is relatively flat, broad and unclear peak in the area where the bedrock is highly dipping.

We were able to determine a good correlation between the depth of the bedrock (determined by borehole) and the H/V peak frequency (figure 4). Using this correlation curve, we can determine a "mean Vs curve" as a function of the depth of the bedrock and thus, determine "slice" velocity whithin the paleo-canyon filling. In order to validate this curve, we compare it to Vs values given by few tens of crosshole measurements made on the site: the curve obtained by H/V data fit well the mean velocity curves obtained by crosshole (figure 4).

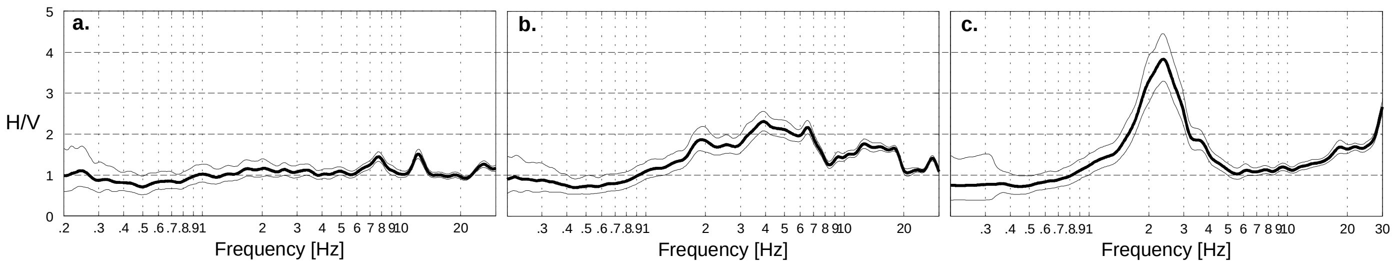

Figure 3: Typical H/V curves obtained on the Cadarache Center. a. rock sites (flat response), b. sites with a highly sloped bedrock (broad unclear peak, c. sites with a flat or moderately sloped bedrock (clear peak).

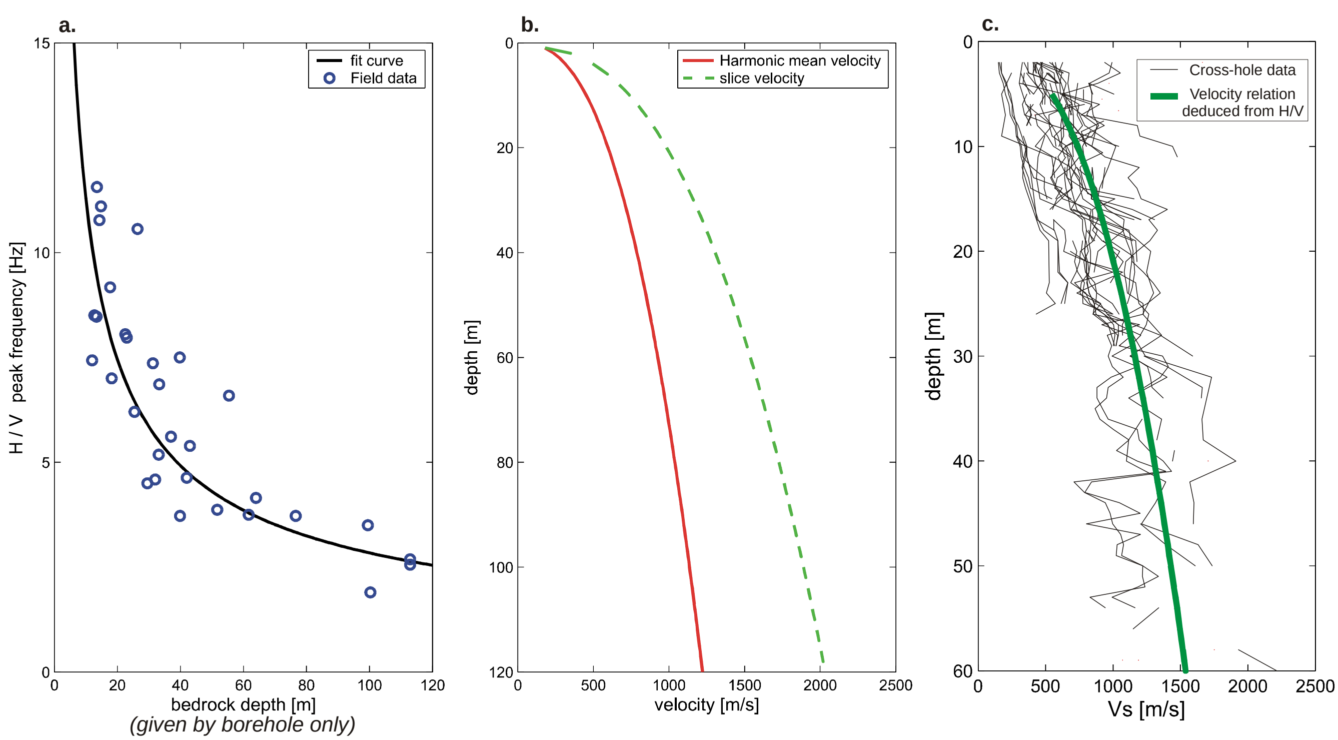

Figure 4: a. correlation between H/V peak frequency and bedrock depth (determined only with borehole at the H/V measurement point) and fit curve. b. Harmonic mean velocity and slice velocity determined from the previous fit curve. c. comparison between slice velocity determined from H/V data and crosshole data (only velocity value obtained within the basin filling material is plotted here).

