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Work Package 2: Identification of Risk scenarios

Activity 2.1: Evaluation of hazard, exposure and vulnerability

Report on the evaluation of geophysical data and seismic site effects in the Maltese archipelago in relation to the calculation of seismic risk

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Foreword

One of the goals of Work Package 2 is the evaluation of the risk to human life, property and urban/cultural heritage in thetransboundary region, arising from seismic and geomorphological hazards. The evaluation of seismic risk is closely associated with the ability to determine the way in which the ground will respond to earthquake shaking of a given intensity. The level of shaking depends on a number of factors, such as the magnitude, depth and source mechanism of the earthquake, the distance of the earthquake from the site, the geological/geomorphological characterisation of the site under study. It is well known that sites such as sediment-filled basins or alluvial valleys have the potential to amplify earthquake ground shaking, and it is indeed documented in several cases that buildings on such sites have suffered catastrophic damage even though at considerable distance from the earthquake's epicentre.

This report addresses the issue of site characterisation and site effects on the Maltese archipelago. The Maltese islands are made of a sedimentary sequence of limestones and clays. The western half of Malta, as well as the island of Gozo exhibit a more complete sedimentary sequence, in which a layer of softer clays is present either as an outcrop, or buried beneath a harder layer of Upper Coralline Limestone. In either case, the presence of lower shear-wave velocities that characterise the clays relative to the limestone are known to have a potential amplification effect. The measurement of the shear-wave velocity profile at a site enables the eventual modelling of the ground-motion response to earthquake ground shaking.

This report describes the techniques used to perform such measurements and the results obtained at a number of key sites over the Maltese archipelago.

Scientific Report

EVALUATION OF SEISMIC SITE EFFECTS IN MALTA

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Introduction

It is now well-established that earthquake ground shaking is not only a function of the earthquake magnitude and epicentral distance, but also of the site conditions, including soft layers in the sub-soil stratification and topographical features. The literature contains numerous examples of anomalous amplification as a result of site effects. This study reports the results of measurements aimed at characterizing possible site effects on the whole of the Maltese islands. In particular, it has long been felt that the presence of a soft clay layer within the sedimentary sequence in certain areas of the islands has the potential to introduce site amplifications, but the effect had never been experimentally investigated. In this study, experimental measurements of the frequency/amplification characteristics as a function of the geology over the Maltese islands were carried out with a view to identifying areas that could be more vulnerable than others, as well as to produce a map of the site response characteristics, and carry out some validation procedures in order to identify the origin of the amplification.We applied the H/V (Horizontal-to-Vertical Spectral Ratio) method to ambient noise, known also as the Nakamura technique (Nakamura, 1989; Nakamura, 2000). This method, owing mainly to its low-cost, rapidity and ease of operation, has been extensively used in a large variety of locations. Mucciarelli and Gallipoli (2001) present an overview of different methods of data collection and analysis, while Bonnefoy-Claudet et al. (2006) present a review of the nature of the ambient noise wavefield. The SESAME project (Site Effect Assessment Using Ambient Excitation) funded by the European Commission proposed an exhaustive set of guidelines to be followed when using the H/V method (Bard, 2005).

In addition, we investigated the stratigraphy of several sites in the archipelago by using array techniques and we were able to retrieve the thickness of each geological layer at a site as well as the shear-wave velocity within the layer.

Data Collection and Results

Data were collected using Tromino 3-component seismographs (www.tromino.eu), which are compact, self contained and highly portable instruments, and a set of 17 geophones together with the acquisition system. Processing was done via the Grilla™ and SoilSpysoftware. All the instruments and software were acquired through the SIMIT project.

H/V results from single-station measurements

Single-station measurements, which include a review of a number of measurements that had been carried out in previous studies as well as several new sites, were available at about 300 points spread out over Malta and the island of Gozo (Fig. 1).

The results of this study represent an extensive description of the possible site response all over the Maltese islands. A clear correlation between outcrop geology and site frequency response has been demonstrated as shown in Figure 2. Figure 3 reports a few examples of H/V curves obtained.

