SITE CHARACTERISATION AND RESPONSE STUDY IN RABAT, MALTA

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Introduction

The investigation of local ground conditions is an important part of seismic hazard assessment (Fäh et al., 2003). Local geology can greatly alter the seismic waves from earthquakes by amplifying their amplitude, changing the frequency content and increasing the shaking duration during an earthquake (Kramer, 1996). Sedimentary structures hosting dense settlements are likely to suffer from heavy damage, even though they can be situated away from the epicentre of the earthquake (Zor et al., 2010). The main parameters responsible for such effects are the shear-wave velocity (VS) structure and thickness of the sedimentary cover, the impedance contrast between the soft sediments and the underlying bedrock as well as the geometry of their interface (Parolai et al., 2006). Site response studies contribute to earthquake-hazard mitigation strategies such as seismic risk assessments, emergency response-preparedness and land use planning by considering existing and proposed buildings (Zor et al., 2010).

Since 1530, an earthquake intensity of VII on the European Macroseismic Scale (EMS-98) scale was experienced on the Maltese archipelago at least four times, with the major source of seismic hazard being the northern segment of the Malta Escarpment. Earthquake activity can also be attributed to active fault zones in the Sicily Channel and the Hellenic Arc. Even though the latter is situated relatively far away from the islands, an earthquake in 1856, with an epicentral location around 1000 km away from the islands, caused significant damage to buildings, with many houses suffering serious cracks to their walls (Galea, 2007). The public perception about seismic risk remains one of negligence and complacency and up to date, no comprehensive seismic site response study has been done on the islands.

This study is the first of a series of site response analyses which are to be carried out. It is divided in two parts. Firstly, a series of ambient noise measurements were done at a site in Rabat (Malta) to investigate and evaluate different techniques for estimating one-dimensional shear-wave velocity profiles. The chosen site is characterised by outcropping Blue Clay overlying the harder Globigerina Limestone. The data from the first investigations then serve as input to the equivalent-linear analysis programme SHAKE2000 (Ordonez, 2002) which is used for the site response analysis. In this research work, some advantages and limitations of chosen surface-wave techniques are also assessed. Moreover, any difference between equivalent profiles (satisfying the same experimental data) in site response results is investigated.

Geophysical investigations to obtain the shear-wave velocity profile

Methodology

Three different array techniques were first tested at the chosen site which presents the ideal geology for such studies: a velocity profile, in which VS increases with depth. The first part of the study is aimed at testing the capabilities and limitations of the three techniques which are: the Modified Spatial Auto-Correlation (MSPAC, Bettig et al., 2001), Extended Spatial Auto-Correlation (ESAC, Okada, 2003) and f-k method (Capon, 1969). Three different array configurations, an array of 17 geophones arranged in an L-shape and circle respectively and 42 geophones in an L-shaped configuration, were also tested out in the field.

A series of three-component measurements were also conducted to obtain the H/V curve (Nakamura, 1989). Chosen dispersion curves were then jointly inverted with the H/V curve using two different inversion algorithms, the Neighbourhood Algorithm (NA) and the Genetic Algorithm (GA). Five different profiles interpreting the geology of the site were obtained and compared.

Results

A comparison of the dispersion curves using MSPAC and ESAC shows that the two methods, based on the SPAC method (Aki, 1957), are in good agreement. However, it was observed that the f-k method tends to overestimate the Rayleigh-wave velocities at low frequencies, as is also reported in other studies (Zor et al., 2010; Picozzi et al., 2009).

The short L-shaped and circular arrays gave similar results, which can indicate that the wave-field was isotropic, while as expected, the dispersion curve of the longer array consisted of data in the lower frequencies. Table 1 presents a summary of the five best fitting profiles obtained from five separate inversion. The shear-wave velocity of the Globigerina Limestone at this site can be considered to be around 900-1000 m/s, with only NA1 being an outlier, since a velocity of 750 m/s was obtained. This range is similar to that obtained by Pace (2011) and Panzera et al. (2013) in Xemxija and some other sites in Malta using MASW and H/V modelling.

The thickness of the clay obtained for all the models is around 40-50 m. The only model which estimated a 60 m depth to bedrock is GA1. The calculated VS30 values for each profile are 257 m/s, 292 m/s, 307 m/s, 309 m/s and 323 m/s, thus classifying the site as belonging to the class C according to the EC8 classification (Bisch et al., 2012).

Since the recorded ambient noise with the longer L-shaped configuration is richer in low frequencies, the VS profiles GA2 and NA2 were used to perform site response analysis in the next part of this study. NA3 was eliminated since the MSPAC curve is very similar to the ESAC one.

Table 1: The results obtained from the five different inversions. GA stands for Genetic Algorithm while NA for Neighbourhood Algorithm and these refer to the type of algorithm used for the inversion. The Dispersion curve and Configuration columns show the chosen curves used for the inversion

	Dispersion Curve	Configuration		BC	GL
GA1	*ESAC*	*Circle*	V_S	350 m/s	940 m/s
			H	62 m	n/a
GA2	*ESAC*	*L-shape*	V_S	325 m/s	900 m/s
		42 geophones	*H*	40 m	n/a
NA1	*MSPAC*	*Circle*	V_S	325 m/s	750 m/s
			H	37 m	n/a
NA2	*ESAC*	*L-shape*	V_S	370 m/s	990 m/s
		42 geophones	*H*	45 m	n/a
NA3	*MSPAC*	*L-shape*	V_S	375 m/s	925 m/s
		42 geophones	*H*	51 m	n/a

Site Response Analysis using SHAKE2000

Idriss and Seed (1967) first proposed the equivalent linear approach for site response analysis that calculates an approximate nonlinear response through a linear analysis with soil layer properties adjusted to account for the softening during earthquake shaking (Bolisetti et al., 2014).

