HVSR TECHNIQUE FOR BURRIED MONUMENTS DELINEATION AT SAQQARA (ZOSER) PYRAMID

Amin E. Khalil

Geology Department, Faculty of Science, Helwan University, Helwan, Egypt
Amin_Khalil@Science.Helwan.Edu.Eg

Abstract: Saqqara pyramid lies to the south west of Cairo near the epicenter of Cairo earthquake that took place on 12th October 1992. The Pyramid is severely damaged by the earthquake with epicenter at about 14 km away. As a result numerous efforts are exerted to restore the pyramid and to prevent it from total collapse. The current work is motivated by such efforts with focus on the potential of using the spectral ratio method (HVSR) to define subsurface monuments. HVSR method is based on the spectral analyses of recorded ambient method. The ambient noise in front of the southern side of the pyramid is recorded at 15 sites. The sites selected are 9 m apart with a time window of 5 minutes on average. Array shape and dimensions is chosen based on the prior information about the location and extension of the tunnel underneath. The tunnel extended about 20 m underneath the area adjacent to the southern gate of the pyramid. The estimated fundamental frequencies and peak amplitudes are contoured showing some low value trends at the area adjacent to the southern gate. This may lead to the possibilities of the HVSR method to explore the subsurface monuments. However, this statement is still in the early stage and further theoretical investigation is required.
[Amin E. Khalil. **HVSR TECHNIQUE FOR BURRIED MONUMENTS DELINEATION AT SAQQARA (ZOSER) PYRAMID.** *J Am Sci* 2012; 8(8):8-15]. (ISSN: 1545-1003). http://www.jofamericanscience.org. 2

Key words: HVSR; Zoser pyramid; microtremors; archaeology.

1. Introduction

The monumental site at the Saqqara pyramid is currently experiencing active restoration processes after the damaging Cairo earthquake in October 1992. As a result of these activities, tunnels were discovered after the removal of debris. In addition, new entrance at the eastern side of the pyramid was also revealed. At this point the present work is focusing on the potential of using H/V spectral ratio (HVSR) method to explore the presence of other burried structures. The strategy is to relate the distribution of fundamental frequency F_o and peak amplitudes A_o with the position of existing tunnel in qualitative manner. This approach may help in exploring burried monumental treasuries using the non-invasive HVSR method.

HVSR method was first introduced by Nogoshi and Igarashi (1971). However, there were little interests in the technique until the work of Nakamura (1989). At first Nakamura's work was criticized as the physical basis of the technique was not clear. Thus, Nakamura (1996) published a revised illustration of the technique introducing a physical of the technique. Meanwhile, Lermo and Chávez-García (**1994**) obtained also reliable estimates of the soil frequency from the spectral ratio between horizontal and vertical motions of microtremors. Since then the method is receiving high interests in seismological society to define the local site response.

The HVSR received such interest because of its ease in data acquisition and interpretation. Many applications are currently using such technique including seismic microzonation. The method can be used also to model the 1-D shear velocity model at a site which is directly related with the objective of the present research work.

Location and Data Acquisition

The area of study lies to the south of the well known pyramids plateau of Giza. The pyramid itself is called locally Saqqara pyramid after a small village nearby. Zoser pyramid belongs to the third dynasty. It is worth to mention also that the area contains numerous temples and monuments. Geographically, the area is located to the south of Cairo at a distance of about 20 km (Fig. 1).

The ambient noise is measured at 15 points in front of the southern side of the pyramid (Fig. 2). The reason for this choice is two folds. First, most restoration processes are currently taking place through the southern entrance of the pyramid. After the removal of debris, a tunnel at a depth of about 30 m was discovered. The tunnel extends outside the pyramid to the south. The second reason is that the earthquake activities nearby occurs entirely to the south of the pyramid. Thus the results obtained from this work may be used in future simulation of strong ground motion there.