The Lower Coralline and Globigerina Limestone sites, the latter outcropping extensively in the eastern half of Malta and underlying most of the urban and industrial areas, exhibit mainly flat response curves above 0.5 Hz, the main range of engineering interest for typical local structures. The presence of the Blue Clay layer, on the other hand, is highly determinant for site amplification, whether outcropping at surface, or as a buried layer beneath the hard Upper Coralline Limestone layer. Pronounced and well-defined peaks are exhibited on Blue Clay outcrops in the 2–10 Hz range, and on Upper Coralline Limestone in the 1–2 Hz range. These outcrops are present mostly in the western half of Malta and on the island of Gozo. The variation in characteristic peak frequency due to the outcropping BC is attributed to the variation in the layer thickness. Consistently with numerical modelling, the resonance in the UCL is interpreted as being due to the buried clay layer, present under all UCL outcrops except in the east of Malta. Where the BC is overlain by the UCL, the depth and thickness of the clay layer do not seem to influence to a great extent the resonance peak, since this is observed to occur in a narrower band of frequencies (1–2 Hz). The frequency ranges on BC and UCL coincide with resonance frequencies of typical 2–10 storey buildings.

Shear-wave velocity profiles from array measurements

Array measurements of ambient noise were carried out at a number of key sites over the Maltese archipelago with the aim of extracting the shear-wave velocity profiles, and in particular the shear-wave velocities within the UCL, BC and GL. Such data had not been previously available. For these measurements, use was made of the geophone array acquired through SIMIT funding, combined with another array loaned from the University of Catania. The advantage of the extended array was that longer wavelengths and deeper extents could be investigated and numerically modelled.

Array measurements were carried out at sites on varied lithology, and a number of array configurations and numerical methods were investigated in order to obtain the best information out of the noise wavefield. The methods utilised were SPAC(Spatial Autocorrelation), MSPAC (Modified SPAC), ESAC (Extended SPAC) and *f-k*. The dispersion curve of phase velocity *vs* frequency was extracted from the data and a joint inversion procedure, based on a genetic algorithm, was used to obtain an optimum velocity – depth model that fits both the dispersion curve as well as the single-station H/V curve.

Figure 4 shows the locations of the sites at which array measurements were carried out. A few examples will be given.

Figures 6 – 9 show joint inversion results of the dispersion curve (V_R) and the HVSR curve (H/V) obtained in Mdina, Mellieha, Xemxija and Rabat respectively. The first three of these sites are situated on the UCL, while the site in Rabat lies directly on the Blue Clay. The blue lines represent experimental curves and red ones are the best model obtained through the inversion procedure. Green and yellow lines are synthetic curves related to other modelshaving higher misfit.The difference both in the shape of the dispersion curves as well as in the obtained velocity profiles between sites on UCL and those on BC are clear. A dip in the H/V curve after the main peak is tentatively attributed to the presence of a velocity inversion, and is well reproduced in the synthetics.

Following the surface wave inversion procedure at all sites investigated on Malta and Gozo, it is possible to conclude that the shear-wave velocities in each stratigraphic layer have the following ranges of values:

GL: 800 m/s < Vs < 1000 m/s
BC: 300 m/s < Vs < 550 m/s
UCL: 550 m/s < Vs < 900 m/s

It is important to note that the high velocities (higher than 400 m/s) for the BC were obtained wherever the BC was not at the surface, but underlying the UCL.
Also, the low velocity of the UCL (550 m/s) was obtained in Xemxija, where the UCL was extensively fractured in the study area. In the other sites, the shear wave velocity of the UCL was in general higher than 700 m/s.

