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Effects of surface geology on the ground-motion at New Borg El-Arab City, Alexandria, Northern Egypt

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PGA;
Site response

Abstract The effects of the near-surface geology on the ground-motion at New Borg El-Arab City were evaluated in the current work based on the analysis of the ambient noise records (microtremor). Sixty-nine microtremor measurements have been done in the studied area. The dataset was processed using horizontal-to-vertical-spectral ratio (*HVSR*) technique to estimate the fundamental frequencies corresponding to the ground-motion amplification due to the soil deposits. By spatial interpolation of the resulted fundamental frequencies (f_0) of all the measured sites, the zonation map was produced. This map was correlated with the geological features of the study area and demonstrated that the fundamental frequency ranges between 5.8 Hz and 7 Hz were corresponding to the sites located over Quaternary deposit. However, the fundamental frequencies (f_0) increased in the middle of the study area due to presence of parallel Alexandria limestone ridge. Finally, site effect was highlighted by performing a site response analysis. It indicated that, the PGA at surface of the analyzed site is 0.047 g and the maximum spectral acceleration (SA) is 0.157 g. It was also found that, the maximum spectral period from site response analysis is in a good agreement with that one from *HVSR* technique. This confirmed the robustness of *HVSR* for determination of fundamental period or frequency.

1. Introduction

In the framework of urbanization in Egypt, many new cities have been constructed. New Borg El-Arab City is one of the cities whose establishment is mandated in the national plan of Egypt for the establishment of new urban communities.

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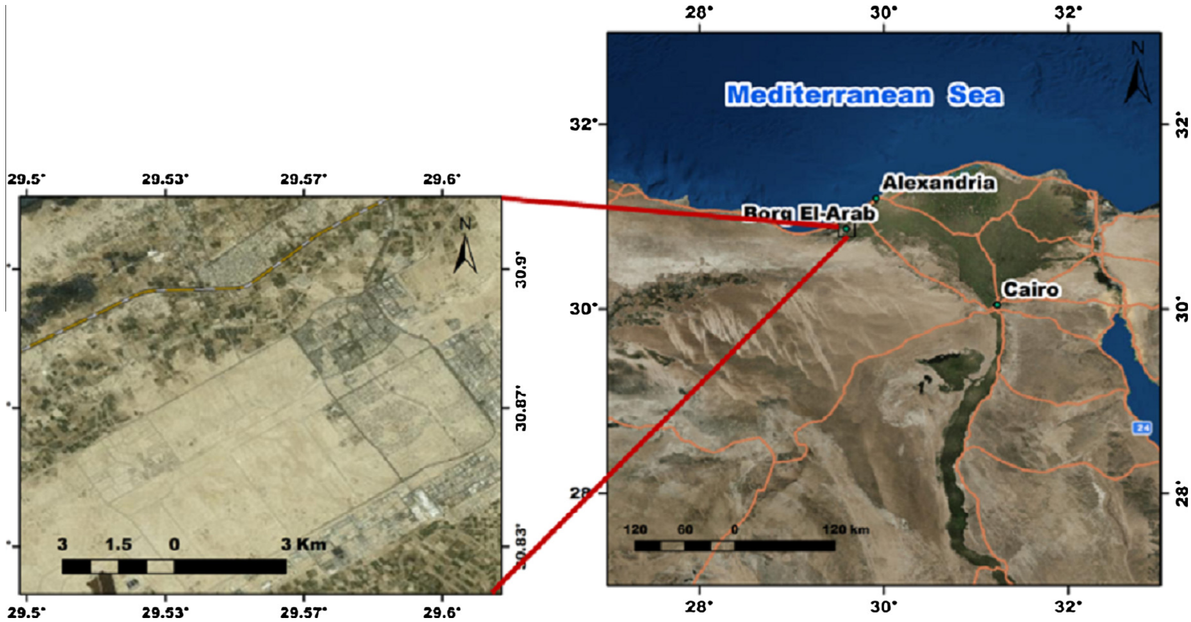

Figure 1 Location map of the studied area.