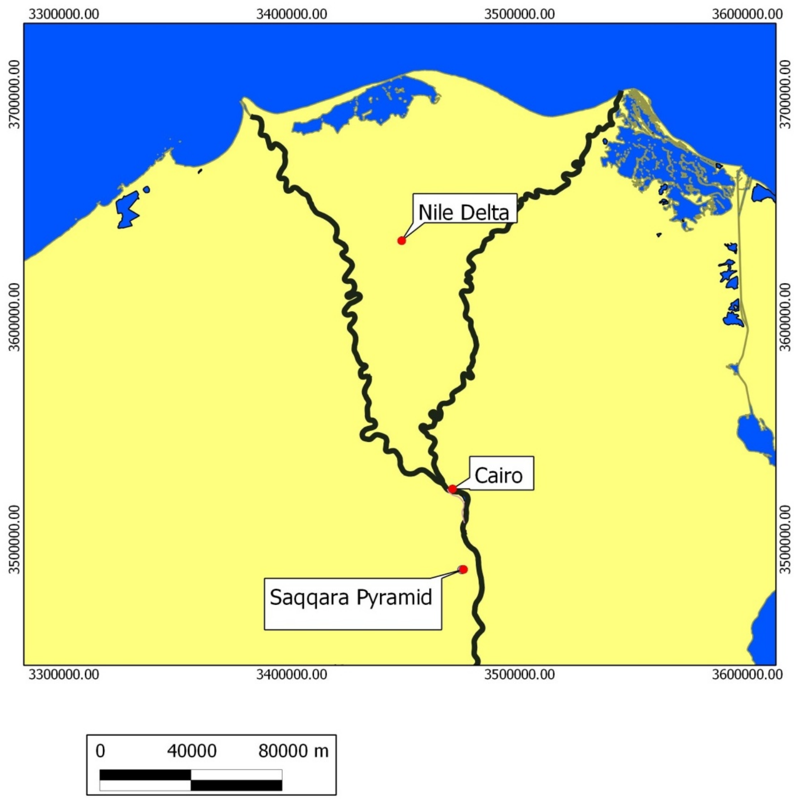

Fig (1). Location map of Saqqara Pyramid.

The recordings were obtained using k2-Altus accelerograph. Time window for recording at each station is chosen as 5 minutes on average. The reason for the time window length is the situation in the site where longer time of measurements is not permitted. Sampling rate at all 15 points is set to 100 sps.

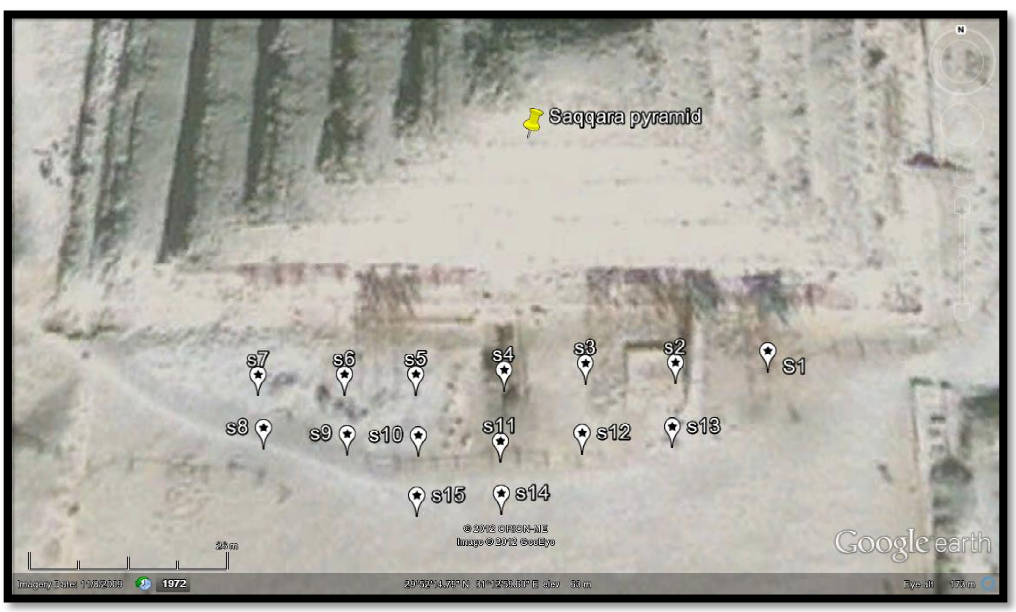

Fig (2). The locations of the sites at which the ambient noise is recorded.

Geologic setting

Giza is located only a few kilometers to the west of Cairo, several hundred meters from the last houses in the southernmost part of the city proper, where a limestone cliff rises abruptly from the other side of a sandy desert plateau.

