Russian Geology and Geophysics © 2019, V.S. Sobolev IGM, Siberian Branch of the RAS
Vol. 60, No. 2, pp. 231–239, 2019 DOI:10.15372/RGG2019036 *Geologiya i Geofizika*

Estimation of the Site Effect Using Microtremor Technique at New Akhmim City, Akhmim, Sohag, Egypt

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Received 18 May 2017; accepted 26 July 2018

Abstract—Local site effect is a significant aspect of seismic hazards, which often causes amplification of ground motions and results in increase in the damage potential of an earthquake. This article displays an experimental study of microtremors data to investigate the dynamic characteristics of the soil and structures in the desert zone of Akhmim City, east of River Nile, Sohag governorate, Egypt. Because of progressive population growth in the Nile valley and delta regions, the Egyptian Governorate considered increasing the number of new communities, especially in the Sohag district, to improve the living conditions. The study area is one of the new urban areas which was suggested by Egyptian Urban Communities Authority (EUCA). For this purpose, the horizontal to vertical (H/V) spectral ratio was used to provide precious information about the soil properties and its engineering features for foundation purposes. The H/V spectral ratio analyses of ambient noise data at the measurement stations were processed and interpreted using Geopsy Software to calculate the amplification factor and fundamental resonance frequency at each observation point.

The results indicate that the resonance frequency ranges between 0.21 and 0.28 Hz at the most of the measurement stations, with some irregularities at stations No. 2 and 4 because of the higher softness of sediments in these locations. Most of lower fundamental frequencies are observed in the southern part of the study area, whereas higher values are observed in the northern part of the study area. The amplification factor ranges between 1.38 and 4.15. Higher values were recorded in the northeastern and southern parts, while lower ones were observed in the northwestern and southwestern parts of the mapped area. It can be concluded that the amplification component increases with increasing softness of the sediments. Interpretation of fundamental frequency distribution map is very significant to estimate the building heights and the number of stories, which was estimated to be 35 to 47.

Keywords: Site effect, microtremor, H/V, fundamental frequency, amplification, Akhmim City, Egypt

INTRODUCTION

Egypt is one of the countries, which are characterized by high population where 97% of its population is concentrated in the Nile valley and delta regions. The growing population and the need for improving the living conditions of the Egyptian community is the reason of construction of new urban areas, industrial zones, land reclamation and different types of developmental projects. In the Nile valley, the only available areas for carrying out such activities are the desert zones surrounding the floodplain on both sides of the Nile valley.

New Akhmim City is one of the new urban areas which was suggested by the Sohag governorate. Undoubtedly, one of the ways to provide valuable information about this area is evaluating and understanding the land suitability for the construction and development. Studying the geophysical characteristics of these zones is one of the most important activity for determining the engineering characteristics of this area.

Microtremor survey is considered the most common method for estimating the site effect, particularly in urban regions. The site effect is generally represented by the fundamental resonance frequency and its associated H/V amplitude ratio of ground motion. (Bard, 2000) reported that through the data processing, every site has a definite fundamental resonance frequency at which ground motion gets amplified. (Mukhopadhyay and Bormann, 2004) concluded that the man-made structures having a fundamental resonance frequency matching that of the site have the maximum likelihood of getting damage. So, in order to build seismically safe constructions, it is urgent to know the response of a specific site. The site response of ground motion may change in various regions according to the subsurface geological structures and soil conditions.

The horizontal to vertical (H/V) spectral ratio method on ambient vibrations (Nakamura, 1989) was used by many authors in urban environments to determine the fundamental frequency and the associated amplification of ground motion (Duval et al., 2002; El Shahat, 2003; Panou et al., 2005; Fergany and Bonnefoy-Claudet, 2009; Gosar, 2010; El-Hussain et al., 2013).

The fundamental objective of this current paper is determining the soil properties and its engineering characteristics for foundation purposes by using the local site effect analysis utilizing the horizontal to vertical (H/V) spectral ratio technique.

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STUDY AREA

The study area is located between Latitudes 26º28′55″and 26º30′20″ N and Longitudes 31º50′05″ and 31º51′35″ E, and covers a total area of about 5 km^2. It is located in the desert zone of Akhmim City east of Nile River below the eastern limestone plateau (Fig. 1). It is surrounded by the limestone plateau from the east and cultivated lands from the west. The limestone plateau is dissected by a number of wadis that drain towards the study area and Nile River.

