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Geological, Geotechnical and Geophysical Aspects of Zafarana Wind Farms Sites and Their Expansion at Gabel El Zeit Sites Egypt

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Geological, Geotechnical and Geophysical Aspects of Zafarana Wind Farms Sites and Their Expansion at Gabel El Zeit Sites Egypt

H Kamal[1] , G Saudi[2] and Abdel Aziz Abd Aal[3]

[1] *Soil Mechanics and Geotechnical Engineering Department, Housing and Building National Research Center (HBRC), Cairo, Egypt*
[2] *Steel and Structural Engineering Department, Housing and Building National Research Center (HBRC), Cairo, Egypt*
[3] *National Research Institute of Astronomy and Geophysics (NRIAG), Cairo, Egypt*

Abstract. The growing need for sustainable power generation has led to increasing number of power plants, of fossil-fuel type and of non-conventional type. The foundation types of wind turbine towers in power plant structures are mainly depend on the geotechnical and structural considerations and other geological and geophysical considerations. The safety and economic conditions also play a vital role in the design of foundations. Such foundations must effectively be designed taken into consideration large overturning moments and dynamic loading due to extreme wind and earthquakes. The present research is focused on studying the geotechnical, geological and geophysical aspects and characterizes of soils in Zafarana Wind Farms sites and their expansion at Gabel El Zeit sites on the Suez Gulf of Egypt.   The study first address and study the geological aspects of both sites Zafarana Wind Farms sites and Gabel El Zeit sites. Secondly,   the geotechnical and geophysical characteristics are studied based   on establishing data base from 698 borings and 8 seismic refraction profiles across Zafarana wind Farm sites and 10 borings and 2 seismic refraction profiles at Gabel El Zeit site. The geotechnical testing and geophysical profiles were   compiled to determine the variation of the soil profile as well as the characteristics of the soil layers within the study sites. The results showed construction of 8 representative boring logs at Zafarana Wind Farm sites and 2 representative boring logs Gabel El Zeit sites to represent the characteristics of the soil layers and site statgerphy. Also, the study shows the result of compression wave velocity and shear wave velocity across both sites and within the studied soil layers up to 30 m. All these results   from this research will help to study the foundation and the structure of wind turbine tower , where these types of tall structures are similar to chimney structures in design and other engineering considerations.

Keywords: Zafarana Wind Farms, expansion at Gabel El Zeit, wind turbine tower, Geological aspect, geotechnical aspect, geophysical aspect.

1. Introduction

Wind turbine generator structures, as shown in Figure 1,   are typically founded on massive shallow footings that are designed to transmit moderate vertical forces and large dynamic horizontal forces and overturning moments [1,2]. The lack of experimental data and numerical analysis of these types

of foundations may lead a designer to use conservative assumptions. These conservative assumptions can lead to overdesigned foundations, additional costs, and reduced life-cycle cost efficiency of wind farms.

Zafarana Wind Farms and their expansion at Gabel El Zeit are currently generating a capacity of 517MW, making it one of the largest onshore wind farms in the world. It is located in an active seismic zone along the west side of the Gulf of Suez. The main purpose here in this study is to obtain a proper understanding of the geological , geotechnical and geophysical aspects of these sites as well as the local subsurface conditions within the studied layers and their stategrapy. This has been performed by study the geological formations across both sites and establishing data base from 698 borings and 8 seismic refraction profiles across Zafarana wind Farm sites and 10 borings and 2 seismic refraction profiles at Gabel El Zeit site.

2. Zafarana Wind Farms

Zafarana Wind Farm site was analyzed as part of this research to investigate the geological, geotechnical and geophysical characterisation of this site and it consists of eight wind farms over an area round of 12 X 18 km as shown Figure 2. The expansion area in Gabel El Zeit was also analysed in this study which consist of   ten wind farms under construction as shown in Figure 3. The sites of the eight wind farms in Zafarana and ten wind farms under construction in the expansion area in Gabel El Zeit were selected to investigate the geological, geotechnical and geophysical characteristics of these sites.

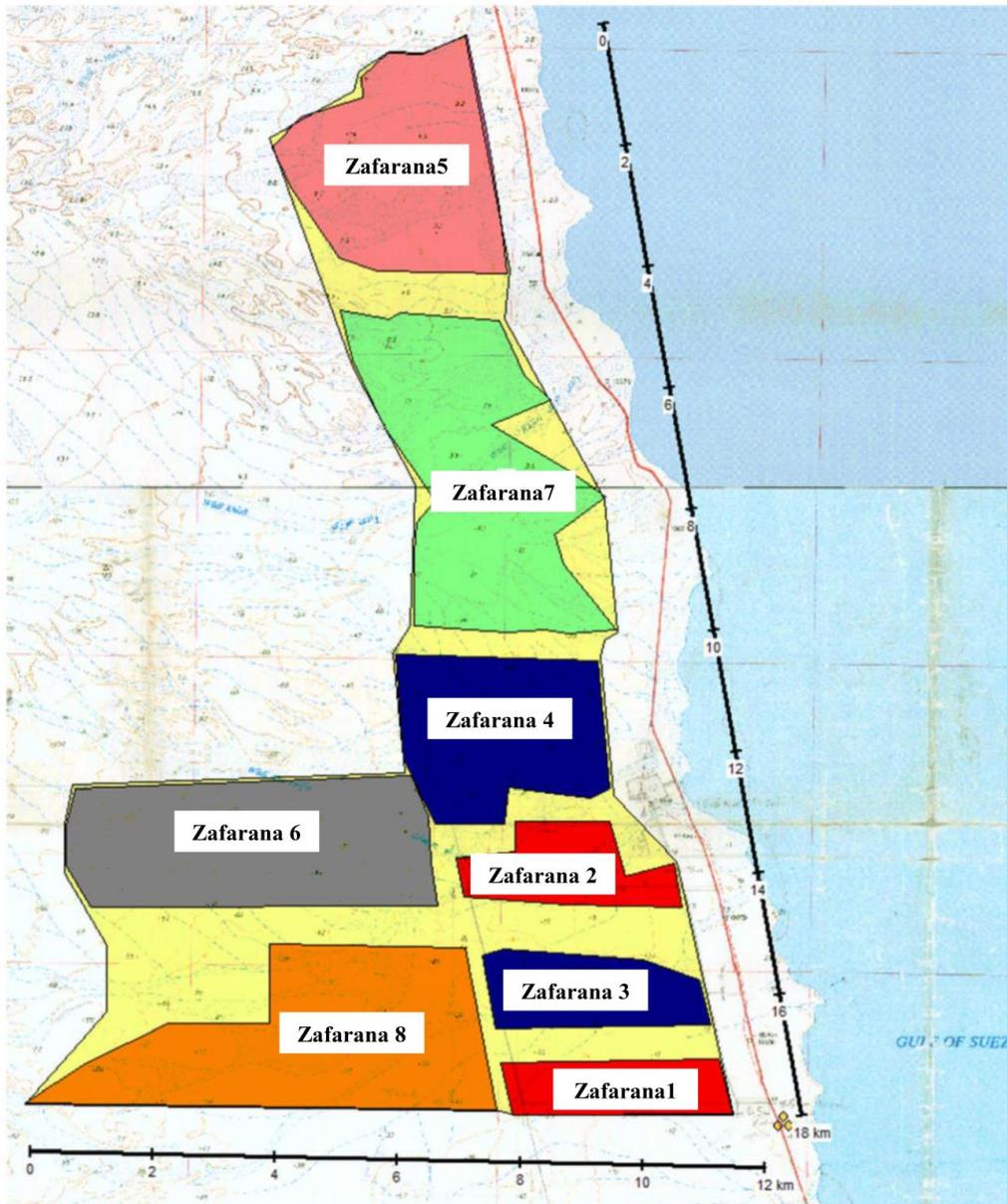**Fig .(1)** A wind turbine generator at Zafarna Wind Farm

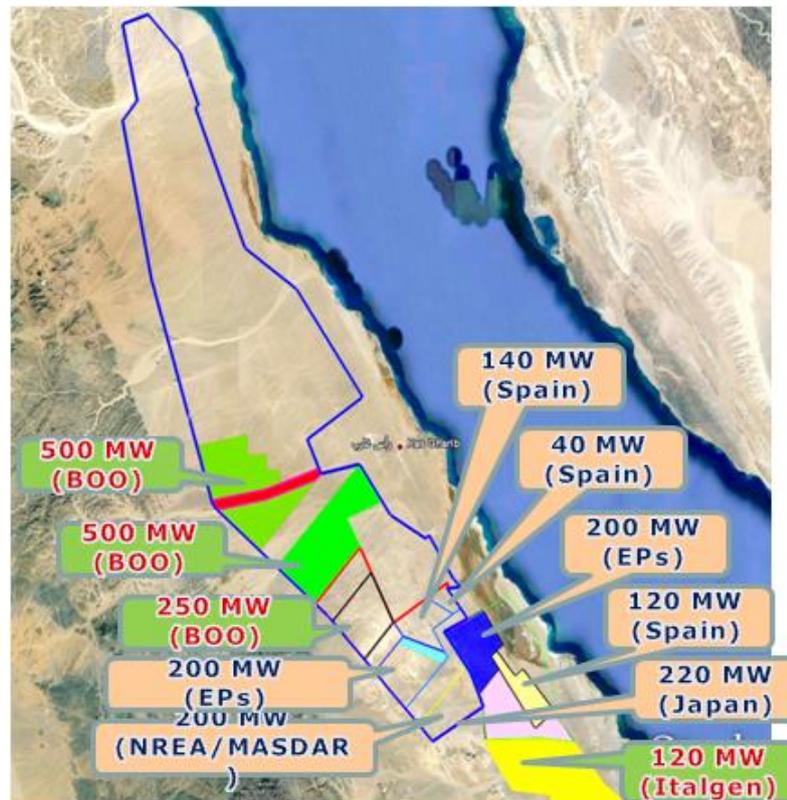**Fig. (2)**   Layout of Zafarana wind Farms