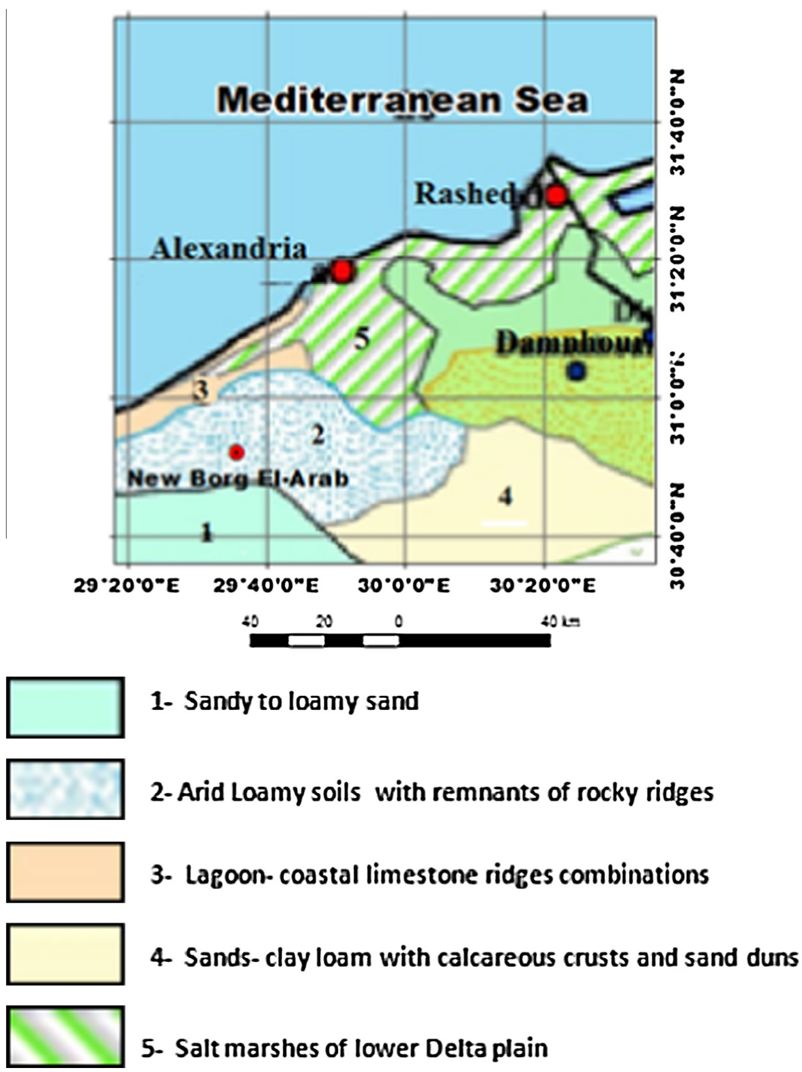

Figure 2 Soil map for the studied area and surrounding (after Omar, 2010).

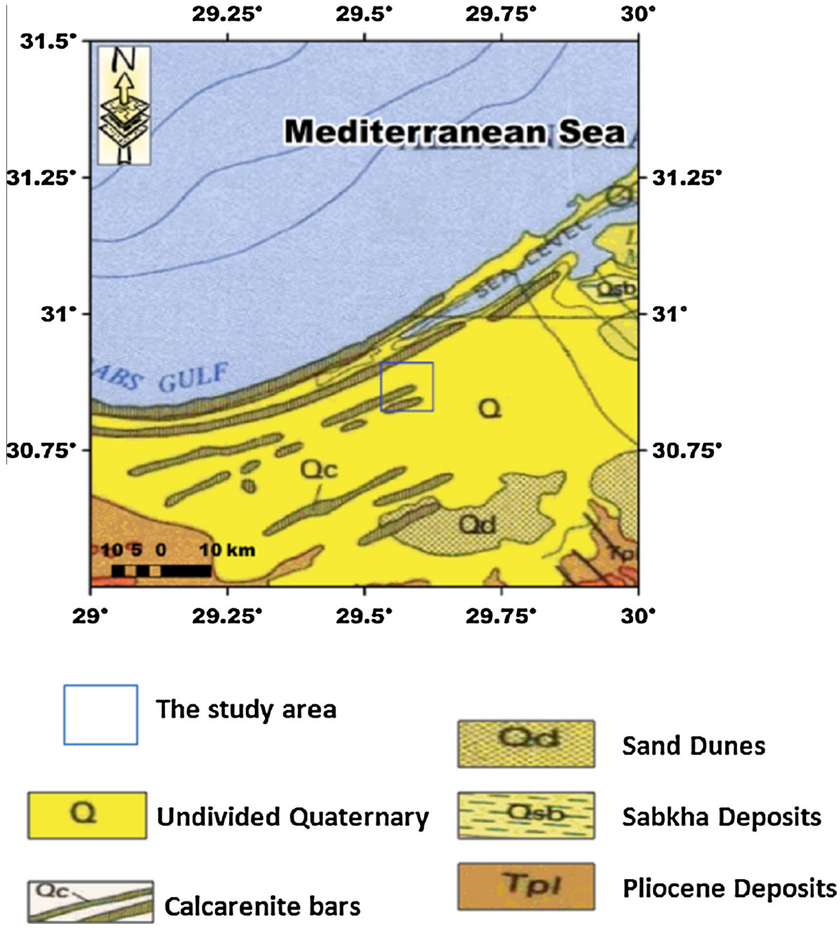

Figure 3 Geological map for the studied area and surrounding (geological survey of Egypt, 1981).

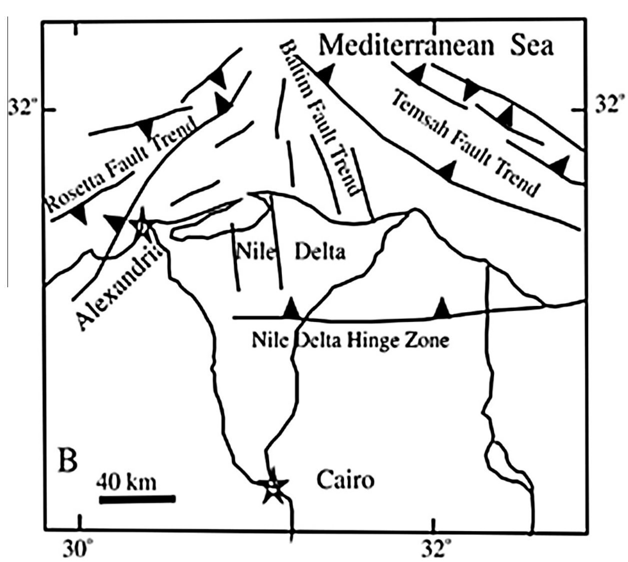

Figure 4 Local tectonic elements in the vicinity of Alexandria (after, El-Sayed et al., 2004).