GEOLOGIC SETTING

Geologically, the study area is a part of Sohag district which was studied by many authors (Mostafa, 1979; Abdel

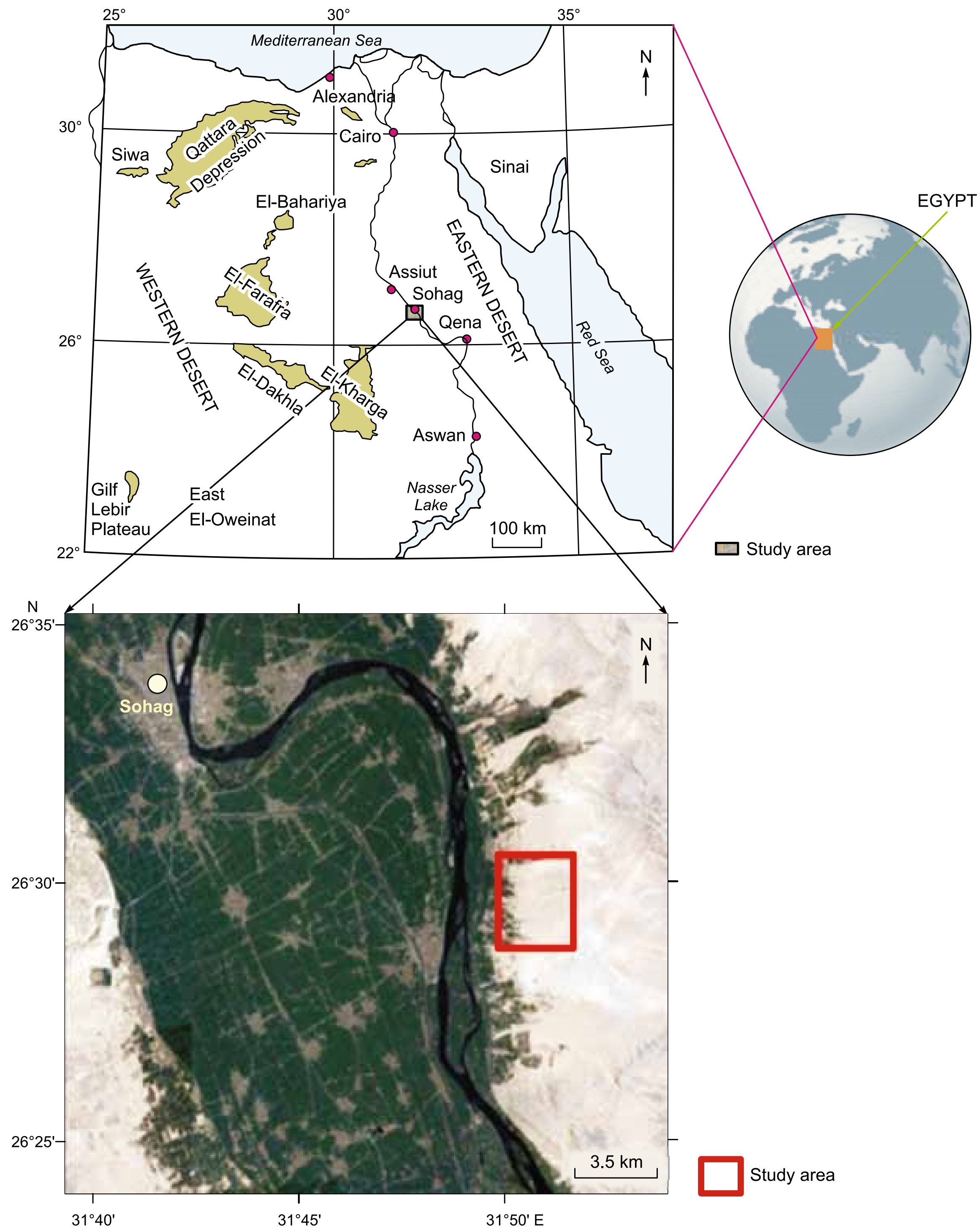


Fig. 1. Location of Egypt on the world map (up) and the study area (down).

Table 1. Description of the main rock units in Sohag area, modified after (Omer, 1996)

Age		Formation	Description
Neogene and Quaternary	Recent (Holocene)	Wadi deposits	Disintegrated product of the nearby Eocene carbonate, in addition to the reworked material from the pre-existing sediments (Ahmed, 1980).
		Alluvial deposits	Clays and silts with sandstone intercalations
	Pleistocene	Dandara	Fluviatile fine sand-silt intercalations and accumulated at low-energy environment (Omer and Issawi, 1998).
		Ghawanim	Nile sandy sediments exhibiting the first appearance of the heavy mineral (Omer, 1996).
		Kom Ombo	Sand and gravel sediments containing abundant coarse fragments of igneous and metamorphic parentage (Hansen, 1968).
		Qena	Quartzose sands and gravels lacking igneous and metamorphic fragments (Said, 1981).
	Pliocene / Pleistocene	Issawia Armant	Clastic facies at the lake margins and carbonate facies in the central zones (Said, 1971).
	Pliocene	Muneiha	Bedded brown and gray clays intercalated with thin beds and lenses of silt and fine sand, and fluviatile-dominated sediments made up of sand, silt and mud intercalations (Omer and Issawi, 1998).
Lower Eocene		Drunka	Medium to thick-bedded succession of limestone, which is a highly bioturbated in some horizons, with siliceous concretions of variable sizes (Mostafa, 1979).
		Thebes	Massive to laminated limestone with flint bands and marl rich with Nummulites and planktonic foraminifera (Said, 1960).