The Pyramids Plateau is formed by massive limestone and dolomites (nummulitic wacke—packestones) of the Middle Eocene Mokattam Formation, which dips with about 5—10° to the SE (Aigner, 1983). Steep escarpments border the plateau to the north and to the east (Fig. 3). Southwards, the Mokattam Formation is overlain by less-resistant sandy marls and marly, weakly cemented limestones (argillaceous mud—wackestones) of the Upper Eocene Maadi Formation (Aigner *op. cit*.). The top unit of the Maadi Formation comprises several meters of massive, partly dolomitized limestone (pack—grain stones) of the so-called "Ain Musa Bed". The Maadi Formation shows a gentler escarpment toward the Mokattam Formation in the north and to the Nile valley alluvium in the east. The present escarpments represent a Pliocene shoreline and document the transgression of the early Pliocene Sea from the Mediterranean up the pre-Nile valley after the largely continental Oligocene and Miocene times. A thin wedge of Pliocene Sediments rests discordantly on the Maadi Formation, but only a veneer remains distinct against the Mokattam escarpment.

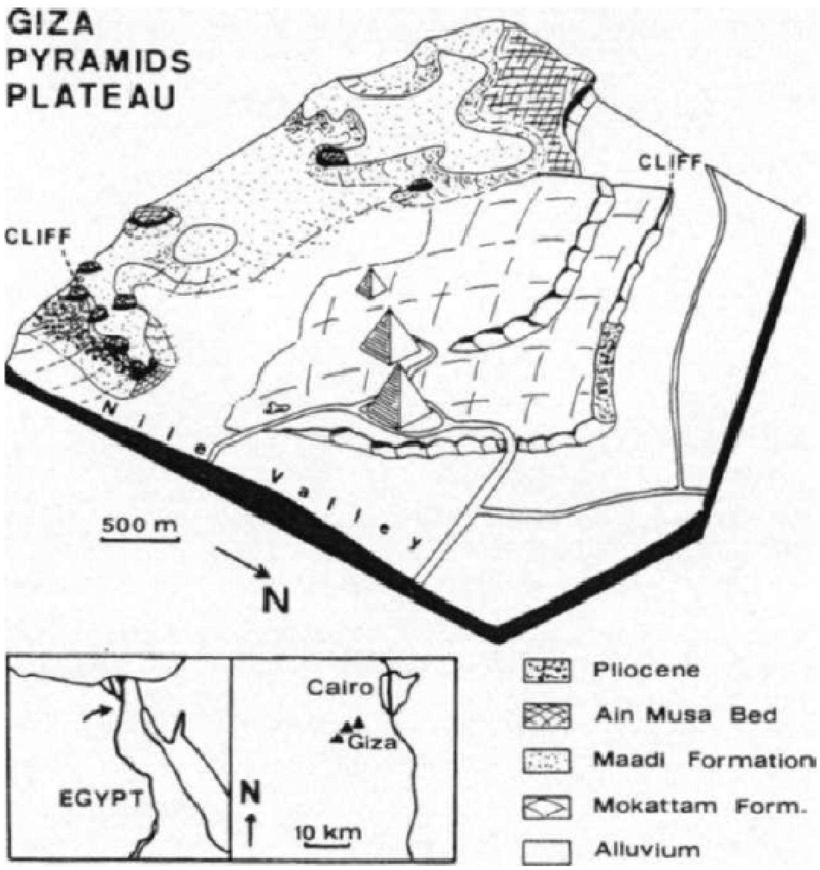

Fig (3). Sketch overview of geologic surface feature at the Giza pyramid plateau (After Aigner 1983)

El-Qady *et al.* (1999) stated that the shallow geologic section of Saqqara area composed of Quaternary deposits which comprises of river terraces of sands and gravel with a thickness varying between 30 to 180 m. These were underlined by gravel units (10 m) of Pleistocene, which underlined by Pliocene formations. Pliocene rocks are varying in composition from limestone to marl and sandstone with total thickness about 23 m. This unit overlaps the Eocene formations with angular unconformity. Eocene rocks are represented by a sandy to marly yellow limestone. These rocks unconformably lie over the Cretaceous limestone rocks. The shallow geologic setting of underneath Zoser Pyramid is shown in Fig. 4.