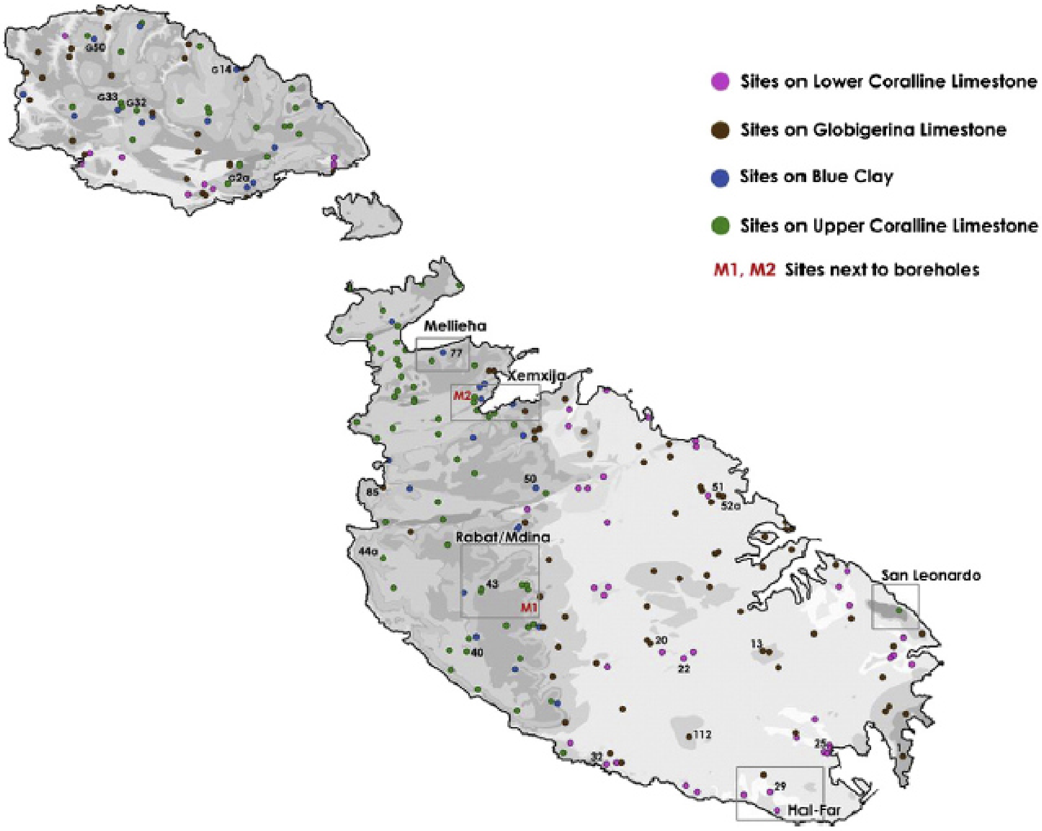

Figure 1: Location of the ambient noise recording sites in Malta and Gozo.

