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SEISMIC MICROZONATION OF CHANIA, GREECE, USING AMBIENT NOISE TECHNIQUES AND EARTHQUAKE RECORDINGS

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Determining the strong ground motion response for different geological formations with traditional methods is still not an easy task, especially in urban areas or when studying large-scale areas that need to be densely covered, despite the recent methodological and application developments. In the past decades, ambient noise recordings have been extensively employed as a tool for the determination of the site effect of geological formations due to seismic excitations. The most common technique, now almost routinely applied, relies on the calculation of spectral ratio of the horizontal to vertical component of ambient noise (HVSR), despite the lack of a rigorous theoretical basis for its application (Bard, 1999). In the present study, a combination of array and single station measurements of ambient noise have been performed in the urban area of Chania and its southern basin, in order to determine the main soil dynamic properties.

The broader Chania study area consists of: a) Tripalion basement and “platenkalk” limestones which are found at the mountainous area located to the South of the study area, b) Quaternary deposits filling the basin of Chania, south of the main city complex and to the north of the basement formations and, c) Neogene sediments fill the main Chania urban area at the North (Fig. 1). According to Mountrakis et al. (2012), the Neogene sediments covering the city area are composed of marls, limestone, marls with sandstone interscalations, calcareous conglomerates with breccia, and quartzitic-phylitic conglomerates with breccia.

In the framework of the present work, 200 single-site HVSR measurements were performed in the broader Chania area (Fig. 1, blue dots). The obtained results for the HVSR data showed a strongly varying behaviour between recording locations on Neogene and Quaternary deposits. In general, Neogene sediments showed a single broad HVSR peak at very low frequencies (below 1Hz, typically in the range 0.4-0.6Hz), indicating a very thick Neogene layer overlying the bedrock (geological and/or seismic). On the other hand, measurements at Quaternary sites showed in most cases two peaks, with the first one being similar to the Neogene formations, while the second one was identified at much higher frequencies, ranging between ~0.8-4.0 Hz. HVSR measurements were grouped on the basis of the visual similarity of the HVSR curves, in order to examine the common features for the various geological formations.

In order to explore the origin of the double-peaked HVSR curves in Quaternary formation sites, we employed additional ambient noise recordings, collected by arrays. With this technique it is possible to calculate the one dimension velocity profile of S-waves, while its depth penetration depends on the array aperture (Tokimatsu, 1997). We performed measurements at 13 noise array sites

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distributed within the main complex of Chania city, in order to define the velocity structure of the superficial layers (Fig. 1, black circles). The f-k method was used to extract the slowness dispersion curve and a modified version of the neighboring inversion algorithm was applied in order to retrieve the one dimensional velocity profile of S-waves, as proposed by Wathelet (2008). Results show that the upper surface layer of Quaternary deposits have V_S velocities of the order of ~300-450 m/sec, while for the Neogene formations the upper layer show much higher velocities (V_S~1000 m/sec), followed by more stiff layers with velocity ~1700 m/sec or higher. None of the measurements succeeded to reveal the velocity of actual geological bedrock of the area down to maximum depth of 500 m, although in some sites a deeper layer with velocities higher than ~2200 m/sec was identified, possibly reflecting the presence of basement limestones.