Fig. (3) Layout of the Expansion area of Gabal El Zeit wind Farms including 11 wind farms in this location from 140MW to 500 MW

3. Geological Investigation

The Red Sea Basin Province originated as an Oligocene continental rift impacted by left-lateral wrenching. Rift location and borders are defined by crustal weaknesses created more than 500 Million age , including the late Proterozoic to early Paleozoic cratonization of the Arabian-Nubian shield, its suturing to the African continent, and subsequent supercontinent breakup. Those events resulted in the juxtaposition of structurally and compositionally different basement terranes. Said [3], and El-Gezery and Marzouk [4] showed that the depth of the basement increases northwards towards the Mediterranean Sea. The Paleozoic rocks are characterized by continental clastic deposits. The marine episodes are minor in space and time. The Paleozoic period ends with the Upper Carboniferous Lower Permian marine deposition, that followed the Hercynian orogenic phase and the subsequent erosional period. Predominant continental deposition started again in the Mesozoic. The Cenozoic witnessed the transformation of the Tethys into the Mediterranean Sea during the Paleocene-Eocene. The Miocene was a period leading to the formation of present Red Sea coast sediments and sediments in the northwestern part of the Gulf of Suez. The Quaternary was determined by regression with minor transgression. Uplift and tectonic disturbances mark the Pliocene-Quaternary boundary in the Red Sea region [5]

The geological features indicate that the study area consists of coastal and wadi deposits. There are no intensive faults at Zafarana area. However, some faults, taking the NW-SE trend, appear at the area between Quseir and Ras Ghareb and also between Marsa Alam and Quseir.   The oldest known formation in the study area is of Late Precambrian age, igneous and metamorphic rocks forming the northern edge of the African Shield [6] as shown in Figure 4 and Figure 5.
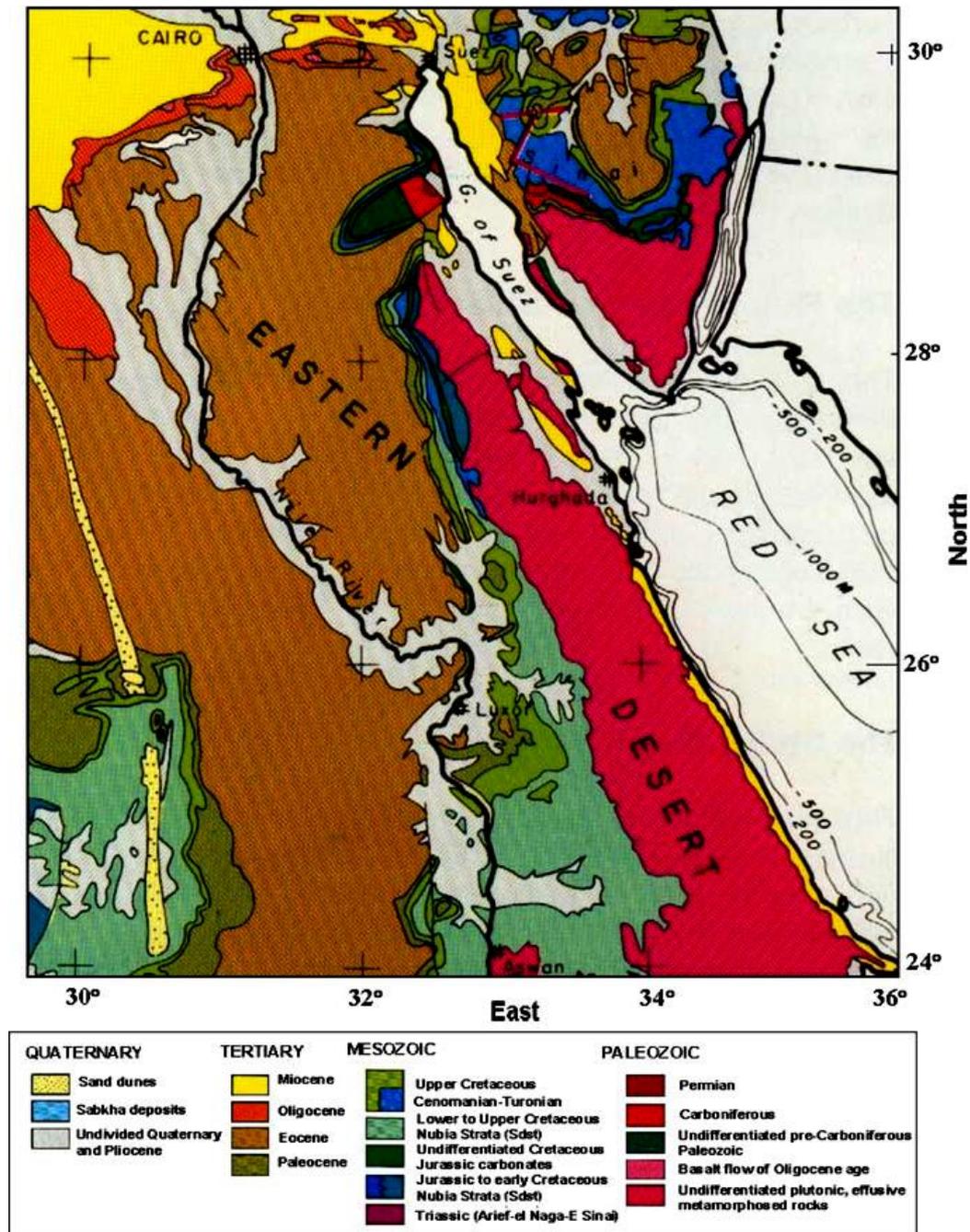

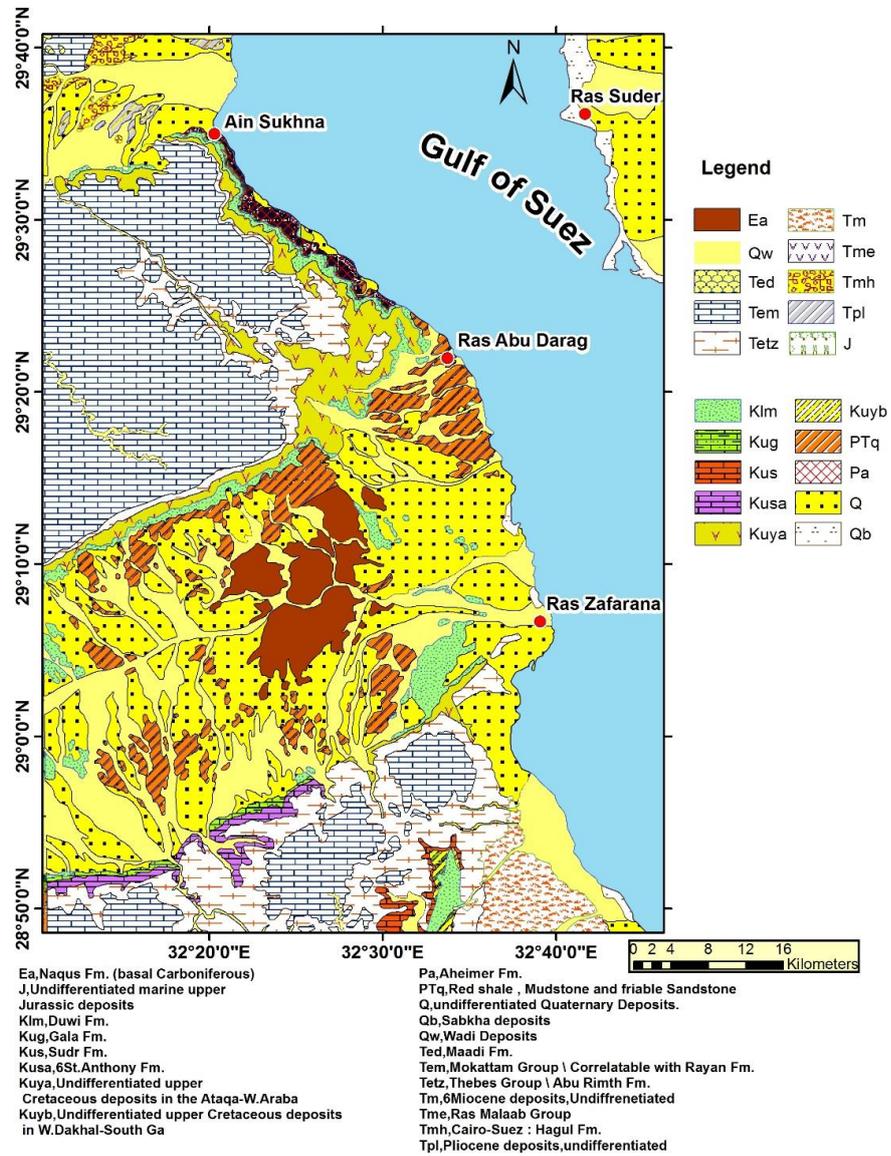**Fig. (4)**   Surface geological map of the Red Sea Governate [6]

Ea,Naqus Fm. (basal Carboniferous)
J,Undifferentiated marine upper
 Jurassic deposits
Klm,Duwi Fm.
Kug,Gala Fm.
Kus,Sudr Fm.
Kusa,6St.Anthony Fm.
Kuya,Undifferentiated upper
 Cretaceous deposits in the Ataqa-W.Araba
Kuyb,Undifferentiated upper Cretaceous deposits
 in W.Dakhal-South Ga