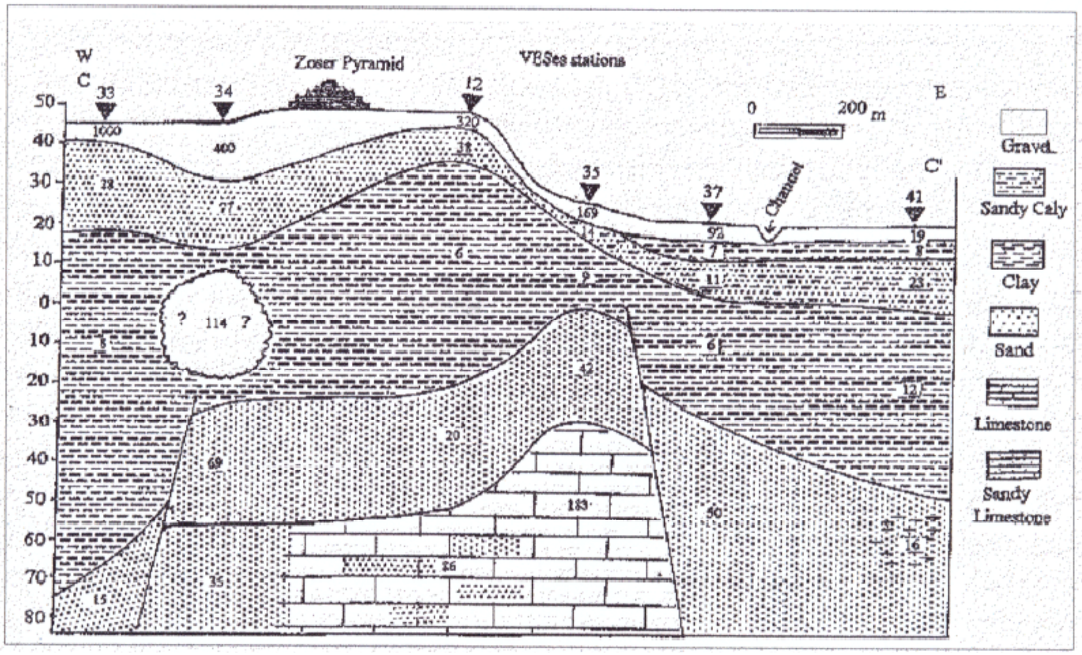

Fig (4). Geologic profile underneath zoser pyramid (After El-Qady *et. al.* 1999)

Description of Zoser Pyramid

The pyramid tomb of king Zoser (ca. 2667-2648 BC) of the 3rd Dynasty at Saqqara, the first ever to be built, is justly named the Step Pyramid. Located within a large enclosed mortuary complex and originally conceived as a huge mastaba, the tomb was gradually enlarged until it encompassed the six-stepped structure still visible today, rising up to a height of 60 m. Purportedly conceived by the architect Imhotep, the entire complex measures 277 x 544 m and is surrounded by a high wall featuring one real and fourteen false doors. Apart from the pyramid itself, the complex comprises among others several open courtyards, some used in connection with the Sed Festival, a secondary mastaba tomb called the 'Southern tomb', two buildings which have been interpreted as representations of the shrines of Upper Egypt and Lower Egypt, a serdab (hidden tunnel) with a statue of the king, and several other buildings. Built entirely in stone, the pyramid complex sought to imitate earlier structures made of perishable materials. Both the Step Pyramid and the Southern tomb contain subterranean apartments, used for the burial of the king and eleven members of his family, which are partly decorated with blue faience tiles and with depictions of the king performing rituals during his royal jubilee (from the internet at site http://www.saqqara.nl).

H/V Spectral ratio method (HVSR)

The HVSR method (Nogoshi and Igarashi, 1971; Nakamura, 1989, 1997, 2000, 2008, 2009, Lundei and Albarelo, 2010) is chosen as a result of the nature of the site where no active source is permitted. The method generally estimates the fundamental frequency F_0 and amplification of soil sediments through evaluating horizontal to vertical components spectral ratio (i.e. dividing the spectrum of the horizontal component by the spectrum of the vertical component). Nakamura (1989, 1996) demonstrated using theoretical modeling and using the results of Bonnefoy-Claudet *et al.* (2006) that energy near F_0 is mainly belonging to the multiple reflections of Body waves. He also pointed out that the amplitude of the Rayleigh waves H/V curve is almost zero near F_0 and that its peak occurs at $2F_0$.

According to Nakamura hypothesis the method is capable of revealing both the fundamental frequency and the amplification ratio (amplitude of H/V spectra). However, there is general agreement the method gives reliable estimates of F_0 only. Pilz *et al.* (**2009**) pointed out that there are high uncertainties in measuring the amplification ratio using HVSR method.