Having established that the measurements are reliable, we have conducted a set of profiles perpendicular to the palaeo-canyon in Cadarache. We present here a few of them. Each profile consists in approximately twenty measurement points. All H/V curves were calculated using the vibrations recorded during the night. We rejected the few measuring points showing a broad unclear peak, typical of a sloped bedrock and using the frequency / depth relation established above. We were able to determine the depth the bedrock along profiles. These results are shown in Figure 5. The profiles were used, with other geological and geophysical information, in order to construct a geological 3D model of the Cadarache valley (Guyonnet-Benaize, 2011).

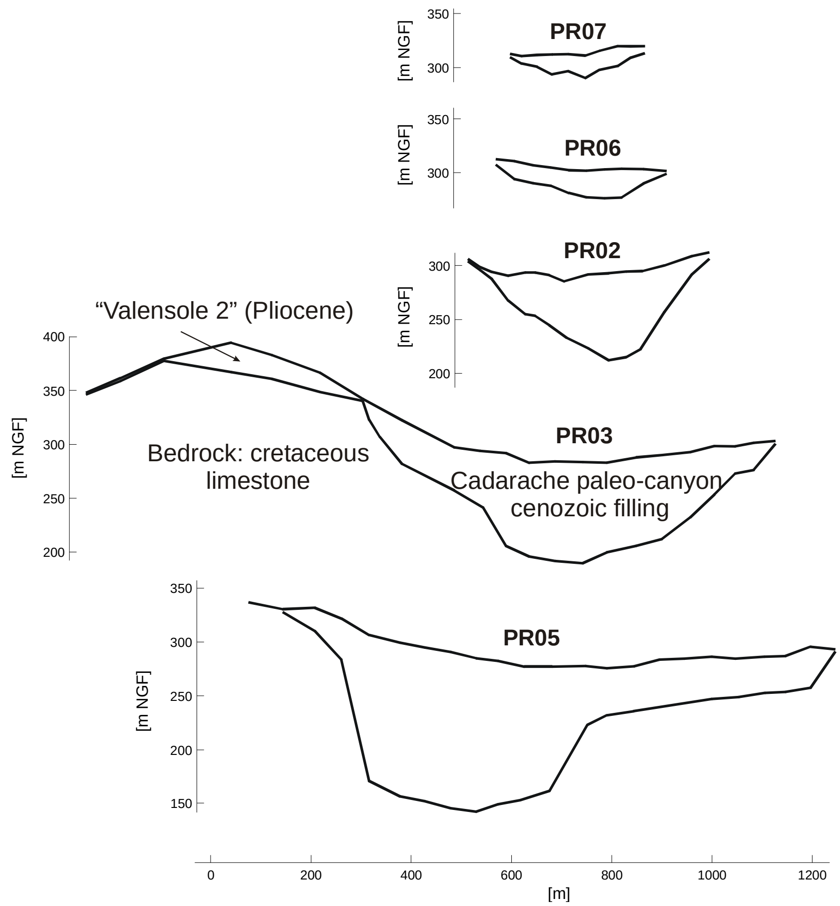

Figure 5: Cross-sections in the Cadarache valley. The bedrock depth determined from H/V measurements.

DISCUSSION ON THE FREQUENCY SHIFT BETWEEN DAY AND NIGHT

So far we have simply observed empirically that the night H/V response was consistent with geology. It is now important to understand what may be the cause of this variation. It is often assumed that the method H/V produces reproducible results, regardless of the noise level. SESAME guidelines (2004) also proposes to realize measurements during a few tens of minutes. This duration does not allow to appreciate the noise variation between day and night.

However, some works showed that frequency changes could occur. For exemple, Cara et al. (2010) have shown a case study where a change between day and night was also observed. Cara et al. 2010 explain that the day wavefield is dominated by surface waves and the H/V response is dominated by the phenomena of Raleigh wave ellipticity. Conversely, during the night, the wavefield is dominated by body waves and the H/V response can be explained by SH waves transfer function. Bonnefoy-Claudet (2004) showed by simulation that for sites where the velocity contrast between sediments and bedrock is low, the "mechanism of formation" of the H/V peak could depend on the nature of ambient noise.