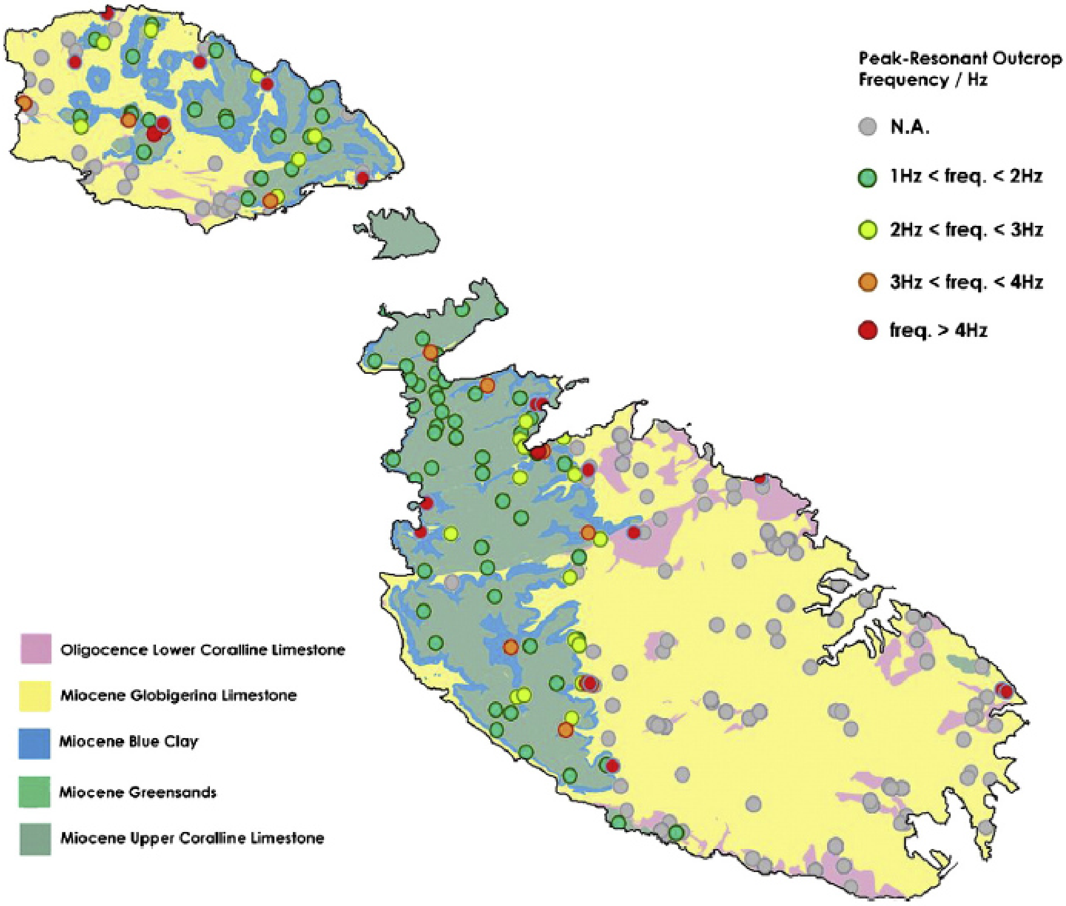

Figure 2: Site resonance frequency map for the Maltese islands. NA means “No amplification”.

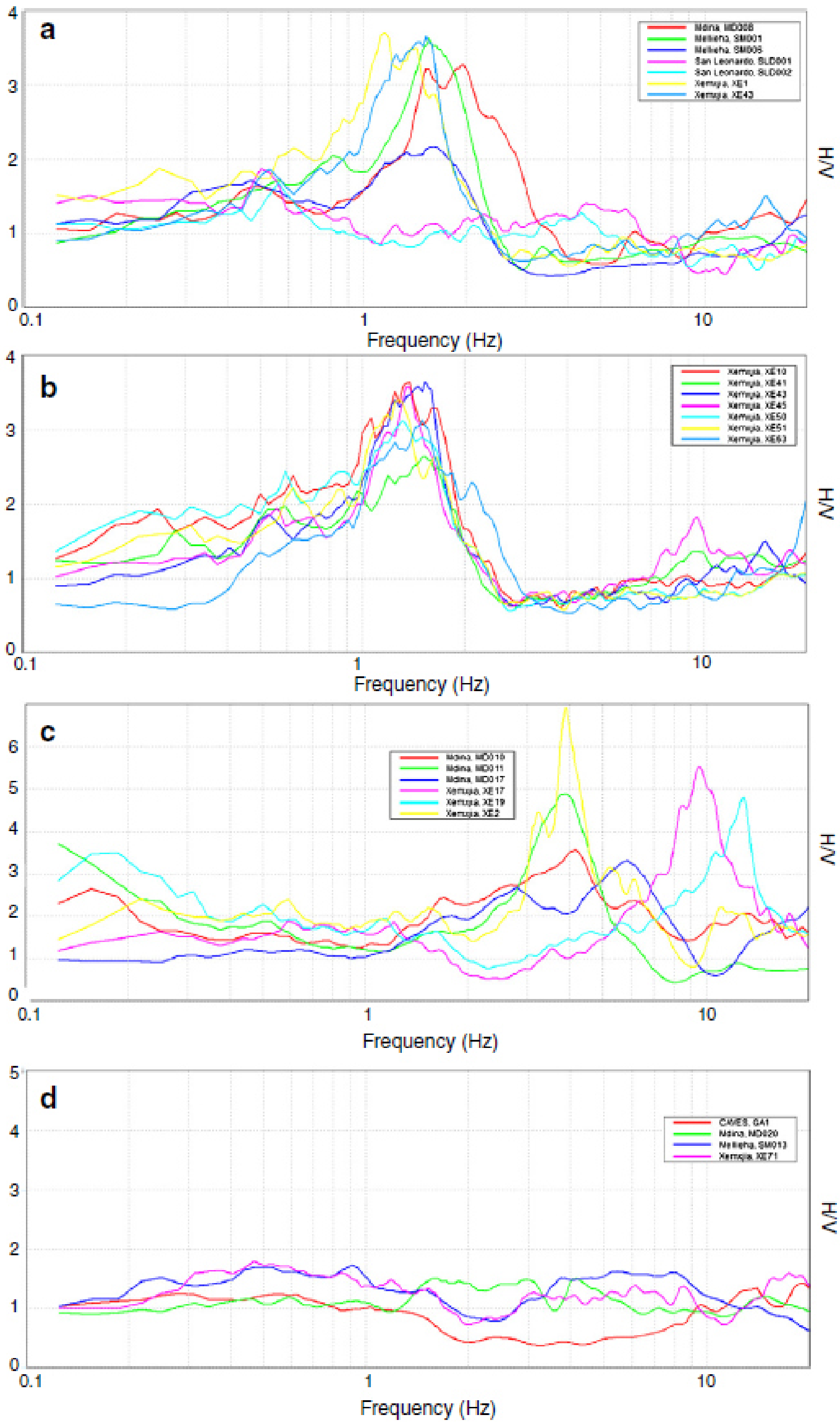

Figure 3: Examples of H/V curves obtained in different locations (see Fig. 1). (a) Sites on Upper Coralline Limestone. Note that the two curves from San Leonardo that show noamplification represent the only site in Malta where Upper Coralline Limestone is not underlain by Blue Clay; (b) sites on Upper Coralline Limestone in one locality, Xemxija; (c) sites on Blue Clay; and (d) sites on Lower Coralline Limestone and Globogerina Limestone.