The city is located at about 45 km west of Alexandria City and few kilometers from the Mediterranean coast (Fig. 1).

A few years ago, site effect in Borg El-Arab City was the main reason behind the tilting of the power line cable pillar as indicated by Abdel-Hafez et al. (2006). On the other hand, Alexandria is hit by about 25 damaging earthquakes through the time period 320–2000. About 14 of these earthquakes were located mainly in the Hellenic Arc region with relatively large magnitudes. The other nine earthquakes are located off-shore of Alexandria City with moderate magnitude (El-Sayed et al., 2004). In terms of seismic risk, the unconsolidated sediment materials could amplify ground motion during earthquakes and this causes building on these grounds to become more vulnerable to earthquake damage than those built above the hard rocks. Considering such seismic activity around the area with previous problems in the site motivated us to evaluate the site effect for the New Borg El-Arab City.

Evaluation of site effect is conducted in terms of fundamental frequency at Sixty-Nine field experiments using single station microtremor measurements that have been carried out. Then, these data are analyzed using horizontal-to-vertical-spectral ratio (*HVSR*) technique which is called Nakamura technique (Nakamura, 1989). At the end, a site response analysis is performed for checking the results of *HVSR* and highlights the effect of site.

2. Geological and tectonic settings

The surface layers of the study area are mainly covered by Quaternary deposits that consist of Arid Loamy soils (sand, silt and clay intercalations) with remnants of rocky ridges

(Figs. 2 and 3). Oolitic limestone of Middle Miocene is underlying the surface layer. Moghra Formation of Lower Miocene is underlying the oolitic limestone which is shaly sand, calcareous, gypsiferous and cherty (Bayoumi and Sayed, 1973). One of the parallel Alexandria limestone ridges intersects the study area (Basheer et al., 2014).

On the other hand, the study area is located close to offshore Nile Delta, which is affected by north–south to north–northwest, northwest and northeast to north–northeast orientated faults. These are referred to as the Baltim, Temsah and Rosetta trends, respectively (Abdel Aal et al., 1994). Also, the study area is located near to the Nile Delta cone which is considered as a large hinge zone that consists of several southward half-grabens (El-Sayed et al., 2004) as shown in Fig. 4.

3. Data measurements and processing

A survey of single-station to measure the ambient noise was carried out at sixty-nine sites in the new City of Borg El-Arab (Fig. 5) in order to assess the fundamental resonance frequency of the sediment layer and detect its lateral changes. Measurements were performed using the seismometer of model Trillium compact 120s and Data logger model Taurus, taken into consideration the recommended precautions from the previous studies (i.e. Duval, 1994; Mucciarelli et al., 1997; Mucciarelli, 1998; El-Shahat, 2003; El-Hussain et al., 2013). These precautions are mainly related to the sensor and the situ. The sensor should set down directly on the ground, whenever possible and avoid long external wiring, which may bring mechanical and electronic interferences. For the situ, we avoided measurements in windy or rainy days and kept away, as much as possible, from roads with heavy vehicles, construction machines, known industrial machines, and generators. The recording duration at each site was ranging from 40 to 60 min with a sampling rate of 100 samples per second.

The collected data have been processed using the *GEOPSY* software developed within the framework of the European project SESAME (http://www.geopsy.org). The *HVSR* was computed according to the following methodology: (1) correction for the base-line effect; (2) windows of length from 25 to 60 non-overlapping seconds were selected among the quietest part of the recorded signals using an anti-trigger algorithm. This is done by detecting transients based on a classical comparison between the short term average "STA", i.e., the average level of signal amplitude over a short period (typically around 0.5–2.0 s), and the long term average "LTA", i.e., the average level of signal amplitude over a much longer period (typically several tens of seconds). Then, tapered with a 5% cosine function before the computation of spectra, (3) an amplitude spectrum is computed using the Fast Fourier Transform (*FFT*) for the three components; (4) The *FFT* spectra were smoothed with the "Konno and Ohmachi, 1998" function; and (5) For each window the geometric mean for the two horizontal FFT spectra was divided by the vertical ones yielding number of *H*/*V's* curves for each site. These *H*/*V's* are then averaged and standard deviations at each frequency of interest are calculated. The fundamental frequency and the corresponding amplitude at each site could then be determined.