Moneim, 1988; Omer, 1996; Omer and Issawi, 1998). Generally, the sedimentary sequence exposed at the area consists of different rock types ranging in age from lower Eocene to Recent. Summarized descriptions of these main units are outlined in Table 1. A general geologic map of the study area is shown in Fig. 2.

Structurally, Sohag region represents a part of the stable shelf in the tectonic framework of Egypt (Said, 1962). Structural features in this area are branched into fractures, faults and folds. The fracture trends in the study area are NNW, NNE, ENE, E–W and WNW (Senosy, 1994). Whereas the majority of the fault trends are N20-40W and N10-40E which are known as the Gulf of Suez–Red Sea and the Aqaba fault trends. Whilst all folds are more or less parallel to associated faults and considered as drag folds (Youssef, 1968).

Geomorphologically, the area is bounded from the east by the limestone plateau dissected by many wadis running mainly in the E–W directions; below this plateau to the west, there are low land areas then the agricultural areas adjacent to the Nile (Issawi, 1993; Abdel Moneim, 1999).

NAKAMURA'S METHOD

The ratio between horizontal (H) and vertical (V) spectral technique was modified by (Nakamura, 1989). This technique estimates the ratio between the Fourier amplitude spectra of the horizontal (H) to vertical (V) components of the ambient noise vibrations recorded at one single station (3-component). Nakamura's method proposed the ratio between horizontal and vertical ambient noise records is related to the fundamental frequency of the soil beneath the site and hence to the amplification factor. This technique is based on the hypotheses that the microtremors consist of many waves, but basically of Rayleigh waves propagating in the soft surface layer overlying the solid bedrock. Four Fourier spectral amplitudes are produced from the horizontal and the vertical components of the motion at the surface and at the bottom of the layer (VS, HS, VB, and HB). The vertical component of the microtremor motion is not amplified by the soft layer. The microtremors are produced by local surface sources (traffic and industrial noise) without any role from deep sources. The amplification of the vertical component is exclusively related to the depth of Rayleigh wave's motion and ambient noise is generated by reflection and refraction of shear waves within superficial soil layers and by surface waves.

FIELD MEASUREMENTS

An extensive survey of single-station ambient vibration recordings was carried out at 16 selected sites at the study area (Fig. 3) using a Trillium Compact 120 Seismometer and a Taurus logger in order to find the fundamental resonance frequency of the sedimentary layer. This study takes into account some precautions according to (Nakamura, 1997, 2009; Bard, 2000; El Shahat, 2003; SESAME, 2004; Gosar, 2010; El-Hussain et al., 2013) as follows: the sensor was set down directly on the ground and avoiding long external wiring, which may bring mechanical and electronic interferences; measurements in windy or rainy days should be avoided; in addition to the above, the measurements was carried out in desert area, hence it is better to avoid any influence the results such as measure in sites near underground structures, pipes, trees, structure, car parks and close to roads with heavy vehicles.

The Taurus portable Seismograph and Trillium Compact 120s Seismometer were used for data gaining and recording. This seismograph is a compact and modern field porta-