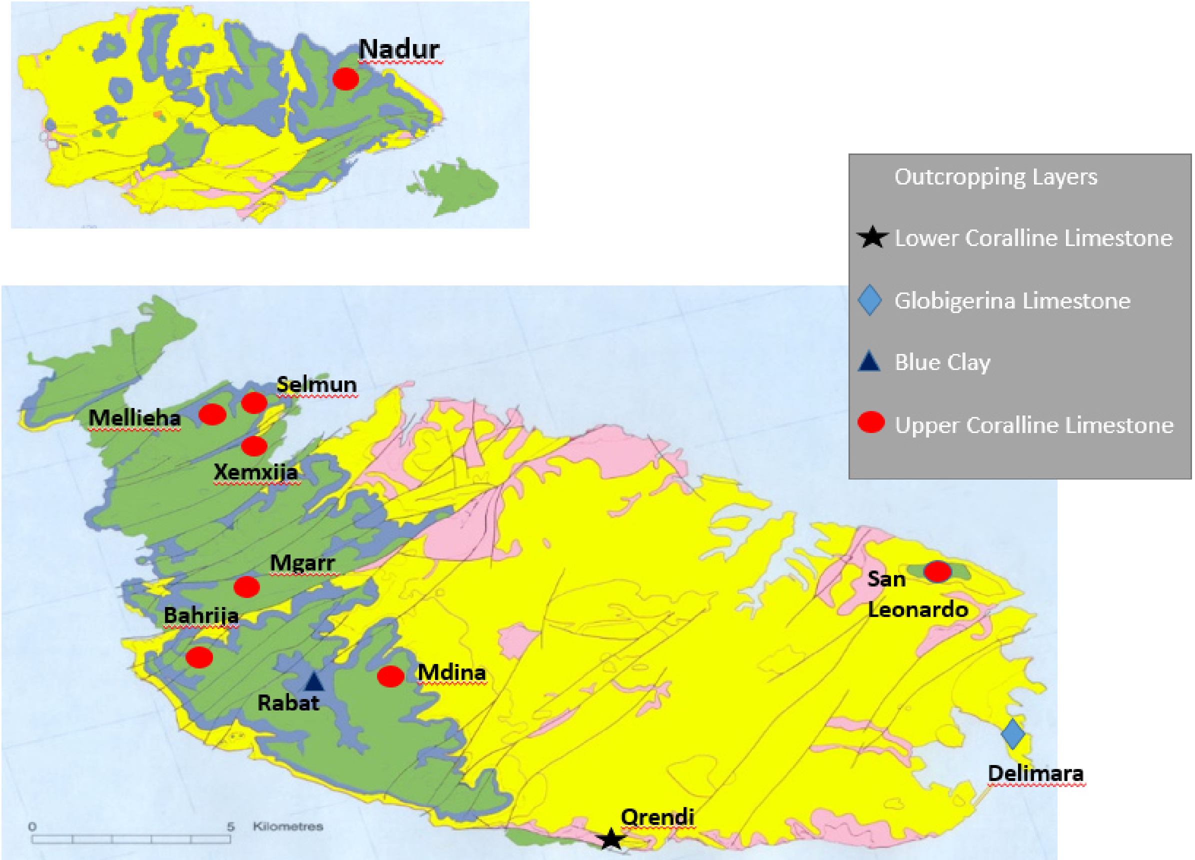

Figure 5: A geology map of the Maltese islands together with the places where array measurements were taken.