It often occurs in urban environments that *H*/*V* curves exhibit local narrow peaks. In most cases, such peaks usually have an industrial origin, related to some kind of machinery (turbine, generators, etc.). In order to detect this type of peak, the following kinds of tests are recommended (SESAME report, and El-Hussain et al., 2013):

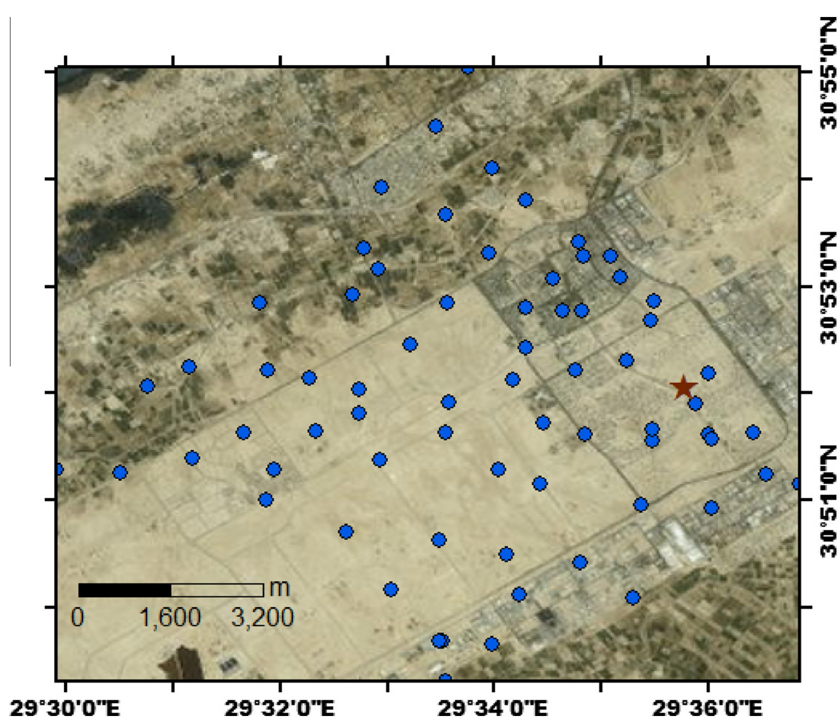

Figure 5 The surface distribution of the recorded sites (blue dots) with the location of borehole for site response analysis (star) in the city.