These authors have shown that in some cases, the frequency associated with Raleigh wave ellipticity phenomenon could be slightly different from the frequency associated with the SH waves transfer function. This explains the differences observed by Cara et al. (2010). In the case of Cadarache, most of those elements are present: low velocity contrast between bedrock and sediments, significant variation in the nature of the noise between the day (anthropogenic noise, dominated by surface waves) and night (natural noise, dominated bulk waves). However, the frequency difference observed in Cadarache (which can almost reach a factor of 2) can not be explained only with those elements.

We propose the following hypothesis to complete the explanation (summarized on figure 6). At night, the noise is low, it is dominated by natural bulk waves. The frequency of the H/V peak can be interpreted as representative of the transfer function of SH waves. At a given location, the frequency is representative of the geology at the vertical of the measuring point. During the day, the noise is strong, it is dominated by anthropogenic surface waves. The frequency of the H/V peak can be interpreted as representative of the phenomena of Raleigh wave ellipticity. However, the dominant frequency of the valley center also influences a part of the valley edges and the frequency of the H/V peak is not necessarily representative of the geology at the vertical of measuring point. This hypothesis involving the multidimensional nature of the studied site complements previous explanations.

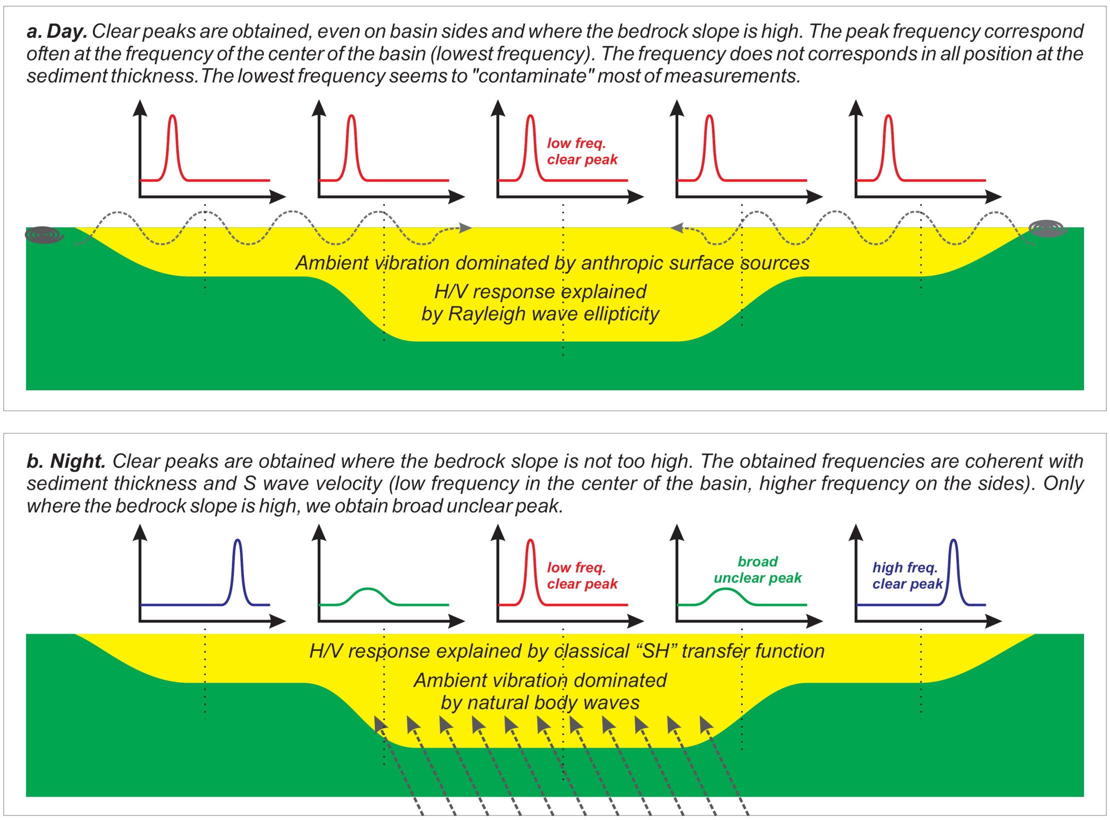

Figure 6: frequency shift between day and night: explanation proposition.

CONCLUSIONS

In the case of Cadarache, the H/V method allowed to built a reliable mapping of the bedrock depth. This study has shown however that, contrary to what is commonly accepted, there are cases where the frequency of the H/V peak can vary greatly depending on the noise nature. We therefore recommend to perform at least one long measurement (24 hours) on a new site to be studied in order to define the best measuring period (or to ensure that there is no change between day and night). Moreover, if our hypothesis about the explanation of the observed variation in Cadarache is true, it could have implications on how to interpret the H/V frequency in terms of depth of bedrock in some multi-dimensional sites. The interpretation should therefore be different depending on the H/V response is dominated by the phenomena of Raleigh wave ellipticity or SH wave transfer function. We plan to test our hypothesis by multidimensional simulations of noise.

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