Continuous efforts on the analysis of ambient noise using HVSR technique extended the use of the method beyond the estimation of F_0 and amplification ratio. The work of Fäh *et al.* (2001) proposed that the HVSR curve can be represented using the ellipticity of Rayleigh waves. Thus the method usage is extended to include the determination of 1-D shear velocity model.

As a result of this high interest in the method the Sesame project (**2004**) was carried out to standardize the H/V spectral ratio method. The extensive work carried out through this project produced parameters that govern the reliability of the estimated resonance frequency. Such standards are shown in table (1).

Table (1). Criteria for reliable HVSR curve and clear HVSR peak defined by SESAME project (2004)

Criteria for a reliable H/V curve **i) $f_0 > 10 / l_w$ *and*** **ii) $n_c(f_0) > 200$ *and*** **iii) $\sigma_A(f)<2$ for $0.5f_0<f<2f_0$ if $f0>0.5$Hz** **or $\sigma_A(f)<3$ for $0.5f_0<f<2f_0$ if $f0<0.5$Hz**	• l_w = window length • n_w = number of windows selected for the average H/V curve • $n_c = l_w \cdot n_w \cdot f_0$ = number of significant cycles • f = current frequency • f_{sensor} = sensor cut-off frequency • f_0 = H/V peak frequency • σ_f = standard deviation of H/V peak frequency ($f_0 \pm \sigma_f$) • $\varepsilon(f_0)$ = threshold value for the stability condition $\sigma_f < \varepsilon(f_0)$ • A_0 = H/V peak amplitude at frequency f_0 • $A_{H/V}(f)$ = H/V curve amplitude at frequency f • f^- = frequency between $f_0/4$ and f_0 for which $A_{H/V}(f^-) < A_0/2$ • f^+ = frequency between f_0 and $4f_0$ for which $A_{H/V}(f^+) < A_0/2$ • $\sigma_A(f)$ = "standard deviation" of $A_{H/V}(f)$, $\sigma_A(f)$ is the factor bywhich the mean $A_{H/V}(f)$ curve should be multiplied or divided • $\sigma_{logH/V}(f)$ = standard deviation of the $logA_{H/V}(f)$ curve, $\sigma_{logH/V}(f)$is an absolute value which should be added to or subtractedfrom the mean $logA_{H/V}(f)$ curve • $\theta(f_0)$ = threshold value for the stability condition $\sigma_A(f) < \theta(f_0)$ • $V_{s,av}$ = average S-wave velocity of the total deposits • $V_{s,surf}$ = S-wave velocity of the surface layer • h = depth to bedrock • h_{min} = lower-bound estimate of h
Criteria for a clear H/V peak ***(at least 5 out of 6 criteria fulfilled)*** **i) $\exists f^- \in [f_0/4, f_0] \mid A_{H/V}(f^-) < A_0/2$** **ii) $\exists f^+ \in [f_0, 4f_0] \mid A_{H/V}(f^+) < A_0/2$** **iii) $A_0 > 2$** **iv) $f_{peak}[A_{H/V}(f) \pm \sigma_A(f)] = f_0 \pm 5\%$** **v) $\sigma_f < \varepsilon(f_0)$** **vi) $\sigma_A(f_0) < \theta(f_0)$**	

Threshold Values for σ_f and $\sigma_A(f_0)$

Frequency range [Hz]	< 0.2	0.2 – 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0
$\varepsilon\, v(f_0)$ [Hz]	$0.25 f_0$	$0.20 f_0$	$0.15 f_0$	$0.10 f_0$	$0.05 f_0$
$\theta(f_0)$ for $\sigma_A(f_0)$	3.0	2.5	2.0	1.78	1.58
$\log \theta(f_0)$ for $\sigma_{logH/V}(f_0)$	0.48	0.40	0.30	0.25	0.20

Data Analysis

The data recorded at 15 points in front of the southern side of Zoser pyramid are analyzed using GEOPSY Software (http://www.geopsy.org). The starting point in the analysis is to apply band pass filter to remove unwanted signals from the recorded ambient noise. Butterworth band pass filter of the fourth order is applied to the time series. The band pass parameters selected lie between 0.5 Hz up to 20 Hz. Another filter (STA/LTA filter) is used to remove the transient signals that affect the HVSR computation.