Pa,Aheimer Fm.
PTq,Red shale , Mudstone and friable Sandstone
Q,undifferentiated Quaternary Deposits.
Qb,Sabkha deposits
Qw,Wadi Deposits
Ted,Maadi Fm.
Tem,Mokattam Group \ Correlatable with Rayan Fm.
Tetz,Thebes Group \ Abu Rimth Fm.
Tm,6Miocene deposits,Undiffrenetiated
Tme,Ras Malaab Group
Tmh,Cairo-Suez : Hagul Fm.
Tpl,Pliocene deposits,undifferentiated

Fig. (5)   Surface geological map of the Zafarana region [6]

4.   Geotechnical Investigation

Geotechnical database was established for Zafarana sites and   698 borings were collected from previous geotechnical site investigations reports where   the distribution of the 698 Borings have the same location of wind turbines towers cause under each wind turbine one boring was executed as shown in Figure 6. Also 10 borings were collected from previous preliminary geotechnical site investigations report for Gabel El Zeit sites as shown in Figure 7.
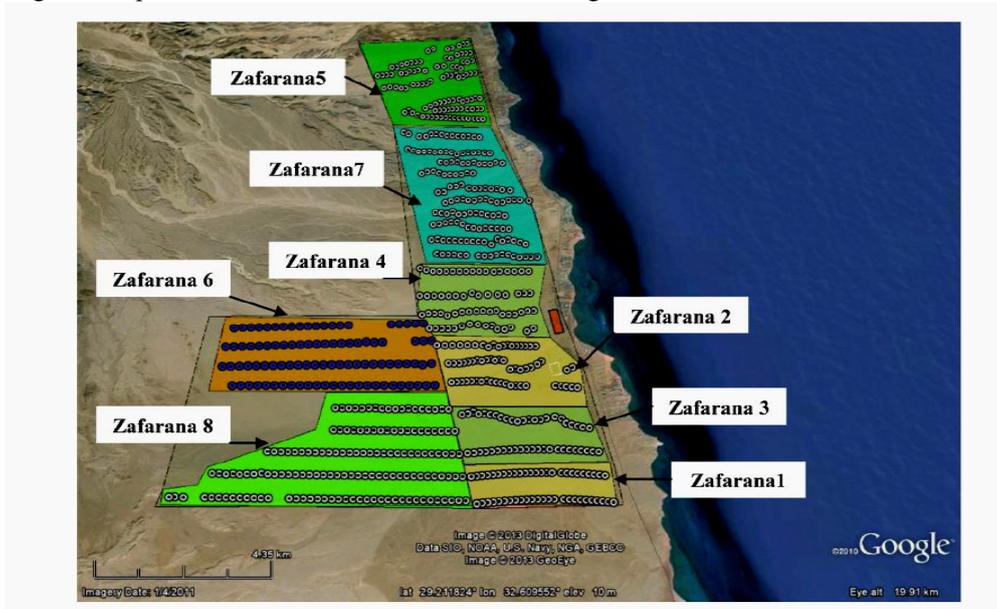

Fig. (6)   The Distribution of 698 Borings at Zafarana wind farms
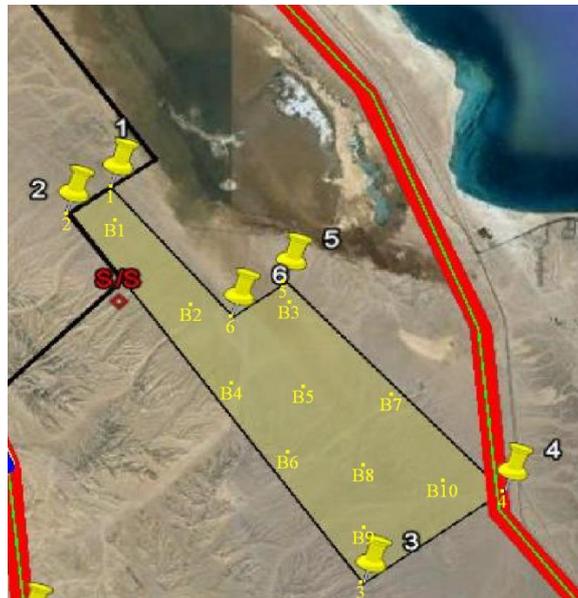

Fig. (7) The Distribution of 10 Borings at Gabal El Zeit wind farms for preliminary geotechnical of investigation.

4.1 Geotechnical Investigation of the Zafarana Sites

4.1.1 Subsurface formations across the Zafarana sites

Based on the results of the previous site investigation and laboratory testing the soil formations encountered in the boreholes show five main formations, which are Wadi deposits, Clay, Claystone, Sand and Sandstone. The subsurface formations at the site can be summarized as follows:

1. **Wadi Deposit:** Reddish brown to yellowish brown wadi deposit that consist of gravel, sand, silt, clay and iron oxides. The gravel is identified to be of dolomitic origin. This layer appears most boreholes from the ground surface to a depth varying from 0.25 m to 15.0 m from the ground surface.
2. **Clay:** Hard sandy laminated, lean or fat reddish yellow to greyish brown clay with interbedded band of claystone or sandstone pieces (5-15 cm) and traces of iron oxides, it appears at most boreholes from 3.7 m to 10 m.
3. **Claystone:** Reddish to yellowish brown very weak to medium hard sandy claystone interbedded by thin to thick band of sand or sandstone (5- 15 cm). It is stained by iron oxides, it becomes fragmented in some times. This layer appears at most boreholes from 7.5 m to 15 m .
4. **Sand:** Yellow to reddish brown sand with different percent of silt, could be cemented or clayey, it appears with interbedded of sandstone or clay stone pieces, calcanrous, and with traces of iron oxides. This layer appears most boreholes from 25 m to 6 m.
5. **Sandstone:** Yellow to reddish brown fine to medium grained sandstone, interbedded by thin to thick band of claystone (5- 15 cm). It is stained by iron oxides. This layer appears at most boreholes from 6 m to 15 m.

Groundwater is not encountered in any of the boreholes at the time of investigation.

4.1.2 Evaluation of soil Properties from field and laboratory testing

1. Wadi deposit

Reddish brown to yellowish brown wadi deposit that consist of gravel, sand, silt, clay and iron oxides. The gravel is identified to be of dolomitic origin. The SPT blow counts N values of this layer varies from 33 to 50. The blow counts 50 are counted after depth of penetration 6 to 13 cm. It has to be noted that the presence of gravel and/or cementation may contribute to the high values of blow count N values. Therefore, evaluation of soil parameters based on SPT results should be dealt conservatively. The following is an evaluation of the soil properties in order to deduce design parameters that can be used in the geotechnical analyses.

- **Bulk Unit Weight:** The bulk unit weight of the deposit is conservatively estimated to be about20 kN/m^3. This value is recommended to be used in the geotechnical analyses.
- **Friction Angle:** The friction angle is estimated based on SPT test results, taking into consideration that these SPT results may be affected by the presence of high gravel content and/or cementation, which will increase the SPT test results. Accordingly, a conservative value of 37°can be considered in the geotechnical analyses.
- **Deformation Modulus:** A conservative value of Young's modulus of 40 MPa can be considered in the geotechnical analyses.

2. Clay Layer

Hard sandy laminated, lean or fat reddish yellow to greyish brown clay with interbedded band of claystone or sandstone pieces (5-15 cm) and traces of iron oxides. The liquid limit, plastic limit and plasticity index are in the ranges of 25% to 63%, 14% to 27%, and 9% to 39%, respectively.

- **Bulk Unit Weight**: Bulk unit weight determinations were performed on samples selected from the clay layer. The results indicated a bulk unit weight ranging between 20.99 kN/m^3 and   23.84 kN/m3. An average value of 22.5 kN/m^3 can be considered in the geotechnical analysis.

- **Dry Unit Weight:** Dry unit weight determinations were performed on samples selected from the clay layer. The results indicated a dry unit weight ranging between 19.32 kN/m^3 and 21.89 kN/m^3. An average value of 20.6 kN/m^3 can be assumed for the clay layer.
- **Shear Strength:** The measured values of pocket penetrometer qu are of more than 500 kPa. The measured pocket penetrometer qu values indicate undrained shear strength of more than 250 kPa. Based on this interpretation, undrained shear strength of the clay layer of 100 kPa can be conservatively considered in the geotechnical analysis. Such value takes into consideration   the fissured nature of the clay. Considering the plasticity index range of the clay, a drained shear friction angle in excess of about 25° can be conservatively used in geotechnical analysis. The drained cohesion intercept of 0 kPa can be conservatively assumed.
- **Swelling Potential:** One-Dimensional Swell tests were performed on samples selected from the clay layer at various depths from the ground surface. The results indicated swelling pressure of (0) MPa. When the samples were subjected to inundation, no sign of swelling was observed in the Oedometer. In fact a reduction in volume was observed. These values indicate that no expansiveness according to the classification by Snethen et al. [7] as shown in Table 1.

The free swell tests showed results of free swell less than 85% with the majority of the results showed less than 50% free swell.

Table 1. WES classification system based on Snethen et al. [7]

Classification of Potential Swell	Potential Swell %	Liquid Limit %	Plasticity Index %	Natural Soil Suction kPa
Low	<0.5	<50	<25	<150
Marginal	0.5-1.5	50-60	50-60	150-400
High	>1.5	>60	>50	>400

- **Deformation Modulus:** Based on the range of plasticity index (9-39%), a ratio of 300 between deformation modulus and undrained shear strength was used to estimate the defmmation modulus of the clay. Such ratio resulted in a value of deformation modulus of 30 MPa that can be considered in the geotechnical analyses.

3.   Claystone Layer

Reddish to yellowish brown very weak to medium hard sandy claystone interbedded by thin to thick band of sand or sandstone (5- 15 cm). It is stained by iron oxides, it becomes fragmented in some times.