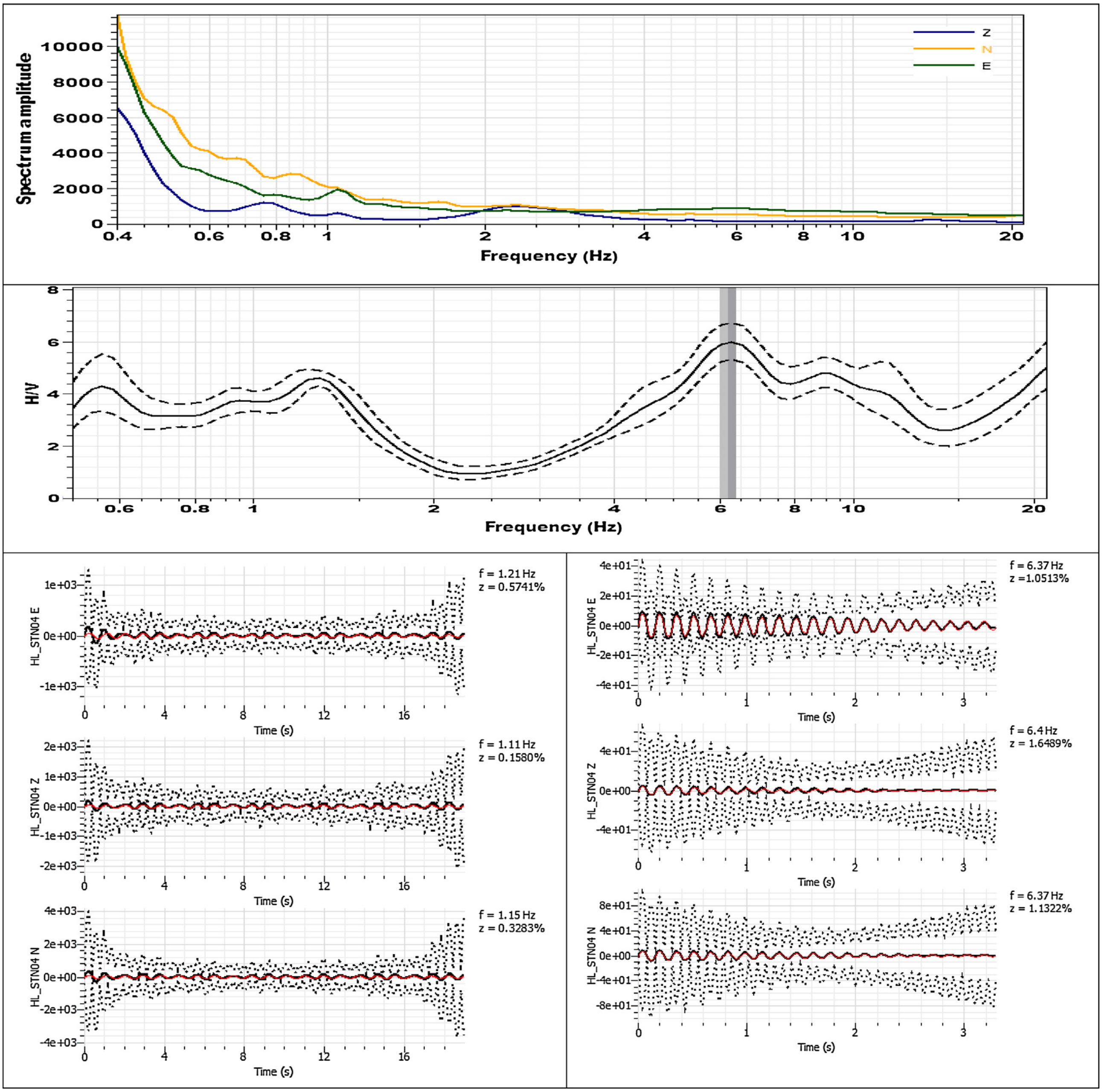

Figure 6 Panel 1 demonstrates the amplitude spectrum of three components at site-50, Panel 2 illustrates the H/V spectral ratio curve, Panel 3 shows the damping test for the peak amplitude at frequency 1.15 (Hz) (left side) is of industrial origin and at frequency 6.37 (Hz) (right side) which is of natural origin.

(a) FFT spectra exhibit sharp peaks at the same frequency for all three recorded components.
(b) Peaks get sharper with decreasing smoothing. In the case of industrial origin, the H/V peak should become sharper and sharper, while this is not the case for a natural peak linked with the soil characteristics.
(c) Damping test through random decrement technique (Dunand et al., 2002). In this technique if the corresponding damping (Z) is very low (below 1%), an industrial origin may be assumed, and this frequency should not be considered in the interpretation because they are not related to the site characteristics.

4. Results of microtremor measurements

After discarding peaks of an industrial origin, the frequency corresponding to the peak which has maximum amplitude is considered to be (f_0). The frequencies corresponding to the other peaks may be interpreted as subsoil locally characterized by occurrence of significant impedance contrasts or seismic interfaces at different depths. In the current study, the majority of the measured sites indicated the f_0 is varying from 5.8 Hz to 7 Hz (Fig. 6). Other values for f_0 were from 10 Hz to 12 Hz (Fig. 7), and a few sites indicated $f_0 > 15$ Hz (Fig. 8).