Recorded time windows at the 15 points are then subdivided into shorter time windows of lengths ranging from 35 to 50 seconds. Afterwards, the HVSR technique is applied to estimate the fundamental frequency and peak amplitude at each site. The fundamental frequencies and peak amplitudes is then statistically analyzed to produce the average estimates of both variables at each site. Table (2) summarizes the estimated fundamental frequencies and peak amplitudes at the 15 sites.

The results show that the fundamental frequency of the area ranges generally between 0.2 and 0.44 Hz (Fig. 5). At sites S7, S8, S9, S10 and S12 the fundamental frequency increase to range between 17 and 32 Hz (Fig. 6). The peak HVSR curves on the other hand, ranges from 3 to 17.5.

Table (2). The fundamental frequencies and amplitudes obtained from the ambient noise analyses at Zoser pyramid.

Site No.	Fundamental frequency	Peak Amplitude
1	0.437	6.54
2	0.2	5.15
3	0.36	16.17

4	0.2	4.45
5	0.23	17.5
6	0.21	9.1
7	25.37	4
8	26	4.5
9	31.8	3.8
10	28	4.8
11	0.13	7.4
12	17.4	3
13	0.23	11.3
14	0.2	12
15	0.4	5.2

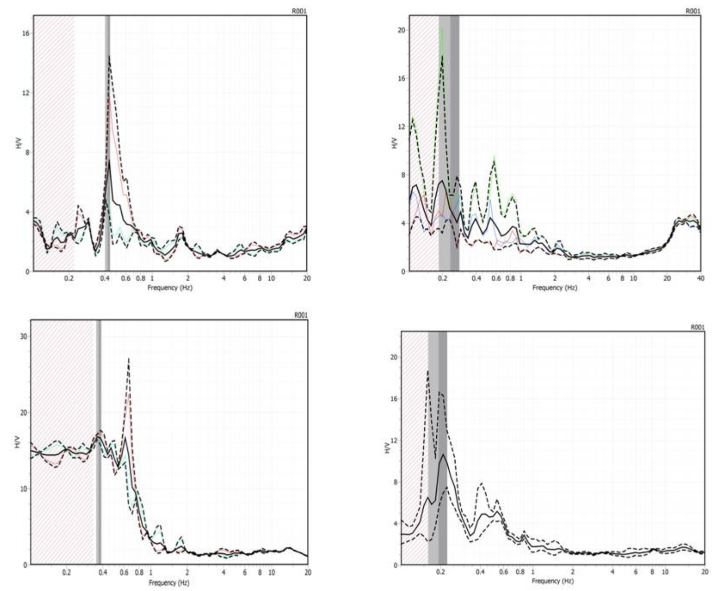

Fig (5). Samples of HVSR curves with fundamental frequency ranging between 0.2 and 0.45Hz

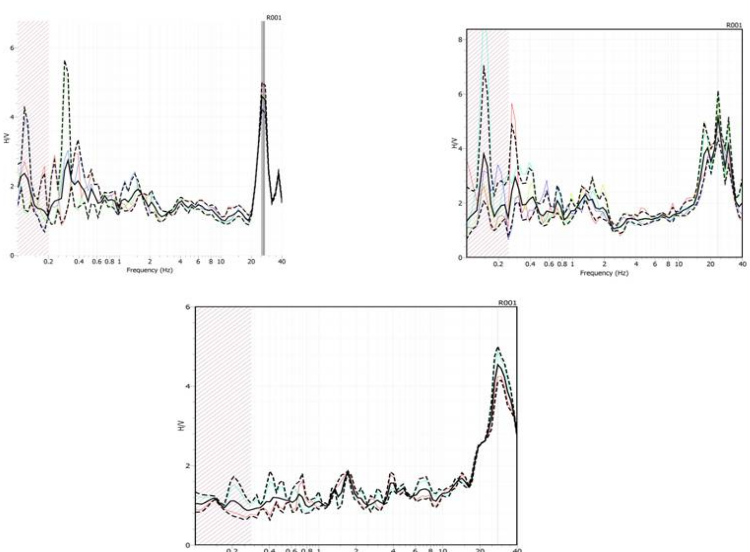

Fig. (6). Samples of HVSR curves showing high fundamental frequency that reach 32 Hz.