- **Bulk Unit Weight:** Bulk unit weight determinations were performed on samples selected from the claystone layer. The results indicated a bulk unit weight ranging between   21.48 kN/m^3 and 24.43 k:N/m^3. A value of 23 kN/m^3 can be considered in the geotechnical analysis.
- **Dry Unit Weight:** Dry unit weight determinations were performed on samples selected from the claystone layer. The results indicated a dry unit weight ranging between   19.33 kN/m^3 and 23.84 kN/m^3. A value of 21.5 kN/m^3 can be assumed for the claystone.
- **Unconfined Compression Test:** Unconfined compression tests were performed on selected from various depths throughout the layer. The results indicated unconfined compression strength ranging between 0.67 MPa and 35.39 MPa. An average value of 18 MPa can be assumed for intact samples. A reduced value of about 0.5 MPa can be conservatively considered for the rock mass in the geotechnical analysis.
- **Deformation Modulus:** The results of the unconfined compression tests were used to estimate the deformation modulus of the claystone samples. The average value of the estimated deformation modulus of the intact samples was further reduced by 10 to conservatively take into account the rock mass behaviour. The results indicated a very conservative reduced value of 90 MPa to be used in the geotechnical analysis.

4.   Sand Layer

Yellow to reddish brown sand with different percent of silt, could be cemented or clayey, the layer is interbedded with sandstone or clay stone pieces, calcareous, and with traces of iron oxides.

- **Bulk Unit Weight:** Bulk unit weight determinations were performed on samples selected from the sand layer. The results indicated a bulk unit weight ranging between   17.66 kN/m^3 and 22.27 kN/m^3. A value of 18 kN/m^3 can be conservatively considered in the geotechnical analysis.
- **Dry Unit Weight:** Dry unit weight determinations were performed on samples selected from the sand layer. The results indicated a dry unit weight ranging between 15.61 kN/m^3 and 20.91 k:N/m^3. A value of 16 kN/m^3 can be assumed for the sand layer. The lower values are observed in the cemented sand samples.
- **Friction Angle:** The friction angle is estimated based on SPT test results, taking into consideration that these SPT results may be affected by the presence of high gravel content and/or cementation, which will increase the SPI test results. Accordingly, a conservative value of 37°can be considered in the geotechnical analyses.
- **Deformation Modulus:** A conservative value of Young's modulus of 40 MPa can be considered in the geotechnical analyses.

5.   Sandstone Layer

Yellow to reddish brown fine to medium grained sandstone, interbedded by thin to thick band of claystone (5- 15 cm). It is stained by iron oxides.

- **Bulk Unit Weight:** Bulk unit weight determinations were performed on samples selected from the sandstone layer. The results indicated a bulk unit weight ranging between   20.99 kN/m^3 and 24.53 kN/m^3. An average value of 22 kN/m^3 can be considered in the geotechnical analysis.
- **Dry Unit Weight:** Dry unit weight determinations were performed on samples selected from the sandstone layer. 1he results indicated a dry unit weight ranging between 18.15 kN/m^3 and 23.5 kN/m^3. A value of 21 kN/m^3 can be assumed for the sandstone.
- **Unconfined Compression Test:** Unconfined compression tests were performed on samples selected from various depths throughout the layer. The results indicated unconfined compression strength ranging between 0.72 MPa and 23.71 MPa. An average value of 12 MPa can be assumed for intact samples. A reduced value of about 0.5 MPa can be conservatively considered for the rock mass in the geotechnical analysis.
- **Deformation Modulus:** The results of the unconfined compression tests were used to estimate the deformation modulus of the sandstone samples. The average value of the estimated deformation modulus of the intact samples was further reduced by the ratio of 10 to conservatively take into account the rock mass behaviour. The results indicated a very conservative reduced value of 75 MPa to be used in the geotechnical analysis.

5.2 Geotechnical Investigation of the Expansion area in Gabel El Zeit

4.2.1 Subsurface formations across the Expansion area in Gabel El Zeit

Based on the results of the previous preliminary   site investigation and laboratory testing the soil formations encountered in the boreholes show   granular soil where this layers consisting mainly of sand and gravel mixtures with varying percentages. The granular soil were encountered at the location of all boreholes. It extend from ground surface to the end of borehole. At some boreholes the surface layer contains percentage of silt. At few boreholes sand was appeared without gravel.

Groundwater is not encountered in any the boreholes at the time of investigation.

5.2.2 Evaluation of soil Properties from field testing

During the drilling of boreholes, the standard penetration tests (SPT) were performed at approximately 3.00 m – interval in order to obtain approximate relative densities of the soils. No. of blows are mentioned in borehole logs. S.P.T results indicate that the granular soil layers are very

dense,   and giving high bearing capacity at level 2.0 m – 3.0 m. However, a lot of the S.P.T results were affected because of the high percentage presence of gravel.

Table 2.   Results of Standard Penetration Test

No. of Blows (N)	Relative Density
0-4	Very Loose
4-10	Loose
10-30	Medium
30-50	Dense
Over 50	Very Dense

4.3 Representative Boring Logs
4.3.1 Representative Boring Logs of Zafarana Sites
 The 698 collected borings from previous geotechnical site investigations were analyzed to produce eight representative boring logs for the eight Zafarana wind Farms as shown in Figure 8, where these boring logs were used for ground site response analysis .

4.3.2 Representative Boring Logs of the Expansion area in Gabel El Zeit
The 10 collected borings from previous preliminary geotechnical site investigations were analyzed to produce two representative boring logs for the under construction wind farms in the Expansion area in Gabel El Zeit   as shown in Figure 9,   where these boring logs were used for ground site response analysis .
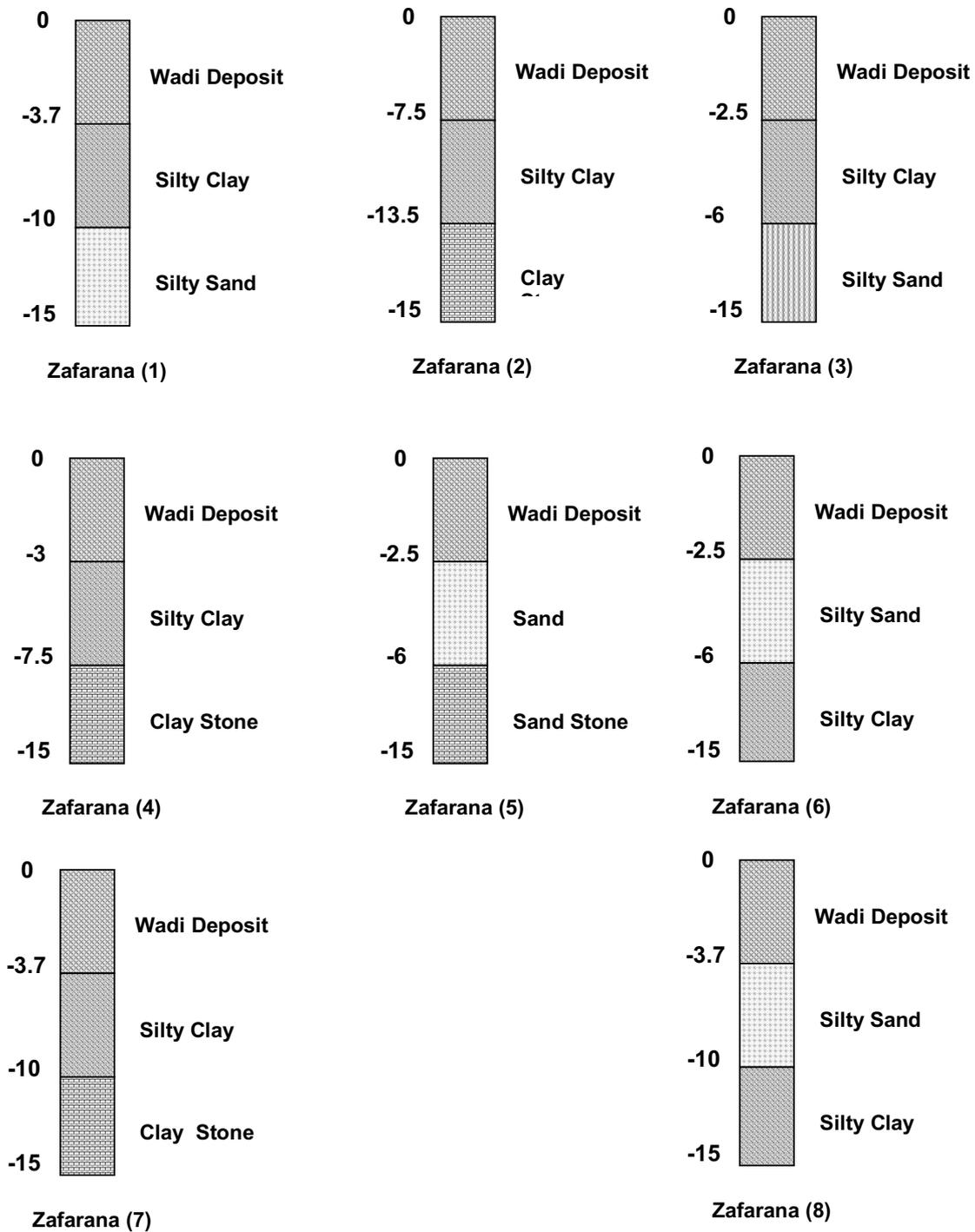
Fig. (8) Eight representative boring logs for the eight Zafarana farms where each farm has a one representative boring logs
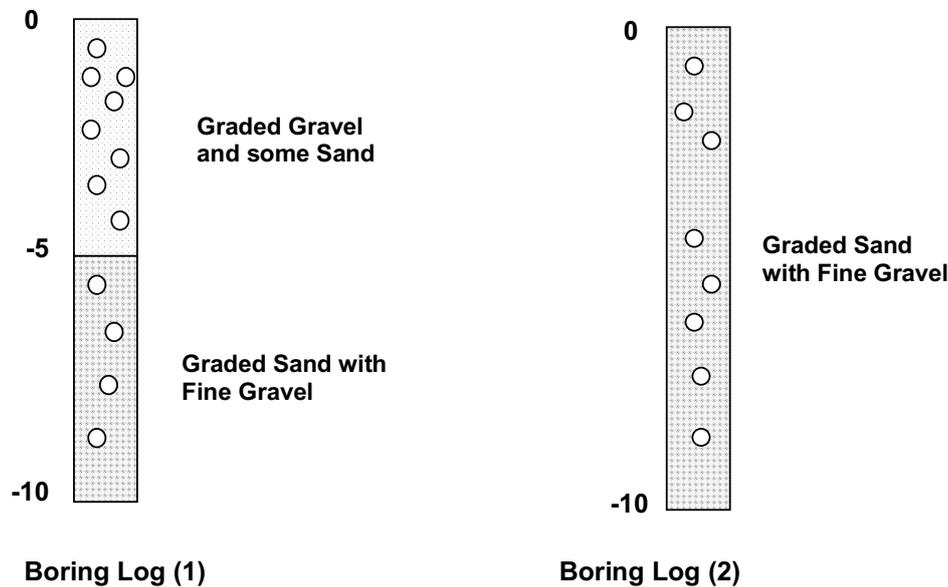
Fig. (9) Two representative boring logs for the expansion area in Gabel El Zeit