As an input for the analysis, the following information has to be provided:

1. A one-dimensional representation of the profile
2. Shear modulus reduction and damping ratio vs. strain curves
3. An acceleration time history

Results obtained in the first part of the study were used to construct the profiles (GA2 and NA2) while the curves used for the different stratigraphic materials have been selected among the available standard ones incorporated in SHAKE2000. Three acceleration time histories, representative of a large, medium and small earthquake, were chosen. These are: the 1693 M7.4 earthquake (simulated by Abela (2014), peak acceleration 0.041g), the 1990 M5.4 earthquake (PGA=0.0356g) and 2014 M4 earthquake with a PGA of 0.000388g (ITACA database http://itaca.mi.ingv.it). Data from the last two earthquakes is real and was recorded by stations in Sicily with epicentral distances being similar as those of Malta, and situated on bedrock.

Figure 1 and 2 show the response spectra with 5% damping ratio and amplification spectra for each profile and bedrock obtained for the 1693 input, while in Table 2 the PGA and spectral accelerations at periods which at periods of 0.1 s, 0.2 s, 0.3 s and 1 s are presented

The first resonance peak of the amplification spectrum is almost equal in frequency and very similar in amplitude, however this agreement decreases with frequency.

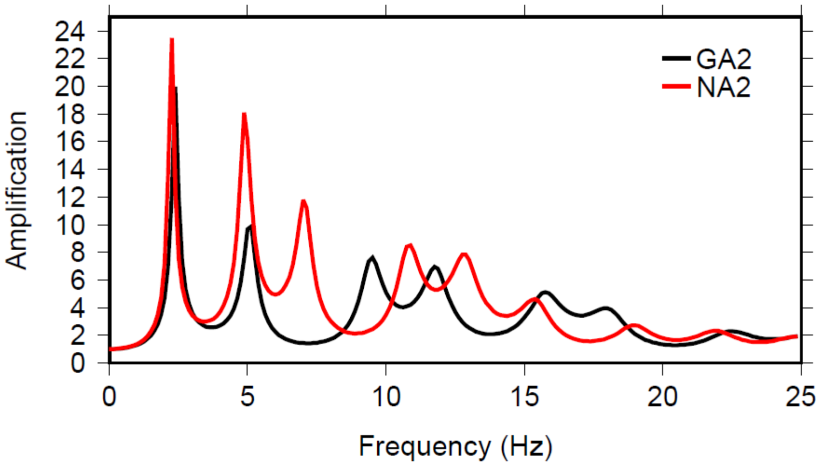

Figure 1: Amplification spectrum for the simulated 1693 earthquake

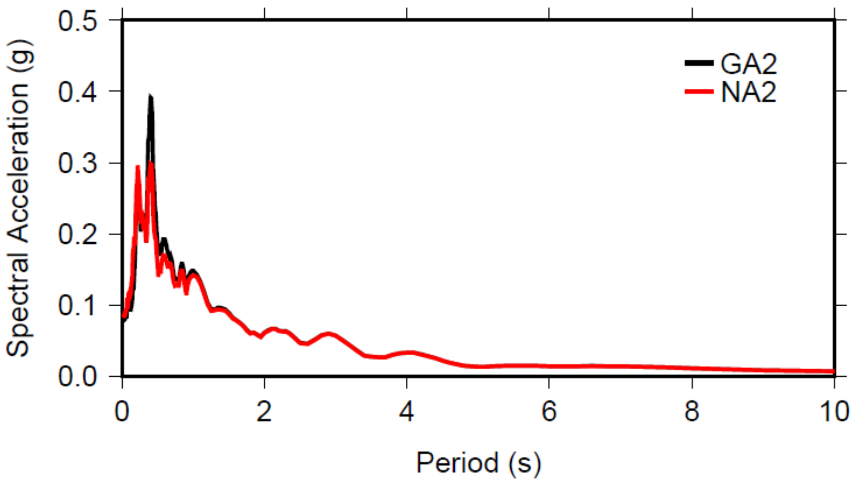

Figure 2: The response spectra for 5% damping at the surface for the simulated 1693 earthquake.

It is observed that the peak ground acceleration (PGA) for the 1693 input motion is about 0.08 g. The maximum spectral acceleration for GA2 is around 0.4 g and corresponds to a period of 0.4 s (2.5 Hz) which is very close to the fundamental period of the soil deposit as found experimentally using single-station ambient noise techniques (H/V). For NA2, the maximum spectral acceleration is approximately 0.3 g and also occurs at both 0.22 s and 0.4 s. Even though the input V_S profiles differed slightly due to the non-uniqueness of surface-wave techniques and the fact that they were obtained from two different inversion runs, this did not reflect any significant differences in the final seismic site response results

Table 2: The main results obtained from the site response analysis for a simulated 1693 event

Model	PGA (g)	Amplification	SA at 0.1 s	SA at 0.2 s	SA at 0.3 s	SA at 1 s
GA2	0.08064	1.967	0.14843	0.22923	0.22173	0.11366
NA2	0.08699	2.122	0.1415	0.25456	0.20558	0.11755

Conclusion

The main objectives of this research were to measure shear wave velocity, estimate site response and calculate response spectra and spectral acceleration at a chosen site in Malta. Different surface wave techniques were used to obtain a one-dimensional V_S profile for the site and after choosing two profiles, the effect of the soft Blue Clay in modifying ground response was obtained by conducting one dimensional equivalent- linear ground response analysis using the software SHAKE2000. Three input motions were tested and the results are presented in terms of response spectrum, amplification spectrum and PGA.

It has been shown that lithographic sequence as in Rabat plays an important role in amplifying ground motion as a significant difference between the input ground motion at the bedrock and that at the surface was observed.

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