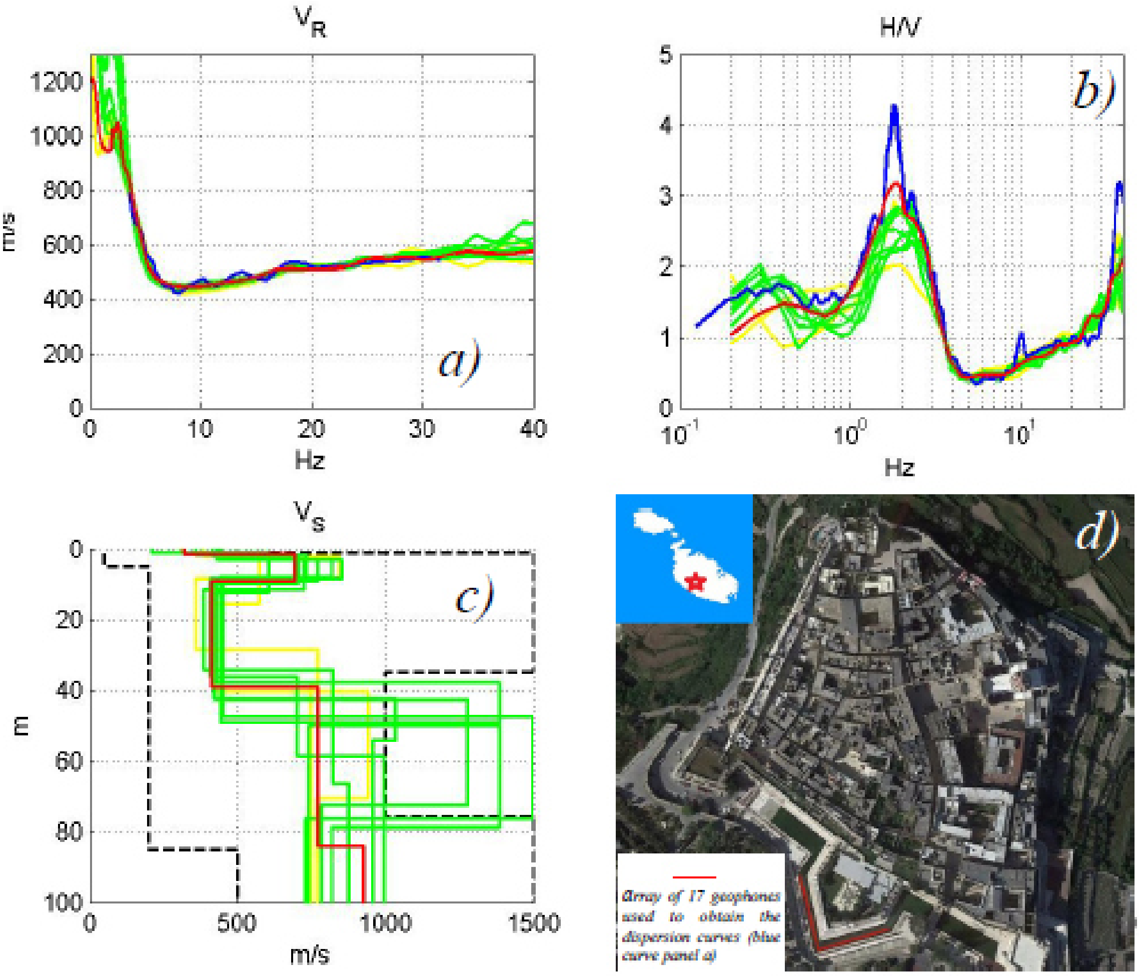

Figure 6: Joint inversion results (c) of the dispersion curve (a) and the HVSR curve (b) obtained in Mdina (d) which is situated on the UCL (see text for details)