6. Geophysical Investigation

Geophysical exploration as shallow seismic refraction has been widely applied in civil engineering; i.e. road tunnelling, dam sites, quarries, hydroelectric power plants, subway constructions, nuclear power plants, cavity and fault detection and many other purposes. P- and S- wave velocity measurements obtained from shallow seismic refraction surveys are used to evaluate the bed rock in order to determine the elastic properties of the materials in the sites under assessment. SH (horizontal shear) waves can be used to study the vibration characteristics of the subsurface layers, which are important for earthquakes resistance structural design. Increasing source energy, stacking and filtering are considered as ways to acquire high quality refraction records, which contain sharp first breaks [8,9].

The refraction method consists of measuring (at known points along the surface of the ground) the travel times of compressional waves generated by an impulsive energy source [8]. The energy is detected, amplified and recorded by special equipment (Seismograph) designed for this purpose. The instant of explosion, or "zero-time," is recorded on the record of arriving pulses. The raw data, therefore, consist of travel times and distances, and these time-distances information is then manipulated to convert it into the format of velocity variations with depth. The subsurface structure is inferred from interpretation methods based on the laws of energy propagation. The propagation of seismic energy through subsurface layers is described essentially by the same rules that govern the propagation of light rays through transparent media [8,9].

The refraction that a seismic pulse undergoes when passing from one material to another depends upon the ratio of the transmission velocities of the two materials. The fundamental law that describes the refraction of seismic pulse is Snell's Law, and this together with the phenomenon of "critical incidence," is the physical foundation of any seismic refraction surveys. Snell's Law and critical incidence are illustrated in Figure 10, which shows a medium with a velocity V_1, underlain by a medium with a higher velocity V_2. Snell's Law is given in the following relation:

$$Sin\ \alpha\ /\ Sin\ \beta = V_1\ /\ V_2 \tag{1}$$

Critical incidence occurs when β = 90 °, at this case:

$$Sin\ \alpha\ =\ V_1\ /\ V_2 \tag{2}$$

Until the critical angle of incidence is reached, almost all of the compressional energy is refracted into the higher velocity medium. When the critical angle is exceeded, the energy is almost totally reflected and no energy is refracted into the high-speed layer.

In shallow seismic refraction surveying of the current study, the basic instrument includes seismic source (a weight drop 150 kg is used), detectors (48 geophones with natural frequency of 40 Hz are used, as shown in Figure 11 for vertical and horizontal geophones), cable (geophone cable connected to the data logger with one meter interval and 48 takeouts), and data logger (Strata View 48 channels seismograph manufactured by Geometrics Company) is utilized with a menu involves an option for standard settings, 24 dB, single-stage, Instantaneous Floating Point (IFP) amplifier, followed by an A/D converter sampling at 1/4 microsecond intervals. The floating point number is fed to a 32-bit, floating-point, digital signal processor (DSP) which performs multi-sample processing to increase the effective resolution and dynamic range. A 24-bit number is generated from the A/D process. The digital signal is stored in a semiconductor memory, where it can be viewed on a display unit, plotted on a paper record, or saved on floppy disk Figure 12. A weight drop 150 kg is used Figure 13.

5.1 Seismic Data Acquisition

In order to classify the shallow foundation section into soil and bed rock and to define the competence scales and geotechnical characteristics, the seismic refraction was carried out through applying the forward, mid-point and reverse acquisition system vertically and horizontally to create the compressional waves (P-waves) and shear waves (S-waves). The object of such P-waves and S-waves is to conclude the variations of velocities (compressional, Vp, and shear, Vs,) with depth and correlate them with the subsurface geologic information, if present. The ground refraction field work executed in the Zafarana wind farm and the expansion in Gabel El Zeit sites is consisted of eight and two seismic profiles distributed regularly in the sites Figures 14 and Figure 15. Accordingly, for each seismic site, two seismic refraction profiles are acquired, one for the compressional waves and one for the shear waves.

The P-waves are acquired by generating seismic energy using energy source, sending the created seismic waves inside the earth. The direct (head) and refracted (diving) waves are detected through geophones, which are motion sensitive transducers, that convert the mechanical ground motion into an electrical signal, whose voltage amplitude is proportional to the received energy. The Eight and two profiles have 96 meters long spread, the total spread length should be three to five times the maximum depth anticipated [10]. The geophone spacing was fixed and equal to 2 m. The geophones must be firmly coupled to the ground.

The technique is to shot the profile (3 shots) 2 meters far from both ends, also from its mid-point. Figure 16 shows a representative example of the recorded P-wave seismograms at the P-waves seismic profiles.
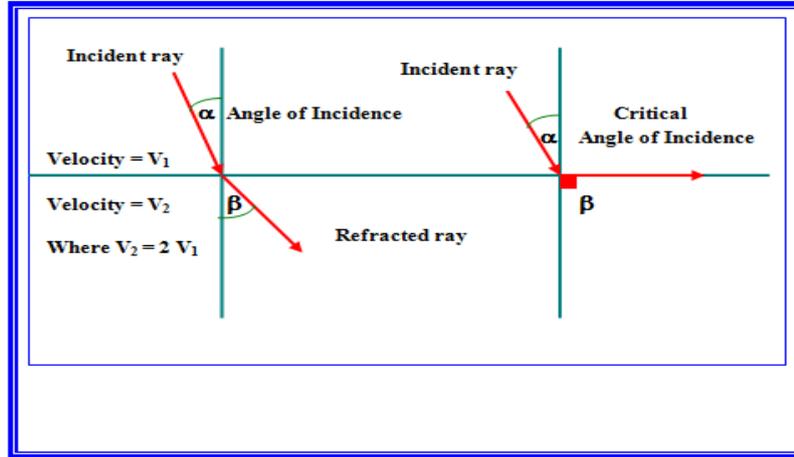
Fig. (10) Refraction of a ray transmitted across a boundary between two media with different velocities ($V_2 = 2\ V_1$)
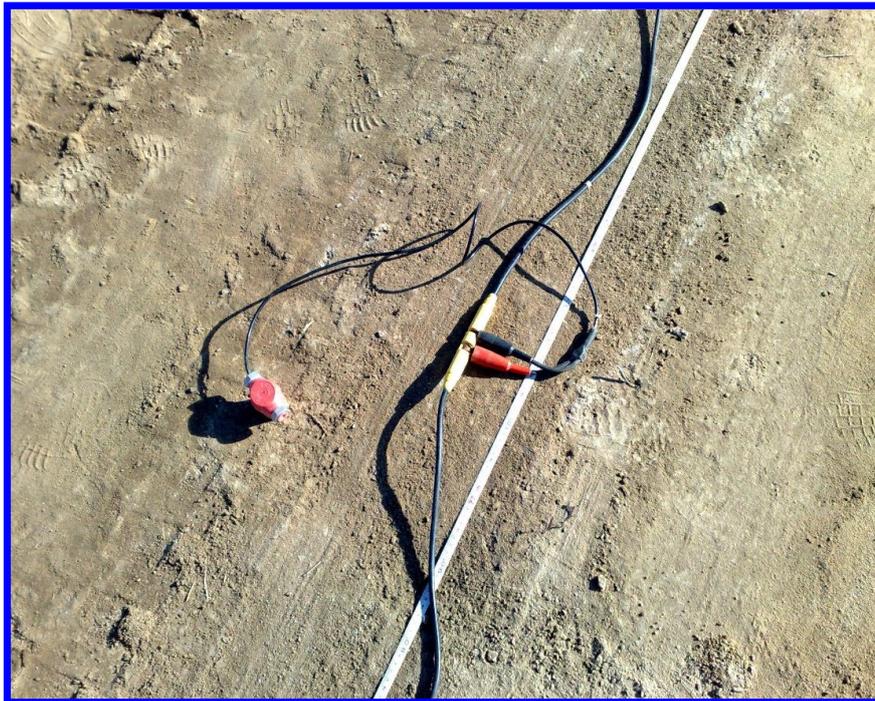

Fig. (11) The types of Vertical and horizontal geophones used in the data acquisition

Fig. (12)   The StrataView data logger which used in the shallow seismic refraction survey