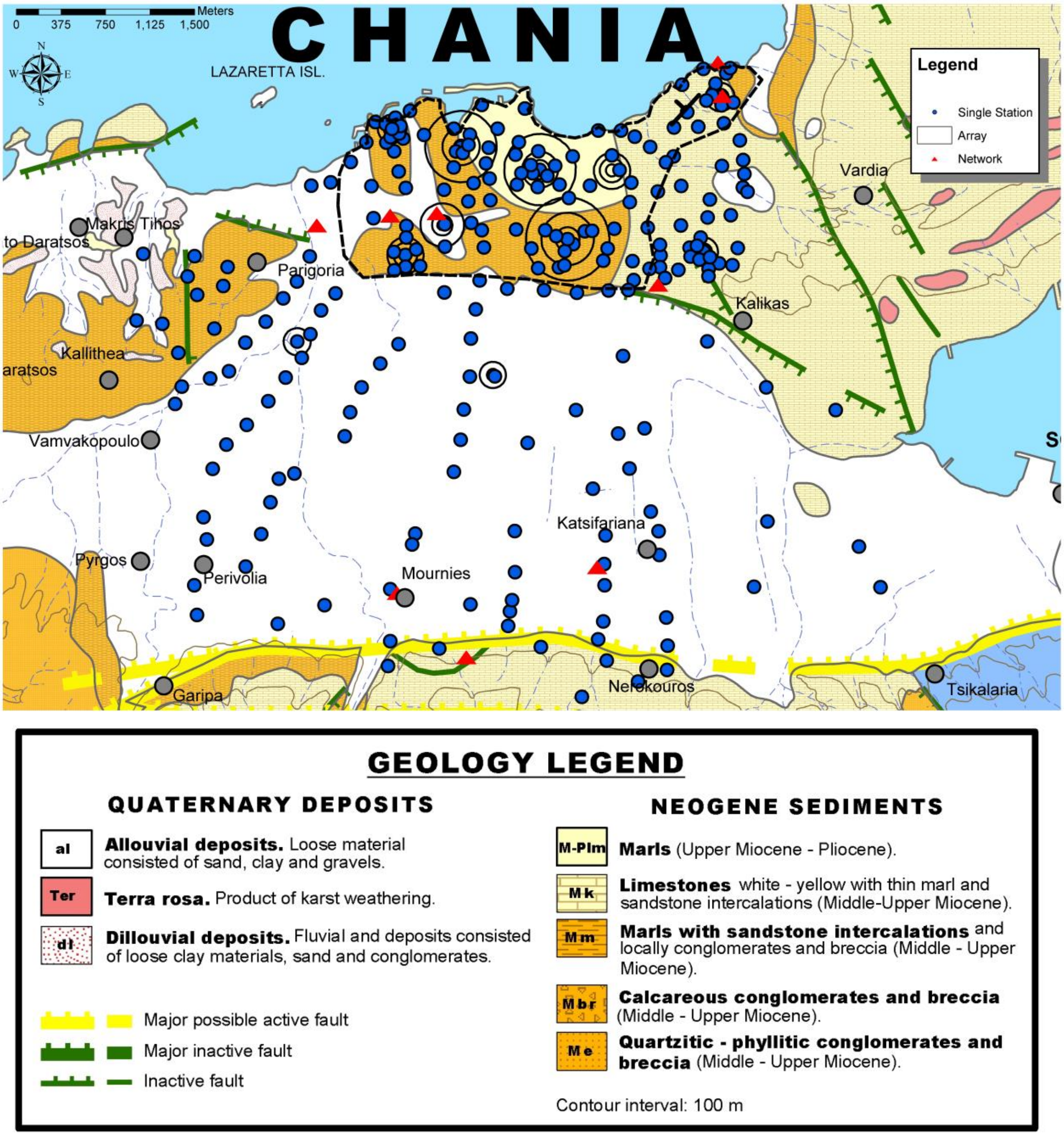

Figure 1. Geological map of the study area. Also shown are the single station sites (blue dots), the noise array measurements (black circles) and temporary seismic network stations (red triangles).

The results of the velocity models, as well as a model of Quaternary sediments thickness derived from available boreholes, were used in order to explore the double-peaked HVSR curve pattern. The comparison of the second HVSR peak frequency showed an excellent correlation with the Quaternary thickness, suggesting that the Quaternary-Neogene sediment discontinuity is responsible for the higher HVSR peak. In addition, the estimated V_S velocity from the quarter-wavelength approach showed an excellent correlation with the Quaternary V_S values estimated from the array measurements. Therefore, in order to validate this hypothesis, we employed the method of Hisada (1994, 1995) and used the velocity models from the array measurements in order to derive synthetic HVSR curves. The results verified the possibility to obtain doubled-peaked HVSR curves for the Quaternary sites, one (lower frequency, f<1Hz) controlled by the deeper basement-Neogene sediments discontinuity and a second one (higher frequency, f>1Hz) controlled by the shallower Neogene-Quaternary interface.

To validate the HVSR results, we installed 5 seismic motion sensors at different geological formations, in order to calculate the horizontal to vertical spectral ratio for weak motions from regional seismic events (Horike et al, 2001). The sensors were installed in two phases in order to cover a wider area, for a period of few weeks each time (Fig. 1, red triangles). A total number of 31 and 93 seismic events were recorded during each phase, with magnitude ranging between 1.0 and 4.8 and epicentral distances larger than 50 Km. Horizontal to Vertical Spectral Ratio at earthquake data (HVSRE) was applied only for the S-waves and the obtained results are in good agreement regarding the fundamental frequency peak with the ambient noise HVSR data. Amplitude comparison shows a fair agreement, except for two sites, close to the edge of the Quaternary basin. HVSRE amplitudes are comparable to HVSR ones, and can be considered the upper threshold of recovered HVSR amplitudes.

To summarize, in this work we attempted to characterize a geologically complex area such as Chania using ambient seismic noise measurements. The usage of single station Horizontal to Vertical Spectral Ratio revealed the difference between Neogene and Quaternary formations and was validated using weak motion seismic events at 10 sites, which were processed using the same technique. Moreover, synthetic HVSR curves showed a similar behavior regarding the single and double peaks observed in the experimental curves, with results showing a single peak at Neogene sediments areas and a double peak at areas covered with Quaternary deposits. To assess the main features of the geophysical structure of the dominant geological formations, 13 array measurements of ambient seismic noise were performed, with results showing a top Quaternary cover with low velocity of S-waves ~300-450 m/sec, followed by a faster Neogene layer with velocities of ~1000 m/sec, often followed by a deeper stiffer layer, with S-wave velocity approximately at 1700 m/sec.

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