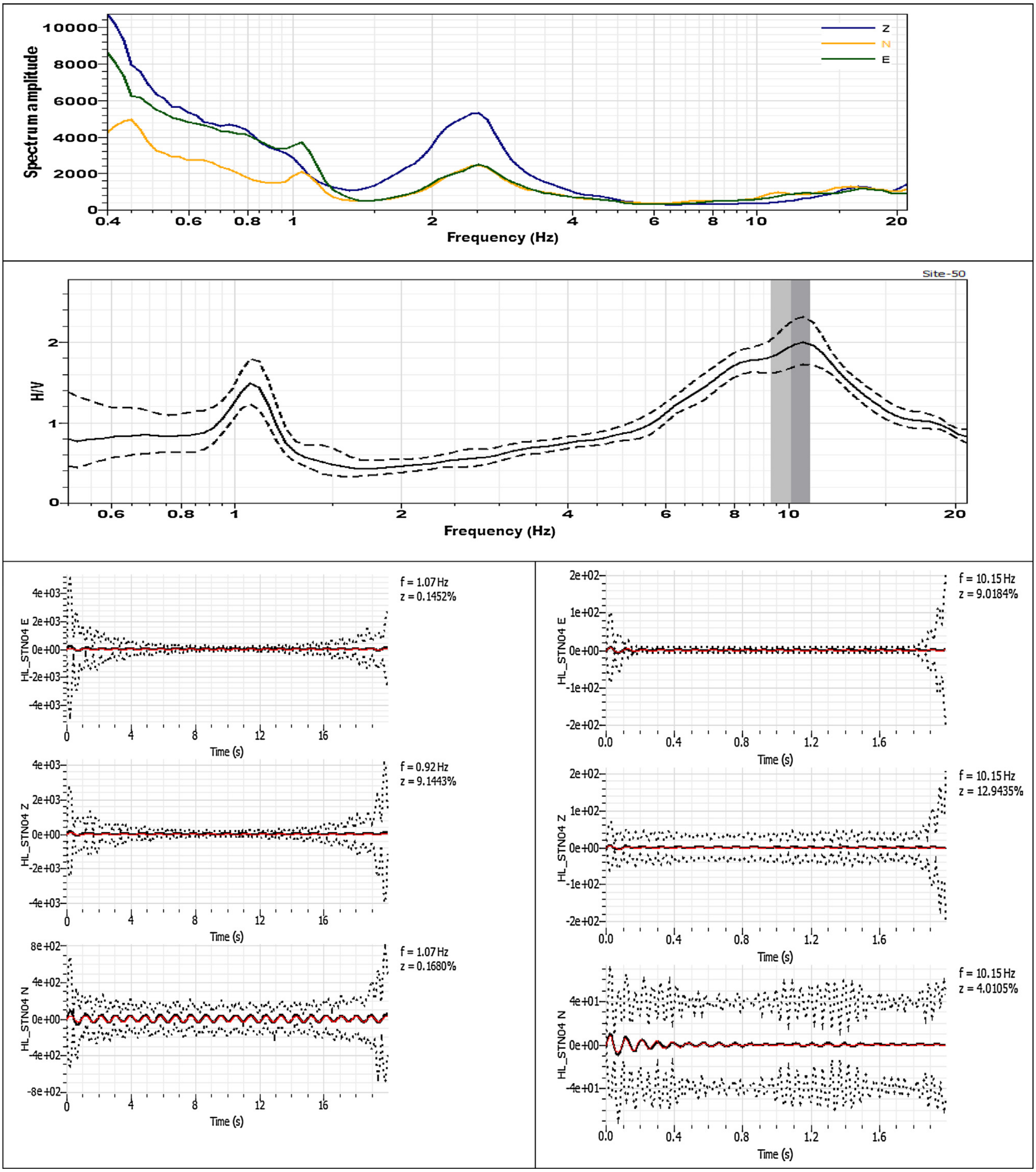

Figure 7 Panel 1 demonstrates the amplitude spectrum of three components at site-10, Panel 2 illustrates the H/V spectral ratio curve, Panel 3 shows the damping test for the peak amplitude at frequency 1.07 (Hz) (left side) is of industrial origin and at frequency 10.15 (right side) which is of natural origin.

By contouring the resulted fundamental frequencies (f_0) of all the measured sites, the zonation map for fundamental frequency was produced, as shown in Fig. 9. The dominant value for fundamental frequencies (f_0) is varying from 5.8 to 8 (Hz) and these values correspond to Quaternary deposit. However, the fundamental frequencies (f_0) increase in the middle of the study area due to presence of parallel Alexandria limestone ridge.

The effects of fundamental frequency in the zonation map could be interpreted taking into account both the height of a building and its fundamental frequency of vibration as it is expressed by the following formula by Shehata (2013):

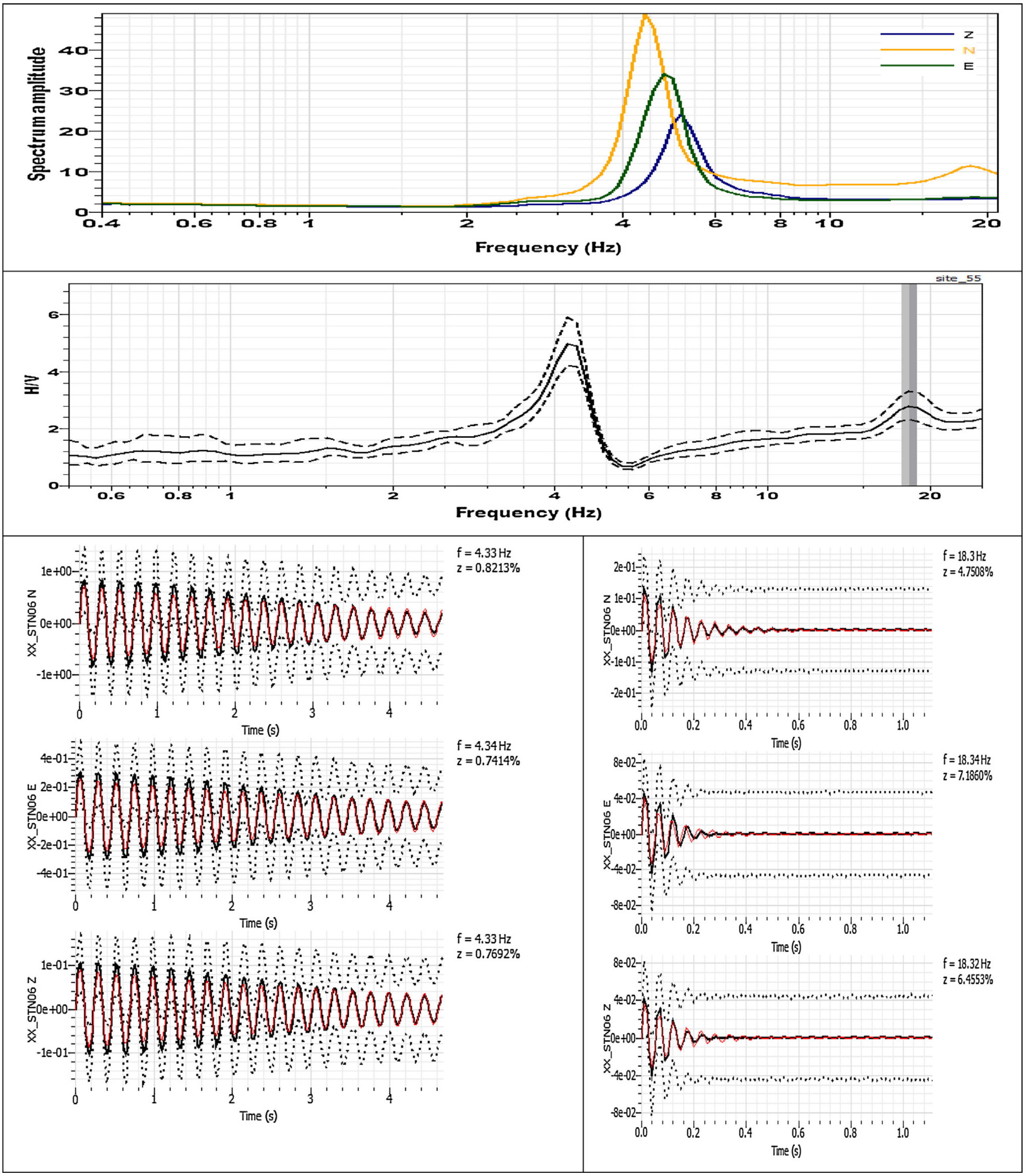

Figure 8 Panel 1 demonstrates the amplitude spectrum of three components at site-23, Panel 2 illustrates the H/V spectral ratio curve, Panel 3 shows the damping test for the peak amplitude at frequency 4.3 (Hz) (left side) is of industrial origin and at frequency 18.3 (right side) which is of natural origin.