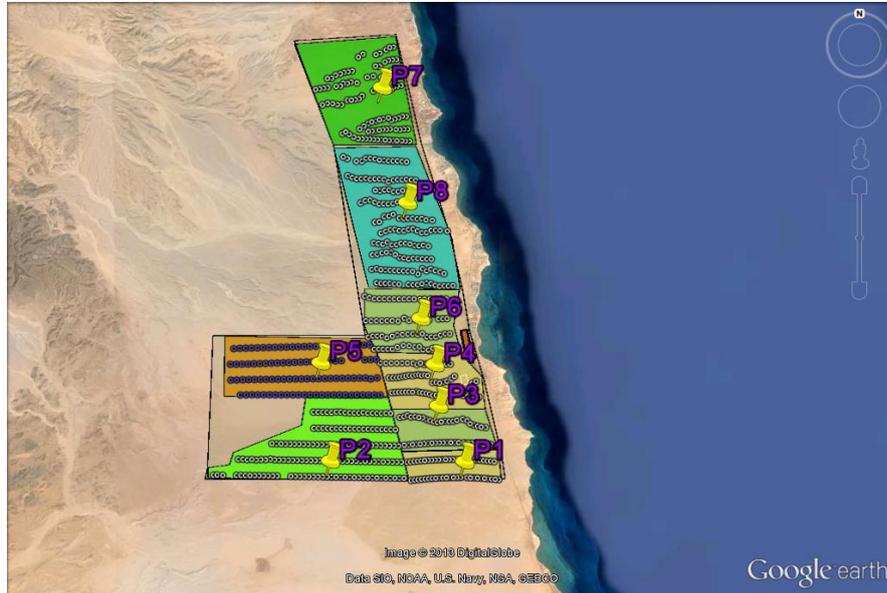**Fig. (13)**   A weight drop 150 kg is used

Fig. (14) Location of seismic profiles conducted at Zafarana wind farm site

Fig. (15) Location of seismic profiles conducted at the expansion of Gabel El Zeit
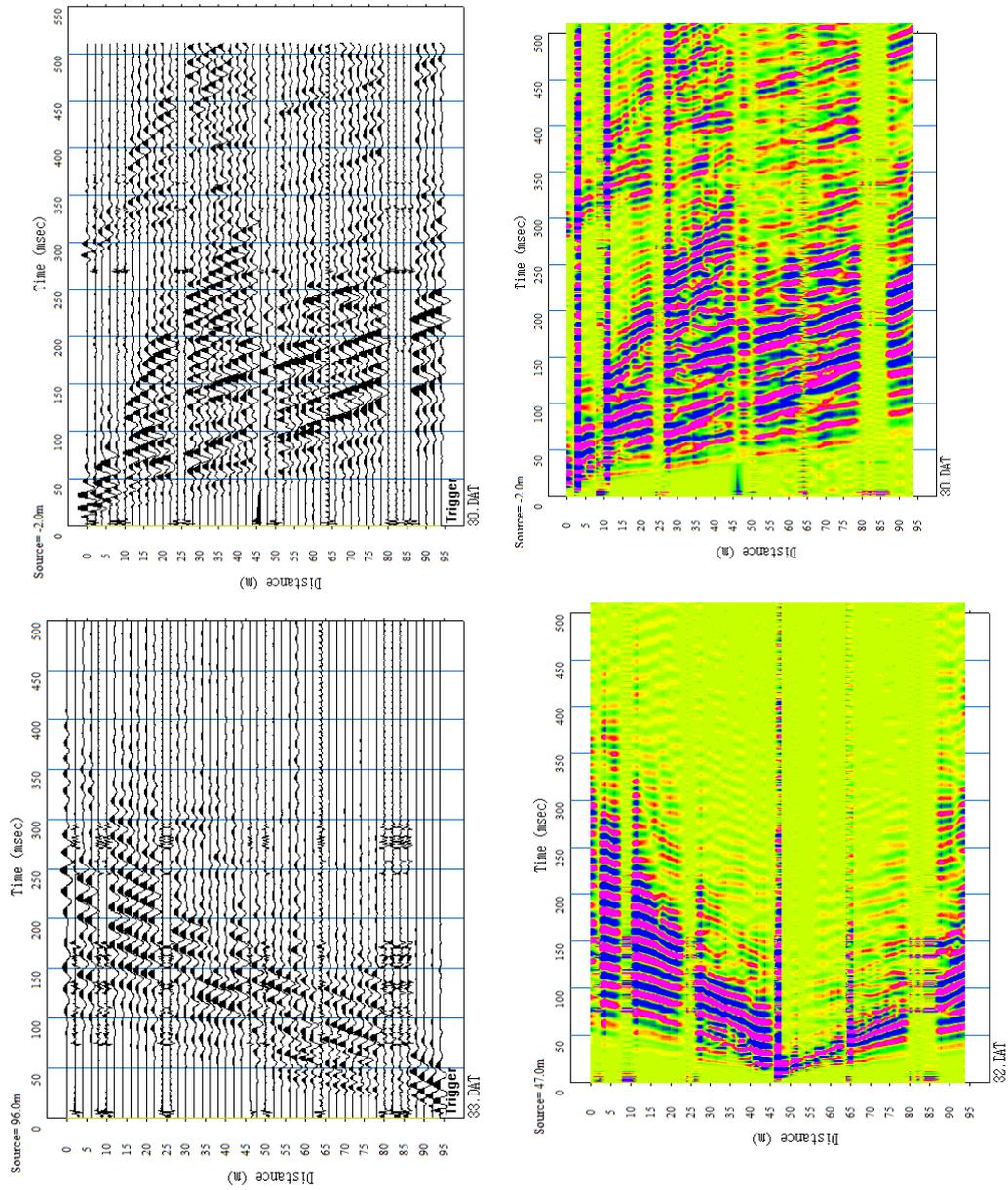
Fig. (16)   Seismograms of P- wave data at Zafarana wind farm site

The generation of shear waves in contrast with the P-waves is more difficult. The shear sources create compressional waves simultaneously with the shear energy [11]. The generation of shear energy is discussed by many authors; such as: [12,13,14,15] .They conclude several steps to provide unambiguous identification of the horizontal shear waves (SH) arrival on the seismic waveform as follow: 1- The first step is to use a source, which produces the largest possible shear waves and the smallest possible waves of other types, 2- The second step is to make measurements at a location, where the source radiation pattern predicts the largest shear wave amplitudes with respect to other types. For a horizontal surface force, measurements along a perpendicular line would detect principally horizontal shear waves (SH), and 3- The third step is to orient the detector to take maximum advantage of the directionality of the shear waves. Transverse detectors would be used.

The thrust of shear wave source design has therefore taken the direction of suppressing other unwanted wave types. Particular emphasis has given to create pure horizontal shear wave (SH) type motion and suppressing P and SV by impact first in one direction and reverse the polarity mode in the seismograph then impact in the opposite direction. By this technique, the amplitude of the horizontal shear waves will enhance, while all the other signals will vanish.

Another technique to determine the shear wave velocities is used in this study. This is the most common type of MASW (Multi channel Analysis of Surface Waves) survey that can produce a 2-D Vs profile [16]. The overall setup is illustrated in Figure 17. The maximum depth of investigation (Zmax) that can be achieved is usually in 10-30 m range, but this can vary with sites and types of active sources used. Field procedures and data processing steps are briefly explained below. 8 MASW profiles are carried out at Zafarana wind farm while 2 MASW profiles were carried out at the expansion area in Gabel El-Zeit.
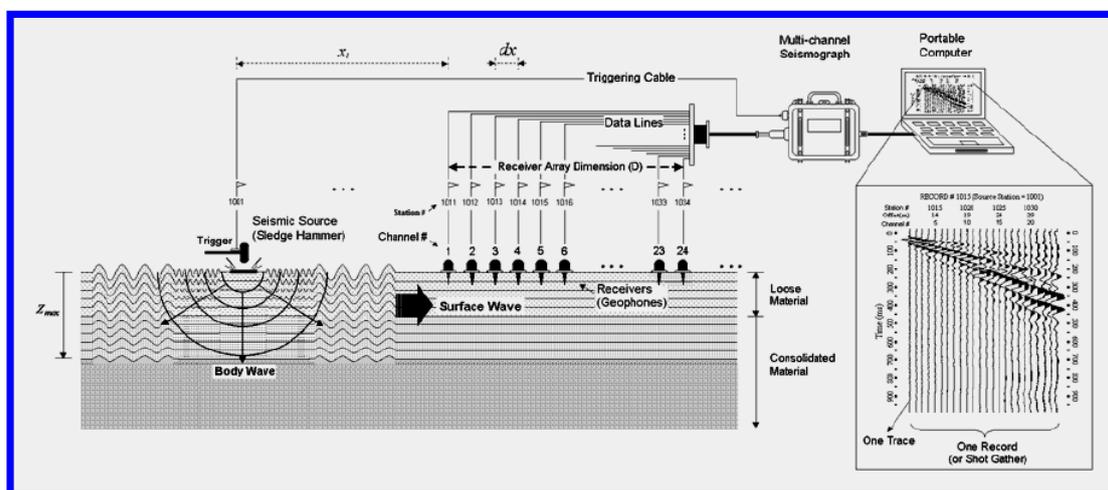

Fig. (17)   The MASW (Multi channel Analysis of Surface Wave) data acquisition configuration for determining the 1-D shear wave velocities