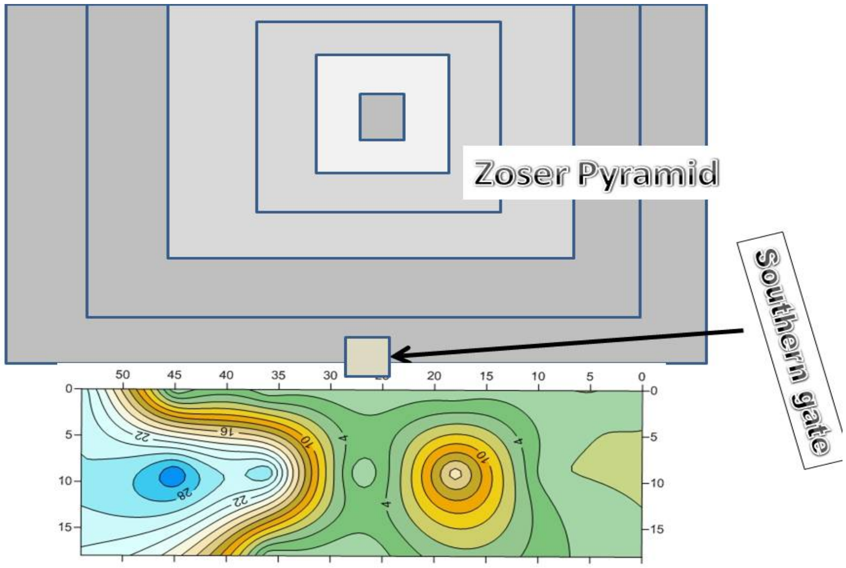

Fig. (7). Map distribution of fundamental frequencies at the fifteen sites in front of the southern edge of Zoser pyramid. Low fundamental frequency area is observed adjacent to the southern gate of the pyramid.

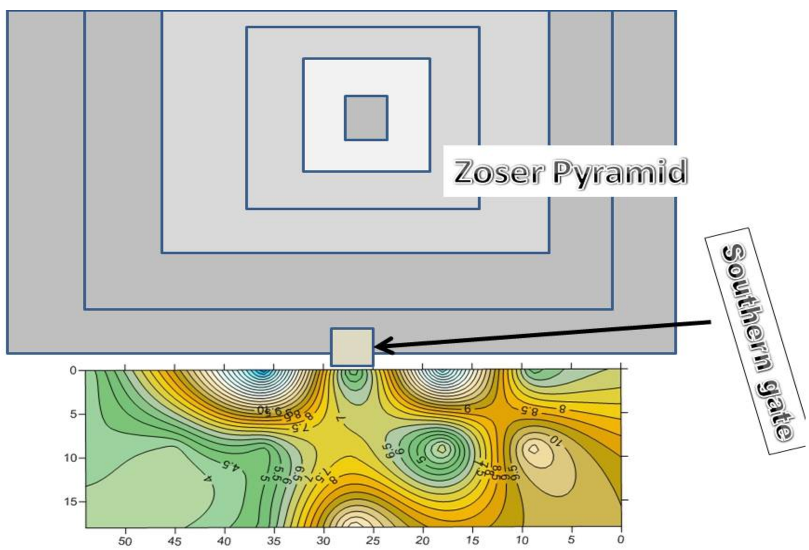

Fig. 8. Map distribution of Peak amplitudes of the HVSR curve. Again lower values is observable adjacent to the southern gate of the pyramid.

Discussion

The objective of the present study is to explore the potential of using the HVSR method to detect burried monuments (e.g. tunnels near Zoser pyramid). To achieve that goal the ambient noise is measured at 15 sites at the area adjacent to the southern side of the pyramid. The distance between any two adjacent sites is set to 9 m. Prior information about site controlled the distribution of the measuring sites.

The strategy that is followed in the present work depends on qualitative observations. Such observation may be viewed as the abrupt change in fundamental frequencies or peak amplitudes that may be attributed to tunnels or burried monuments. The HVSR parameters are mapped to investigate the presence of anomalies or trends.

The map view of both the fundamental frequency and peak amplitudes are shown in Figs. 7 and 8. In Fig 7 the contour map shows narrow area of low fundamental frequencies in front of the southern entrance. The tunnel nearly matches that narrow area. The same observation holds true for the distribution of peak amplitudes (Fig 8). However, the resolution is not as clear as that of the fundamental frequency map.

Further theoretical investigations are needed to verify the findings of the present work. It is well known that the fundamental frequency is directly proportional to shear wave velocity. Thus low the relation between the low F_0 and the presence of tunnel underneath may be accepted to some extent.