$$F = 1/(C_t * H^{3/4}) \tag{1}$$

where C_t is a factor determined according to the structural system and building material, and H is the height of the building (m), from the foundation or from the top of a rigid basement. So, the buildings in the study area should be designed to have inconsistent resonance frequency with the fundamental frequency of the soil.

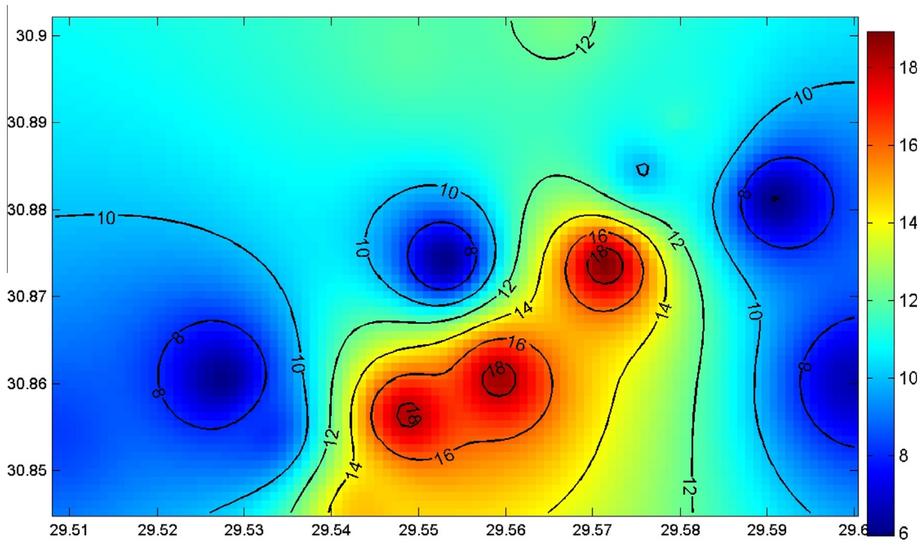

Figure 9 Zonation map of the fundamental frequencies (f_0 in Hz).

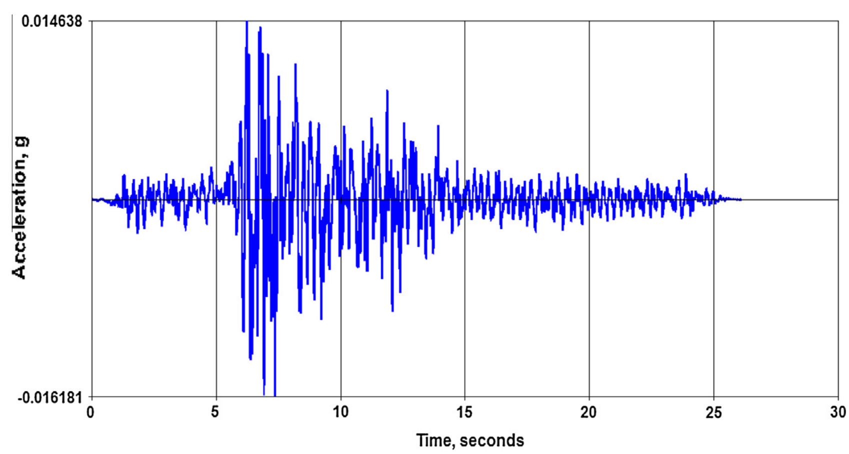

Figure 10 Acceleration time history at the bedrock.

5. Site response analyses

Site response analysis is preformed to highlight the effect of the local soil conditions on ground response during earthquakes and check the results of HVRS for one site (Fig. 5) as a representative example. *SHAKE91+* that is built in *EZ-FRISK* software is used for performing the site response analysis based on the interaction between the acceleration time histories and the soil profiles.

Acceleration time histories are generated using the spectral matching technique in time domain (for more details see Ezzelarab, 2015). The Pacific Earthquake Engineering Research Center (*PEER*) (http://ngawest2.berkeley.edu) database is searched according to the defined earthquakes scenario (distance and magnitude) that has the largest contribution to the seismic hazard from the de-aggregation of probabilistic seismic assessment (*PSHA*) results for 475 years return period by Ezzelarab (2015). This scenario was a result of near-field seismic sources at distances 30–56 (km) with 5.3 Mw. Then the compatible record is scaled using *RspMatch2009* spectral matching algorithm (Al Atik and Abrahamson, 2010) to produce the required input acceleration time history at the bedrock condition (Fig. 10). The PGA value at the bedrock is 0.01618 g.

Table 1 Characteristic of soil profile used in site response study.