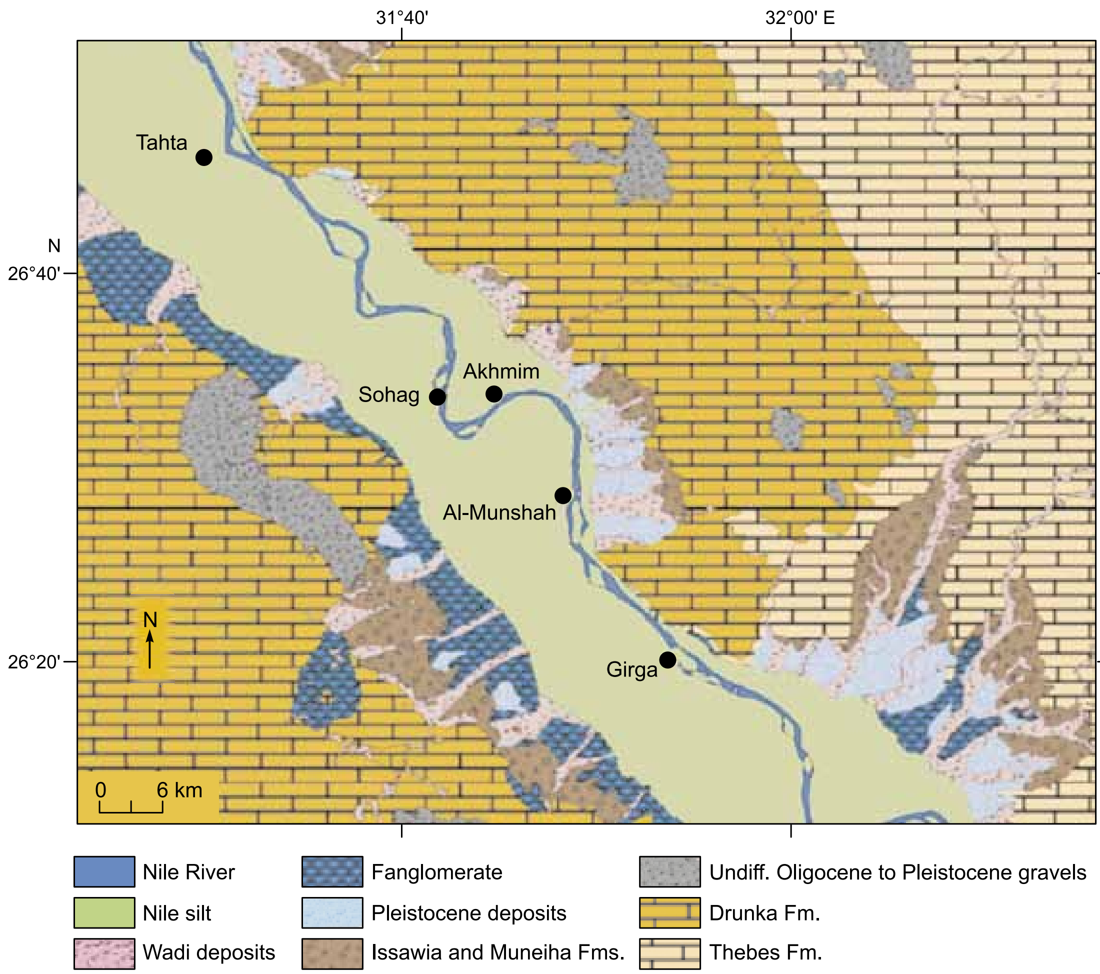


Fig. 2. Geological map of Sohag region including the study area compiled from the Egyptian Geological Survey and Mining Authority (EGSMA, 1989) and Conoco Coral Company (Coral, 1987).

ble, self-contained digitizer and data logger (Fig. 4). The Taurus combines a three-channel 24-bit digitizer, GPS receiver and system clock, removable data storage and remote communication options. The feature of this device is that operates over a wide temperature range without manual recentering, broadband performance from 120 second to 100 Hz with improved noise floor at high frequency, ultra-low power consumption of just 160 mW for low operating costs and higher station reliability.

DATA PROCESSING

Analysis of the (H/V) spectral ratio data was performed using Geopsy software (Geopsy, 2011). The microtremor records are corrected for the base-line effect for each site to guarantee the stationary assumption validity. Different numbers of windows with 25 to 60 seconds nonoverlapping seconds were chosen between the quietest parts of the recorded signals. This step aims to keep the most stationary parts of ambient vibrations and to avoid the transients often related

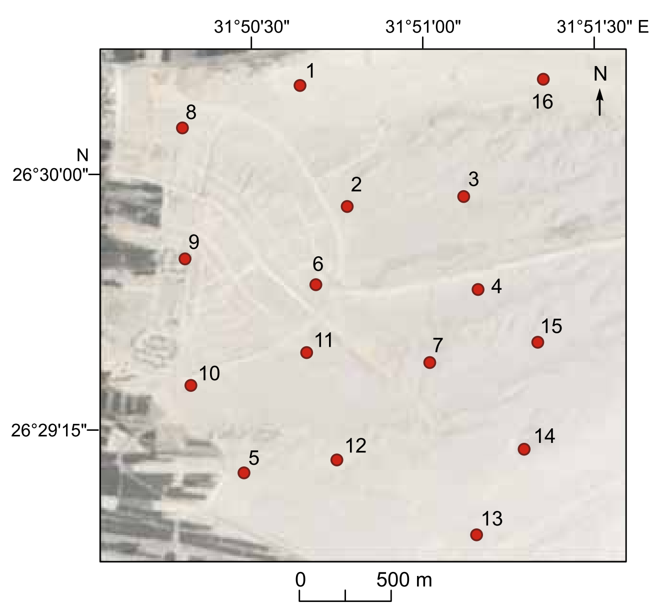


Fig. 3. Locations of microtremors measurements at the study area.

to specific sources like close traffic and footsteps (Duvall et al., 2004). Automatic window selection module of the Geopsy software was chosen for each time window.