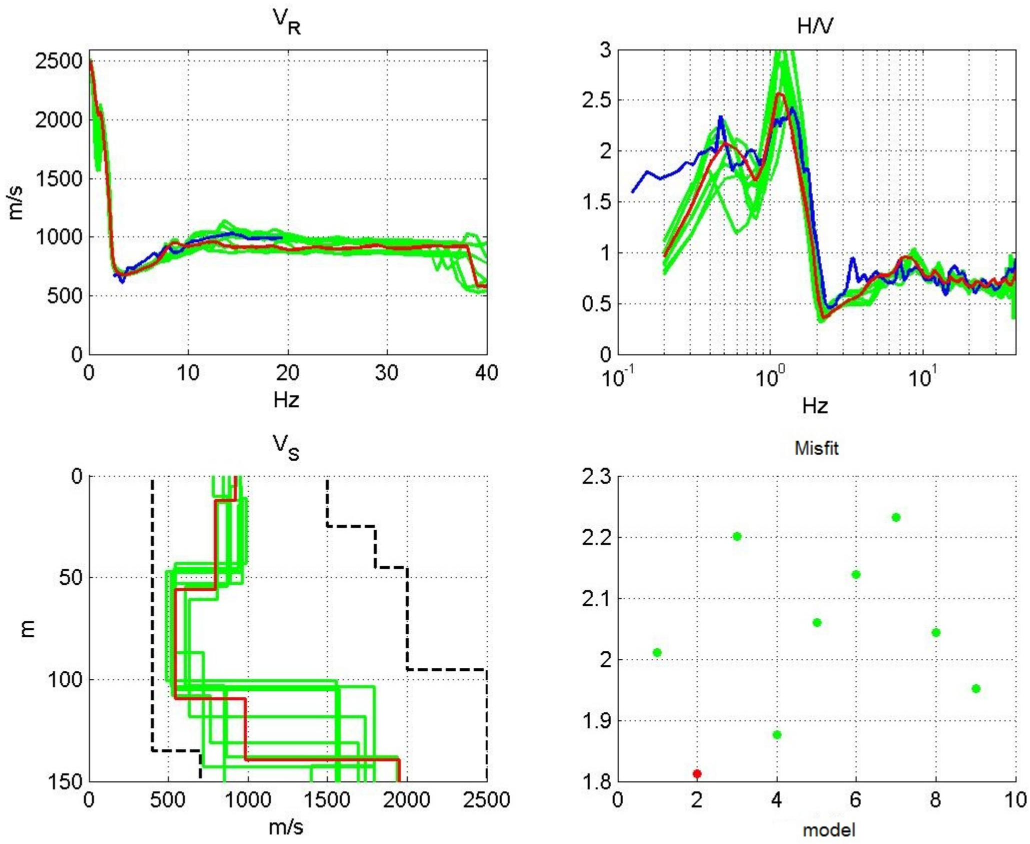

Figure7: Joint inversion results of the dispersion curve (a) and the HVSR curve (b) obtained in Mellieha. The best-fitting velocity profile (c) shows a clear low-velocity layer corresponding to the clay. (d) represents the misfit function for the models in (c), the red point corresponding to the minimum misfit model.