A weight drop 150 kg was used as a source of active MASW. Vertical stacking with multiple impacts can suppress ambient noise significantly and is therefore always recommended, especially if the survey takes place in an urban area. Low-frequency of 4.5 Hz geophones is used. Length of the receiver spread (D) as shown in Figure 17 is directly related to the longest wavelength (λ) that can be analyzed, which in turn determines the maximum depth of investigation (Zmax): On the other hand, (minimum if uneven) receiver spacing (dx) is related to the shortest wavelength (λ) and therefore the shallowest resolvable depth of investigation (Zmin). A one millisecond of sampling interval is most common with a 2-sec total recording time (T=2 sec). Figure 18 shows example of MASW profile at Zafarana site.
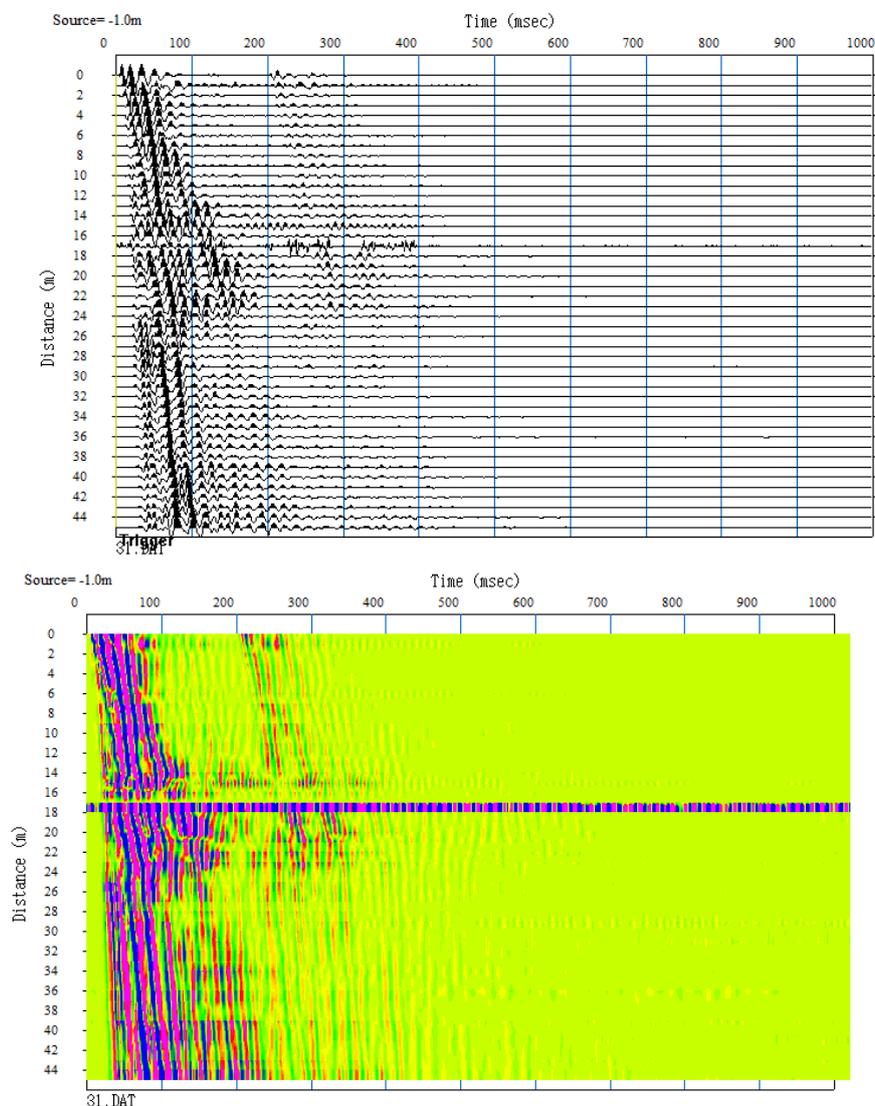

Fig. (18)   Surface wave data examples at Zafarana wind farm site

5.2 Seismic Data Processing

It was pointed out that, the true refractor velocities can't be determined by shotting at only one end of a seismic line, but such velocities can be determined if the arrival times are recorded from both ends. Further, a depth computed from an intercept time actually represents the depth of the refracting surface projected back to the shot point. The reversed profile, however, offers a significant advantage in that, the true velocities and thicknesses of layers can be computed beneath each geophone to allow the mapping of irregular and dipping boundaries by using several methods. The delay time method was discussed by many authors, [17,18,19,20]. The Wave Front method elaborated by; [21,22,23,24]. Hagiwara's method was explained by Masuda, [25]. The Plus-Minus method was discussed by Hagedoorn [26] and the Generalized Reciprocal Method (GRM) is introduced by Palmer [27]. On the basis of the first arrival P-waves picking up, the wave forms are analysed by picking the first breaks and determining the travel time-distance (T-D) curves and depth models using SeisImager software package, which is a complete seismic refraction processing and modelling software. It is based in its processing on the delay time and ray tracing methods for the determination of the specific depth for each refractor beneath each geophone. The MASW profiles were analysed using the SeisImager software package in order to obtain the dispersion curve at each profile and then inverse the phase velocity into shear wave velocity.

5.3 Seismic Interpretation

According to the first arrival P-waves and S-waves picking up, the wave forms are analysed. The deduced time-distance curves and the corresponding 2-D depth model at each profile are obtained in order to interpret the subsurface features.

By applying the MASW technique, we obtain the dispersion curves (phase velocity versus frequencies) and by inversion of the dispersion curves, we obtain the shear wave velocity model. Figure 19   lower panels shows the shear wave velocity model of all conducted seismic lines at Zafarana wind farm. Figure 20 lower panels shows the shear wave velocity model of all conducted seismic lines at Gabel Zeit wind farm.

5.4 Seismic Results

The results reveal that, the obtained subsurface layers consist of four to five layers in all the seismic profiles up to a depth of 30 m at Zafarana site. The first layer with a thickness of (2.5-7) m is formed from gravels and sands and silty sand (S-wave velocity varies from 450 to 903 m/sec). The second layer with a thickness of (3.5 to 8) m is made up of sands and gravels and with less physical properties (S-wave velocity in the range 460 to 860 m/sec). The S-wave velocities of the third layer are ranges between 520-920 m/sec respectively which is composed of sandstone. While the S-wave velocities of the fourth layer are ranges between 540-975 m/sec respectively which it is composed of claystone. The fifth layer is exposed only in two sites (at profile 4 and 6 only) with the S-wave velocities ranges from 700 to 1000 m/sec. The obtained subsurface layers at the expansion area at Gabel El Zeit site consist of three layers in two seismic profiles up to a depth of 30 m. The first layer with a thickness of 5 m is formed from gravels and sands and silty sand (S-wave velocity varies from 299 to 368 m/sec). The second layer with a thickness of 10 m is made up of sands and gravels and with less physical properties (S-wave velocity in the range 360 to 427 m/sec). The S-wave velocities of the third layer are ranges between 419-466 m/sec respectively which is composed of claystone as shown in Tables 3 and 4.