The following significant proceedings were utilized on the microtremor data by using H/V processing module of Geopsy software as offset correction, tapering time series with a 10% cosine taper for avoiding leakage and computing an amplitude spectrum of the Fast Fourier Transform (FFT) for all the three components (Konno and Ohmachi, 1998).

In this study the bandwidth coefficient value 40 was used. At every point of measurements sites, the H/V spectral ratio and standard deviations were calculated. The resonance frequency and the corresponding amplitude level at each location could then be determined. Finally, every peak was checked to determine their origin (natural or industrial).

According to SESAME (Site EffectS assessment using AMbient Excitations), accurate checking was made on H/V curves before taking out the vital information to ensure the reliability of the H/V peaks (SESAME, 2004). It is vital to test the H/V curves especially in the cities because of these curves usually display as local narrow peaks or troughs. But in most places associated with the presence of some types of machinery and generators, these narrow peaks or troughs have usually an industrial origin.

Fig. 4. Taurus seismograph with Trillium 120s seismometer for microtremors recording are in use.

In this study, in order to detect this type of peak, the following types of tests are suggested (El-Hussain et al., 2013; SESAME, 2004): (1) they may exist over a significant area,

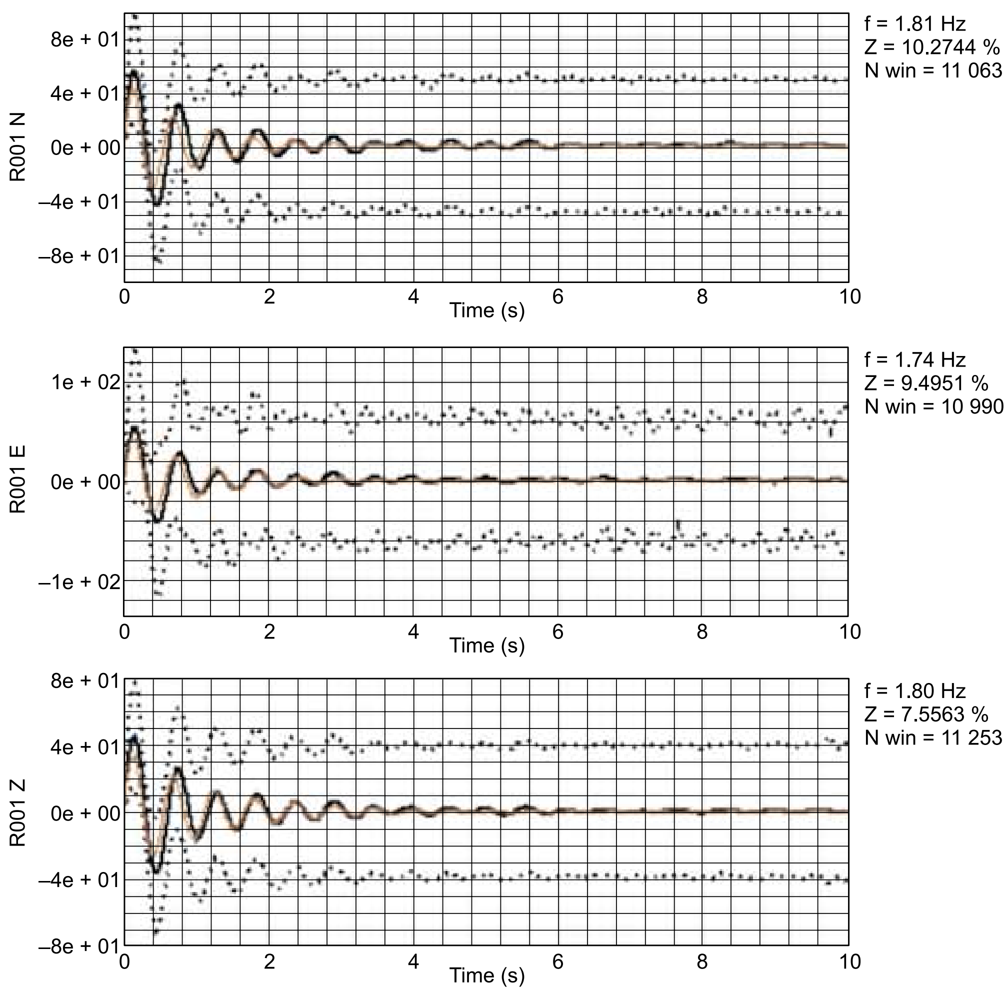
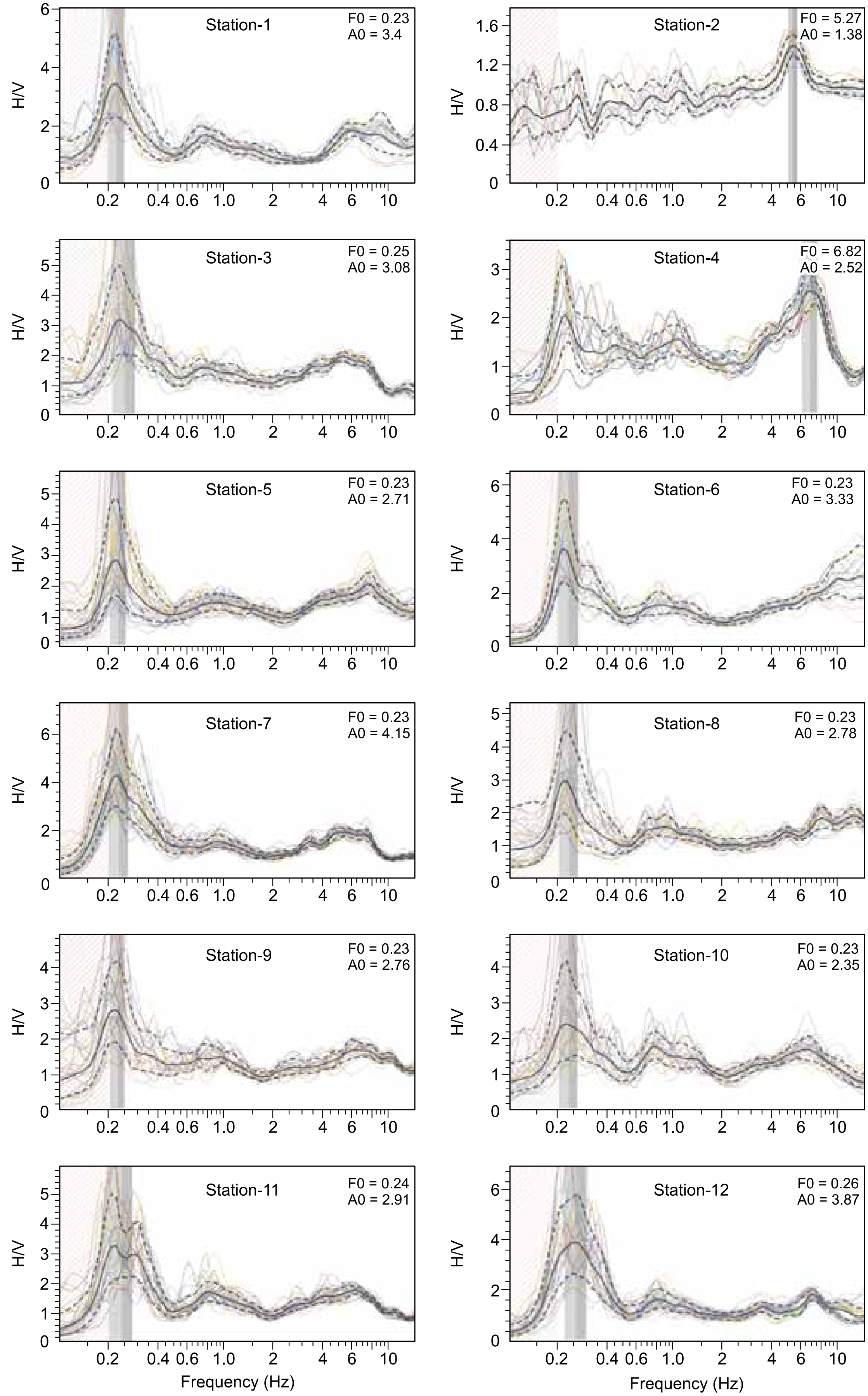