Conclusion

The HVSR method is used to determine to relate the fundamental frequency F_0 and peak amplitude of the HVSR curve with underneath known tunnel. The tunnel extends outside the southern gate of Zoser pyramid at a depth of about 35 meters. To achieve the goal of the present work the ambient noise is recorded at 15 point in front of the southern side of Zoser pyramid. The array shape was chosen based on the prior archeological information with inter-distances between points of 9 m.

Mapping of estimated F_0 and peak amplitude of HVSR curve showed that there exists an area of low F_0 adjacent to the surface projection of the tunnel. The same observation is present also for the map of the peak amplitudes but with lesser resolution. These qualitative observations are encouraging yet more quantitative efforts is needed.

Corresponding author
Amin E. Khalil
Geology Department, Faculty of Science, Helwan University, Helwan, Egypt
AMIN_KHALIL@science.helwan.edu.eg

References

Aigner, T., 1983. A Pliocene cliff-line around the Giza Pyramids Plateau, Egypt. Palaeogeogr., Palaeoclimatol., Palaeoecol., **42**: 313-322.

Bonnefoy-Claudet, S., Cornou,C., Bard, P.-Y., Cotton, F., Moczo, P., Kristek, J. and Fah, D. (2006). H/V ratio: a tool for site effects evaluation. Results from 1-D noise simulations, *Geophys. J. Int.*, **167**: 827-837

El-Qady, G., Sakamoto, C. and Ushijima, K., 1999. 2-D inversion of VES data in Saqqara archaeological area, Egypt. Earth Planets Space, **51**: 1091–1098

Fäh D., Kind F. and Giardini D.; 2001: A theoretical investigation of average H/V ratios. Geophys. J. Int., **145** : 535-549.

Lermo, J. and Chávez-García, F. J. (1994). Are microtremors useful in site response evaluation?, B*ulletin of the Seismological Society of America*, **84-5**:1350-1364.

Lunedei, E. and D. Albarelo, 2010. Theoretical HVSR curves from full wave field modelling of ambient vibrations in a weakly dissipative layered Earth. Geophys. J. Int. **181:**1093–1108.

Nakamura Y. 1996. "Real Time Information Systems for Seismic Hazards Mitigation UREDAS, ERAS and PIC," Quarterly Report of Railway Technical Research Institute, **37** (3): 112-127.

Nakamura, Y. (1997). Seismic Vulnerability Indices for Ground and Structures using Microtremor, *World Congress on Railway Research in Florence*, Italy.

Nakamura, Y. (2000). Clear identification of fundamental idea of Nakamura's technique and its applications, Proc. of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, paper 2656.

Nakamura, Y., 2008. **ON** THE H/V SPECTRUM. The 14th World Conference on earthquake Engineering October 12-17, 2008, Beijing, China

Nakamura, Y., 2009. Basic Structure of QTS (HVSR) and Examples of Applications. NATO Science for Peace and Security Series C: Environmental Security, 2009, Increasing Seismic Safety by Combining Engineering Technologies and Seismological Data, Pages 33-51

Nakamura, Y., 1989. *A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface*, Quarterly Report of RTRI, Railway Technical Research Institute (RTRI), 30(1):25-33

Nogoshi, M. and Igarashi, T. (1971). On the Amplitude Characteristics of Microtremor -Part 2 (in Japanese with English abstract), *Jour. Seism. Soc. Japan*, **24**:26-40.

Pilz, M., Parolai, S., Picozzi,M., Wang, R., Leyton, F., Campos, J., and Zschau, J. 2010. Shear wave velocity model of the Santiago de Chile basin derived from ambient noise measurements: a comparison of proxies for seismic site conditions and amplification, Geophys. J. Int., 182: 355–367.

Sanchez-Sesma, F. J., Kawase, H., Matsushima, S., 2011. DIFFUSE FIELDS IN LAYERED MEDIA. *4th IASPEI / IAEE International Symposium:* Effects of Surface Geology on Seismic Motion. August 23–26, 2011 · University of California Santa Barbara

SESAME (2004). GUIDELINES FOR THE IMPLEMENTATION OF THE H/V SPECTRAL RATIO TECHNIQUE ON AMBIENT VIBRATIONS, RESEARCH REPORT WP12, ONLINE: HTTP://SESAME-FP5.OBS.UJF-GRENOBLE.FR/INDEX.HTM

6/25/2012