The average shear wave velocity up to 30 m depth which is known as V_{S30} is obtained and was used to classify the site according to International Building Code [28]. Table 5 at Zafarana site, the location of profiles p1, 2, p5, p6, P7 and p8 are belong to Class C while the location of profiles p3, p4 are belong to Class B. While at the expansion area at Gabel Ziet site the location of seismic profiles are belong to Class C and D respectively.
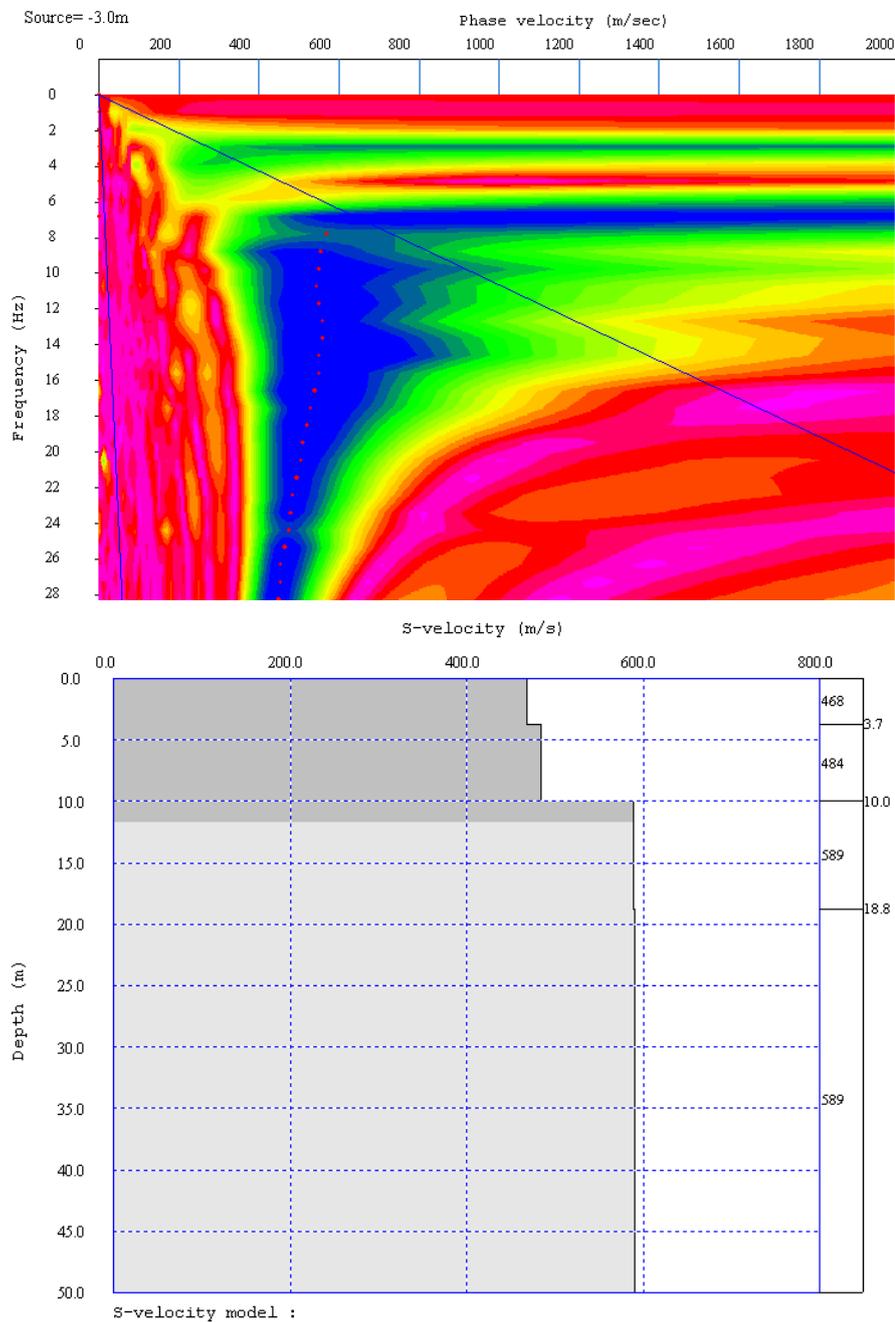
Fig. (19) The dispersion curve (upper panel) and S_wave velocity model (lower panel) for seismic line 1 at Zafarana wind farm
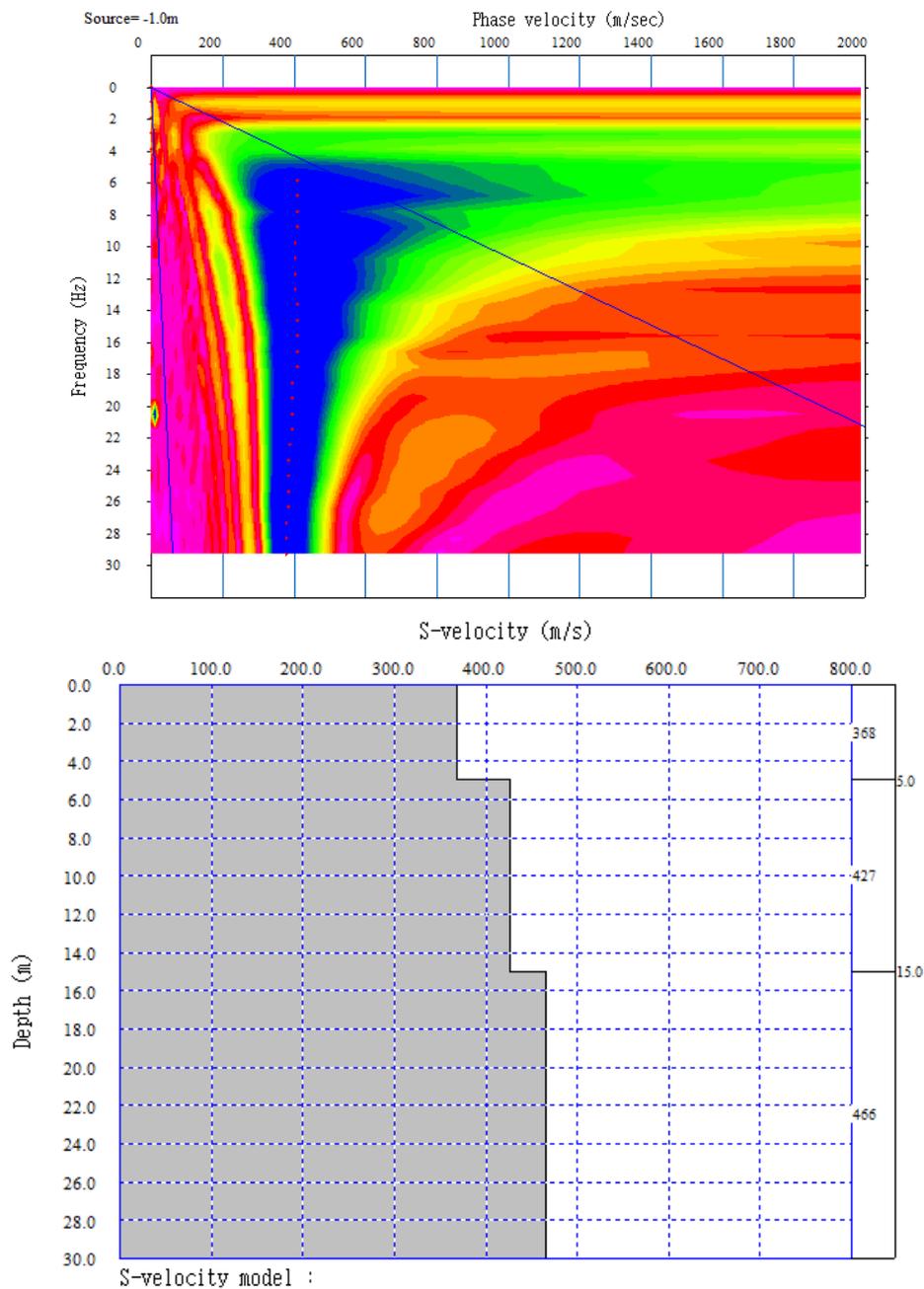
Fig. (20)   The dispersion curve (upper panel) and S_wave velocity model (lower panel) for seismic line 1 at Gabel Zeit wind farm

Table 3. Seismic profiles location and parameters at Zafarana wind farm site

area	profile no	latitude	longitude	vs (m/s)	depth (m)	layer no
Zafarana (1)	1	29.15894	32.61821	468	0 - 3.7	1
(Class C)				484	3.7 - 10	2
				589	10 - 18.8	3
				589	18.8 - 30	4
Zafarana (8)	2	29.15895	32.56264	604	0 - 3.7	1
(Class C)				550	3.7 - 10	2
				685	10 - 18.8	3
				773	18.8 - 30	4
Zafarana (2)	3	29.17914	32.60731	903	0-7.5	1
(Class B)				864	7.5 - 13.5	2
				918	13.5 - 21	3
				970	21 -30	4
Zafarana (3)	4	29.19418	32.60572	894	0 - 2.5	1
(Class B)				861	2.5 - 6	2
				893	6 - 10.5	3
				983	10. 5 - 16	4
				993	16- 30	5
Zafarana (6)	5	29.19461	32.5585	572	0 - 3.7	1
(Class C)				495	3.7 - 10	2
				692	10 - 18.8	3
				756	18.8 - 30	4
Zafarana (4)	6	29.21088	32.59975	629	0 - 3	1
(Class C)				601	3 - 7.5	2
				636	7.5 - 13.5	3
				684	13.5 -21	4
				717	21 - 30	5
Zafarana (5)	7	29.29463	32.58329	448	0 - 2.5	1
(Class C)				470	2.5 - 6	2
				531	6 - 10.5	3
				545	10.5 - 30	4
Zafarana (7)	8	29.2529	32.59395	634	0 - 3.7	1
(Class C)				634	3.7 - 10	2
				638	10 - 18.8	3
				693	18.8 - 30	4

Table 4.   Seismic profiles location and parameters at the expansion area at Gabel El Zeit site

area	profile no	latitude	longitude	vs (m/s)	depth (m)	layer no
(Class C)	1	28.16815	33.1395	368	0- 5	1
				427	5-15	2
				466	15 - 30	3
(Class D)	2	28.15585	33.1579	299	0- 5	1
				360	5-15	2
				419	15 - 30	*3*

Table 5. International building code (IBC 2006)

Site Class	Soil Profile Name	Average Properties in Top 100 Feet		
		Shear Wave Velocity Vs (ft/sec)	Standard Penetration Resistance N	Soil Undrained Shear Strength Su (psf)
A	Hard Rock	Vs> 5000	N/A	N/A
B	Rock	2500 < Vs <= 5000	N/A	N/A
C	Very Dense Soil and Soft Rock	1200< Vs <= 2500	N> 50	Su>= 2000
D	Stiff Soil Profile	600< Vs <= 1200	15<= N <= 50	1000<= Su <= 2000
E	Soft Soil Profile	Vs< 600	N< 15	Su> 1000
E	—	Any profile more than 10 feet of soil having the following characteristics: 1. Plasticity Index PI > 20 2. Moisture Content w>= 40% and 3. Undrained shear strength Su < 500 psf		
F	—	Any Profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays , collapsible weakly cemented soils. 2. Peats and / or highly sensitive clays (H > 10 feet pf peat and / or highly organic clay where H = thickness of soil) 3. Very high plasticity clays (H > 25 feet with plasticity index PI > 75) 4. Very thick soft/ medium stiff clay (H > 120 feet)		

6. CONCLUSIONS

This work presents one of the pioneer studies concerning the investigation of the geological, geotechnical and geophysical characterization and criteria   of the zafarana wind farm sites and their expansion at Gabel Al Zeit sites Egypt. Both geotechnical design parameters and geophysical parameters are evaluated and presented. The conclusions from the current study can be summarized as below:-

- Geological investigation indicate that, the study area consists of coastal and wadi deposits. There are no intensive faults at Zafarana area.

- Geotechnical investigation at Zafarana wind farms shows that, the site consists of five main formations, which are Wadi deposits, Clay, Claystone, Sand and Sandstone.
- The geophysical   analysis demonstrates that the subsurface section is composed of three to five layers at Zafarana wind farm, the second layer is characterized by its less physical properties (S-wave velocities). While the expansion area at Gabel El Zeit site the subsurface section composed of 3 layers up to 30 m depth.
- Geophysical investigation results reveal that, the obtained subsurface layers consist of four to five layers at Zafarana Wind Farm Sites. The first layer formed from gravels and sands and silty sand with average S-wave velocity varies from 500 m/sec. The second layer is made up of sands and gravels with average S-wave velocity 600 m/sec. The S-wave velocities of the third layer has an average value equal to 800 m/sec respectively which is composed of sandstone. While the S-wave velocities of the fourth layer with average 700   m/sec respectively which it is composed of claystone.
- Also Geophysical investigation results at Gabel El Zeit Wind Farm Sites shows that the subsurface soil conditions consists of three layers of gravely sands with average shear wave velocity 350 m/sec.
- The average shear wave velocity up to 30 m depth which is known as VS30 is obtained and was used to classify the site according to International Building Code (IBC-2006), Where   at Zafarana sites, the location of profiles p1, 2, p5, p6, P7 and p8 are belong to Class C while the location of profiles p3, p4 are belong to Class B. While at the expansion area at Gabel Ziet sites the location of seismic profiles are belong to Class C and D respectively.

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