Fig. 5. An example of the damping test for the H/V spectral ratio peak for station No. 5 at the study area, which is of natural origin.


Station-1
F0 = 0.23
A0 = 3.4
Station-2
F0 = 5.27
A0 = 1.38
Station-3
F0 = 0.25
A0 = 3.08
Station-4
F0 = 6.82
A0 = 2.52
Station-5
F0 = 0.23
A0 = 2.71
Station-6
F0 = 0.23
A0 = 3.33
Station-7
F0 = 0.23
A0 = 4.15
Station-8
F0 = 0.23
A0 = 2.78
Station-9
F0 = 0.23
A0 = 2.76
Station-10
F0 = 0.23
A0 = 2.35
Station-11
F0 = 0.24
A0 = 2.91
Station-12
F0 = 0.26
A0 = 3.87
H/V
0.2 0.4 0.6 1.0 2 4 6 10
Frequency (Hz)

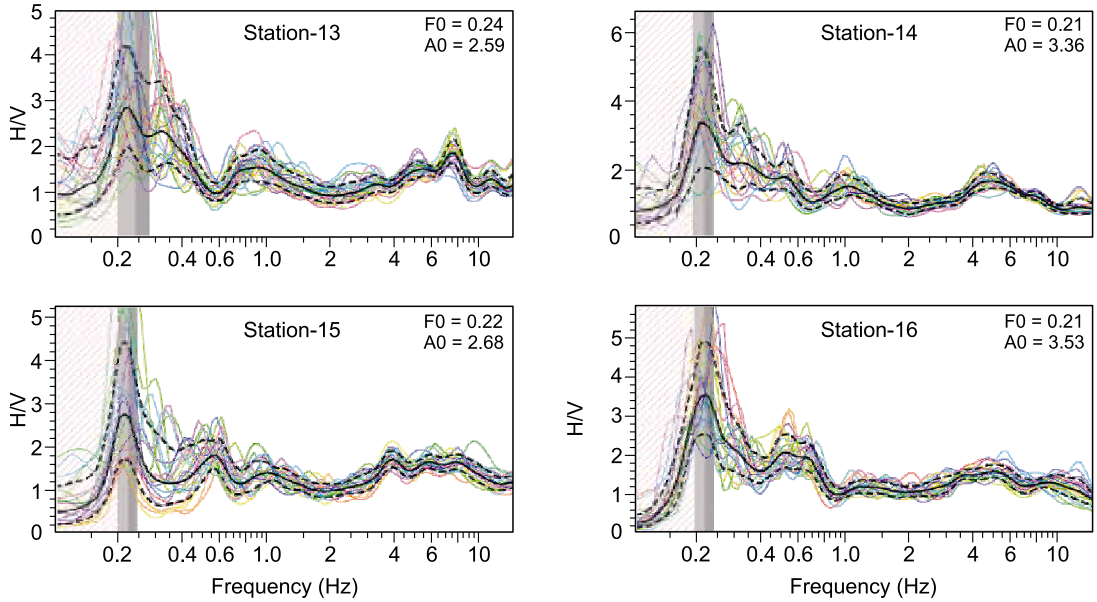


Fig. 6. The H/V spectral ratio curves versus frequency observed at the study area. The black line represents the mean spectral ratio curve, the upper and lower dashed lines are +/– standard deviation of spectral ratios.

the source is more or less "permanent" (at least within working hours), reprocessing with less and less smoothing; (2) in the case of industrial origin, the H/V peak should become sharper and sharper (while this is not the case for a site effect peak linked with the soil characteristics) and another very effective check is to apply the damping test through random decrement technique (Duval et al., 2002) to the ambient vibration recordings in order to derive the "impulse response" around the frequency of interest; (3) if the corresponding damping (z) is very low (less than 1%) (Fig. 5), an anthropic origin may be assumed almost certainly, and the frequency should not be considered in the interpretation.

RESULTS AND DISCUSSIONS

Technique of ambient vibrations H/V spectral ratio is based on the existence of a soil layer of low rigidity overlying another more rigid one. In this case, the H/V spectral ratio usually shows a peak, which matches the fundamental frequency (F_0) of the site and the corresponding peak amplitude (A_0). The reliability of the H/V ratio peaks was tested to assure that no industrial origin of one of the peaks, based on the criteria for reliability of results discussed in the SESAME guidelines. Results of the horizontal to vertical (H/V) ratio curves versus frequencies for the 16 investigated sites were displayed (Fig. 6).

The values of fundamental frequency and the corresponding amplification obtained from H/V curves at these sites which distributed along the study area are shown in Figs. 7 and 8. These maps were modified using Geosoft Oasis Montaj software to exhibit a 3D illustration of the results. In the current study, the majority of the measured sites indicated that, the fundamental resonance frequency (F_0) is varying from 0.21 to 0.28 Hz (Fig. 7). These low values of (F_0) are attributed to the considerable thickness of the soft sediment section (gravel and sands) overlying the bedrock of shale. Two sites (stations Nos. 2 and 4) indicated high fundamental frequencies (F_0). Such high fundamental frequencies may be due to more superficial strata properties (e.g., man-made deposits). Depending on the engineering boreholes data, which are provided by the Faculty of Engineering, Sohag University at the study area, increasing or decreasing of the fundamental frequency value is related to depth of the bedrock. Figure 8 shows the H/V amplitude values (A_0) of the measured sites in the study area ranging between 1.38 and 4.15. The differences in these values of amplification and funda-

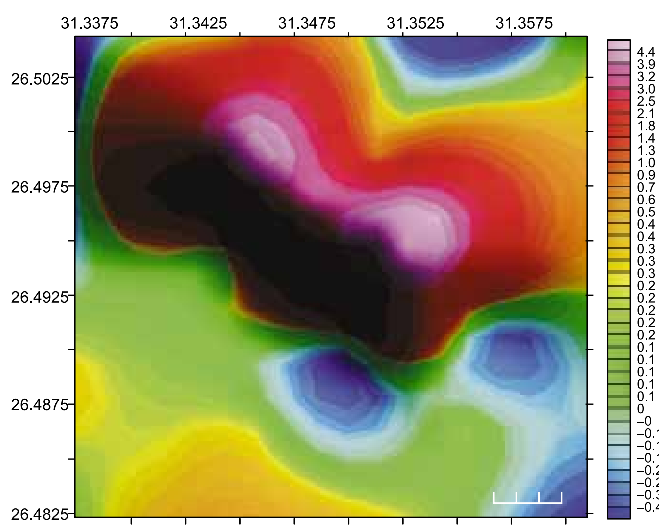


Fig. 7. 3D distribution map of fundamental frequencies (F_0) of the study area.