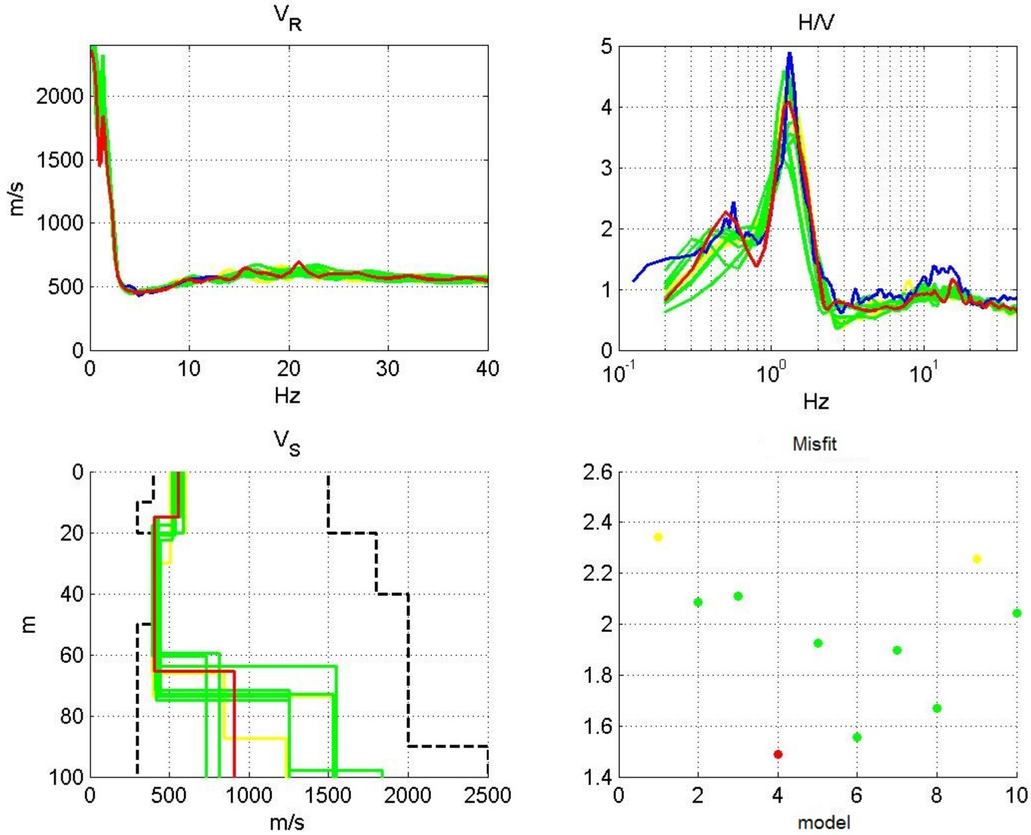

Figure 8: Joint inversion results of the dispersion curve (a) and the HVSR curve (b) obtained in Xemxija.

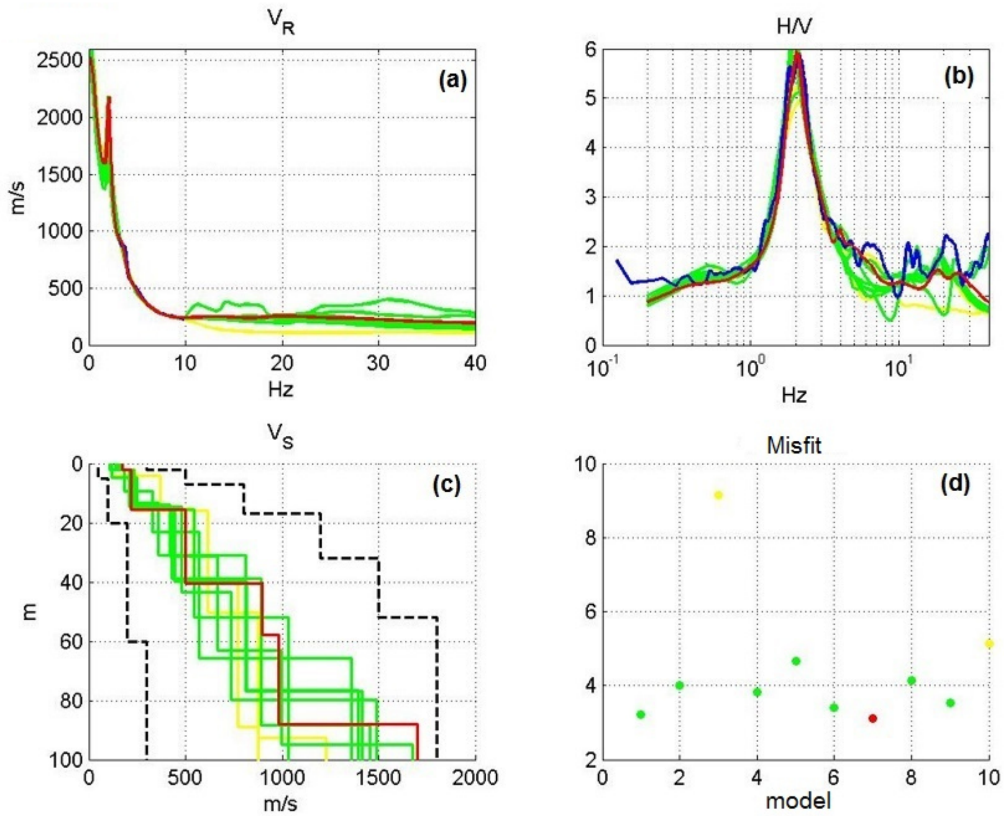

Figure 9: Joint inversion results of the dispersion curve (a) and the HVSR curve (b) obtained in Rabat, on Blue Clay outcrop.

References

Bard, P.Y., 2005. Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations: measurements, processing, and interpretations, *SESAME European Research Project*. WP12, deliverable D23.12, 2004, Available at:http://sesame-fp5.obs.ujf-grenoble.fr/Deliverables2004

Bonnefoy-Claudet, S., Cotton, F. & Bard, P.Y., 2006. The nature of noise wavefield and its applications for site effects studies: a literature review, *Earth-Sci. Rev.,* **79**(3), 205–227.

Mucciarelli, M. & Gallipoli, M.R., 2007. Non-parametric analysis of a single seismometric recording to obtain building dynamic parameters, *Ann. Geophys.,* **50,** 259–266

Nakamura, Y., 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, Quarterly Report of Railway Technical Research Institute (RTRI), Vol. 30, No. 1, pp. 25–33.