Soil description	Thickness (m)	Shear wave velocity (m/s^2)
Brown sandy silt	3	230
Brown sandy clayey silt	3	280
Brown sandy silt	8	375
Limestone	Half-sphere	765

The soil profile for analyzing the site response is provided by Authority of New Borg El-Arab City with the corrected *N* values. Then, the shear wave velocity is obtained using the following formula of Bellana (2009):

$$\overline{V_s} = 126.395(N_{60})^{0.223} \tag{2}$$

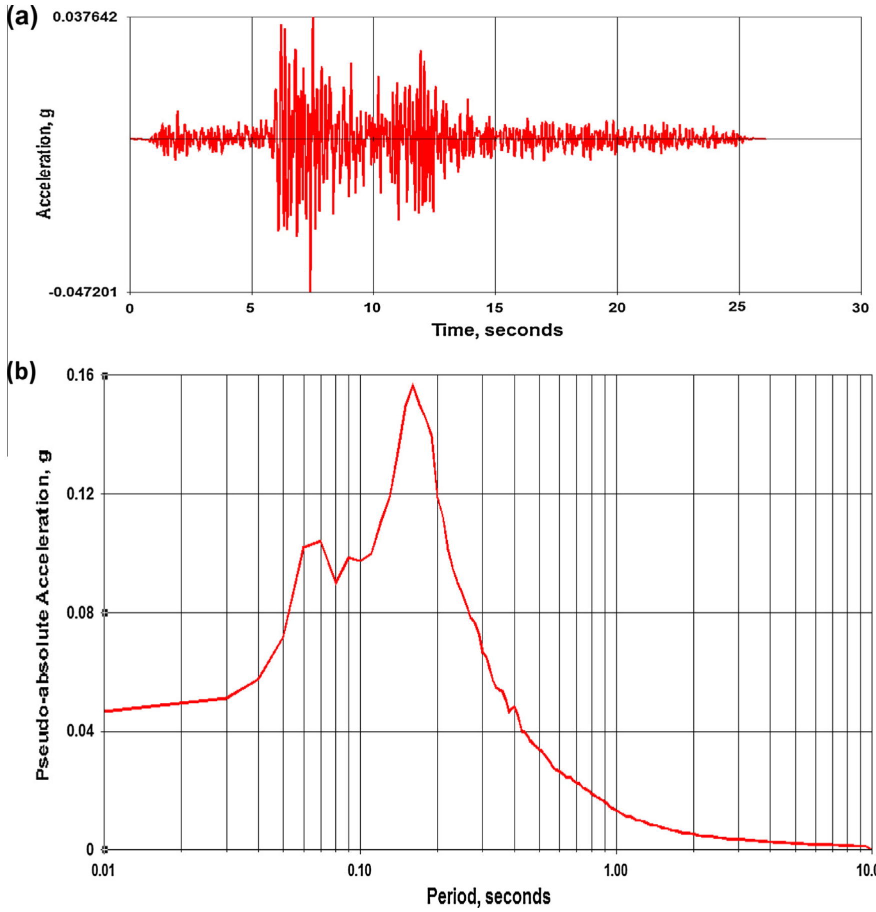

Figure 11 Acceleration time history (a) and response spectrum (b) at surface of the selected site in New Borg El-Arab.

where $\overline{V_s}$ is the average share wave velocity and N_{60} is the energy-corrected SPT blow count.

Table 1 lists the data of the soil profile used in this study. The dynamic properties at each layer in terms of the small-strain shear modulus ($Gmax$) along with the normalized modulus degradation ($G/Gmax$) and damping ratio increase (D) from small to large shear strains (γ) that expressed as modulus reduction ($G/Gmax - \log\gamma$) and Damping ($D - \log\gamma$) curves are adopted from Seed and Idriss (1970) and Schnabel et al. (1972) for sand and rock, respectively.

The acceleration time history at the surface is obtained as well as the response spectrum acceleration as shown in Fig. 11. The PGA at surface of the selected site in New Borg El-Arab City is amplified due to effect of soil profile to be equal to 0.047 g and the maximum spectral acceleration is 0.157 g corresponding to spectral period 0.167 s (about 6 Hz) which is compatible with the value of fundamental frequency from $HVSR$ analyses.

6. Conclusions

The site effect in New Borg El-Arab City is evaluated utilizing the horizontal to vertical spectral ratio ($HVSR$) technique and site response analysis. $HVSR$ indicated that the dominated value of fundamental (f_0) is varying from 5.8 to 7 (Hz). Other values for f_0 were from 10 Hz to 12 Hz. A few sites indicated $f_0 > 15$ (Hz). By Spatial interpolation of the resulted fundamental frequencies (f_0) of all the measured sites, the zonation map was produced. This map was correlated with geological features of the study area and indicated that the dominant value for fundamental frequencies (5.8–7 Hz) is corresponding to Quaternary deposit. However, the fundamental frequencies (f_0) increased in the middle of the study area due to presence of parallel Alexandria limestone ridge. The site response analysis technique indicated that the PGA at surface of the selected site in New Borg El-Arab City is 0.047 g and the maximum spectral acceleration is 0.157 g corresponding to spectral period 0.167 s (about 6 Hz) which is compatible with the value of fundamental frequency from $HVSR$ analyses.

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