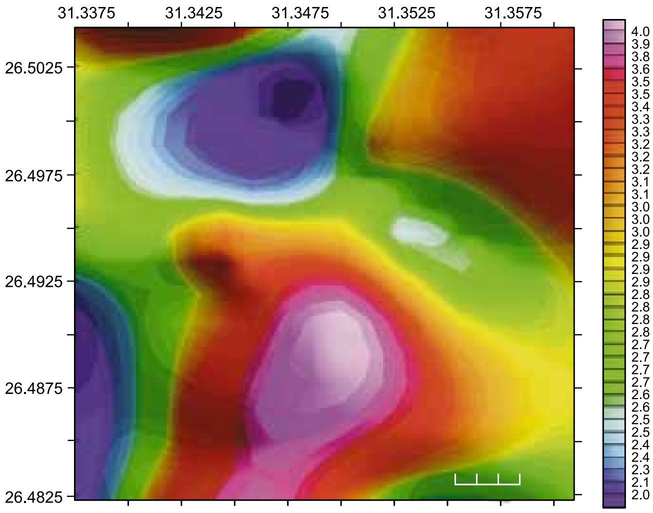


Fig. 8. 3D distribution map of H/V amplitude levels (A_0) of the study area.

mental frequencies at the current area indicate that there is heterogeneity in the local site conditions.

The 3D distribution maps were produced from the resulted fundamental frequencies (F_0) and the corresponding amplitudes (A_0) of all the measured sites. Fundamental frequency map shows that most of the lower values are observed in the southern part of the study area, while the higher ones are located in the northern part (Fig. 7). The amplification distribution map shows that the higher values were concentrated at the northeastern and southern parts while the lower ones were focused at the northwestern and southwestern parts of the mapped area (Fig. 8). These H/V peaks are interpreted based on the effect of the impedance contrast between the overlain sediments and the bedrock of the investigated area. From the microtremor survey it can be said that the amplification component increases with increasing softness of sediments.

On the other hand the fundamental frequency distribution map can be used to calculate the numbers of stories based on (Gosar, 2009) taking into account the height of a building and its fundamental frequency of vibration which can be expressed precisely by the following equation

$$F = 10 / (\text{Number of stories}),$$

where F is the fundamental frequency.

According to the above equation, two anomalous sites of high frequencies were excluded while the low fundamental resonance frequency sites (0.2 to 0.3 Hz) are suitable for constructions and were used for calculation the permissive number of stories. The range number of stories for the low frequency sites was 35 to 47.

CONCLUSIONS

Local site effects were studied in terms of the fundamental resonance frequency (F_0) and the corresponding amplification (A_0) to produce useful maps for planning the study area. The analysis of the horizontal to vertical (H/V) spectral ratio at the measured sites distributed within the current area was carried out to produce distribution maps of (F_0) and (A_0). The analysis was performed using Geopsy software following strict procedures of the guidelines in SESAME project. Various types of the H/V curves were obtained and analyzed.

3D illustration maps for distributions of the resonance frequency (F_0) and the H/V amplitude (A_0) were performed and interpreted. These maps showed that the fundamental frequency in the study area ranges between 0.21 and 0.28 Hz with some anomalies in the stations No. 2 and 4, because of the increased softness of sediments in these locations. The fundamental frequency map shows that most of the lower values are observed in the southern part of the study area, while the higher ones are located in the northern part. The amplification distribution map shows that the higher values were concentrated at the northeastern and southern parts while the lower ones were focused at the northwestern and southwestern parts of the mapped area. From the microtremor survey it can be said that the amplification component increases with increasing softness of sediments. The fundamental frequency distribution map was used to calculate numbers of stories taking into account the height of the building. Two anomalous locations of high frequencies were neglected while the low fundamental resonance frequency locations (0.2 to 0.3 Hz) are used for calculation the permissive number of stories. The range number of stories for the low frequency sites was 35 to 47.

The authors wish to express sincere appreciation to Dr. Mamdouh Kenawy, associated professor of soils, civil engineering department, Faculty of Engineering, Sohag University, Egypt for providing the information about the borehole data and its interpretation.

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Editorial responsibility: V.S. Seleznev