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ASSESSMENT OF SWELLING POTENTIALITY OF CLAY AT EL-FAYOUM NEW CITY: GEOTECHNICAL AND SHALLOW SEISMIC REFRACTION PROSPECTING

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تقييم إمكانية انتفاش الطين في مدينة الفيوم الجديدة بالطرق الجيوتقنية والانكسار السيزمي الضحل

الخلاصة: تمثل مدينة الفيوم الجديدة واحدة من المدن العمرانية الجديدة التي تم تأسيسها مؤخرا في مصر. تعتبر التربة الإنتفاشية في مدينة الفيوم الجديدة من بين المواد الخطرة التي تنتفش عند التشبع بالماء. وتمثل هذه التربة إشكالية للمهندسين المعماريين والمدنيين عند استخدامها كمواد تأسيس تدعم أنواع مختلفة من التراكيب الهندسية وقد تسبب هذه الأنواع من التربة أضرارا بالغة للأرصفة والمباني. التربة الإنتفاشية هي تربة طينية تحتوي علي كمية كبيرة من معدن المنتموريلينيت الذي لديه خاصية الإنتفاش أو الانكماش عند التغير في محتوي الرطوبة.

أجريت العديد من الاختبارات المعملية لتحديد نسبة إنتفاش الطين من خلال حساب الخواص الفيزيائية مثل: المحتوي المائي والكثافة بالإضافة إلي الخواص الجيوتقنية مثل: حدود أتيربرج ومعامل التماسك ونسبة الانتفاش الحر وتم أيضا تحليل التركيب المعدني للطين بإستخدام حيود الأشعة السينية.توثق نتائج الإختبارات المعملية وجود طبقات من الطين تتكون اساسا من المنتموريلينيت التي تتسبب في زيادة احتمال انتفاشية التربة في المنطقة قيد الدراسة.

بالإضافة إلي ذلك تم العثورعلي عدة طبقات طينية رفيعة متداخلة مع الرمال وبلورات من الجبس في منطقة الدراسة.كان سمك هذه الطبقة الطينية في بعض الأحيان أقل من درجة الوضوح السيزمي وفي أوقات أخري أعلي منه. علاوة علي ذلك، تم تحديد درجة الوضوح السيزمي الرأسية للكشف عن سماكة طبقات الطين الرقيقة التي تسبب إنتفاشية التربة والتي بدورها تلحق أضرارا بالغة بالأساسات وتشققات بالمباني المعمارية . وأخيراً تم التوصية ببعض الحلول المقترحة لحل هذه المشكلة.

ABSTRACT: *El-Fayoum New City represents one of the new urban settlements that are recently founded on some parts over Egypt. Expansive soils in El-Fayoum New City are considered among the difficult foundation materials and expand upon wetting. They are considered problematic soils for architectural and civil engineers, when used as foundation materials to support various types of civil engineering structures. This type of soils may cause minor to major structural damages to pavements and buildings. Expansive soils are clay soils containing considerable amount of montmorillonite clay mineral, which has a potential for swelling or shrinking, due to changes in its moisture content.*

Many laboratory tests were carried out to determine the swelling clay behavior. Physical properties such as, bulk density water content and as well as geotechnical properties, like Atterberg limits, consistency index and swelling potentiality have been achieved. Mineralogical composition of clay was also defined using X-ray diffraction. Results of the laboratory tests document the presence of clay layers that are composed essentially of montmorillonite, which cause high swelling potentiality of soil in the area under study.

Several thin clay layers intercalated with sand and gypsum pockets are found in the study area. The thickness of these clay layers is sometimes below the seismic resolution and in other times above it and can be resolved. Moreover, the vertical seismic resolution has been determined to detect the thickness of thin clay layers that may cause soil swelling which in turn, severely damage the foundation and crack the building structures. Finally, essential solutions for this problem were recommended.

INTRODUCTION

The proposed site of El-Fayium New City is located southeast of El-Fayoum City, between latitudes 29°12′ and 29°14′N and longitudes 30°52′ and 30°54′E, as shown in the location map of the study area (Fig. 1). El-Fayium New City is established at desert arid place outside the Nile Valley. Most of these desert places are made up of problematic soils, due to its dry state conditions which effect on its moisture content (Farid and Hamid, 2013).

Geology and Stratigraphy of El-Fayoum New City

The surface of the site is mainly exposed of gravely sand, shale, marl and marly limestone. The geologic map (Fig. 2) and stratigraphic succession (Fig. 3) of El-Fayium New City area reveal a complex sequence of sedimentary rocks ranging in age from Eocene to Quaternary. The shallower part of the geologic section is mainly composed of sand and thin clay layer intercalations with thicknesses almost below the seismic resolution (undetectable). Sometimes, these thin clay layers are above the seismic resolution and can be resolved (detectable). The previous geological and geophysical studies in the area under investigation indicate that the folds in the area are represented by Naalon Mountain with NE-SW direction and two types of normal fault systems are affecting in Fayoum area as North Fayoum depression-Qaroun Lake which is extending NW-SE direction and Gabal Naalon normal fault system which is extending in E-W direction.

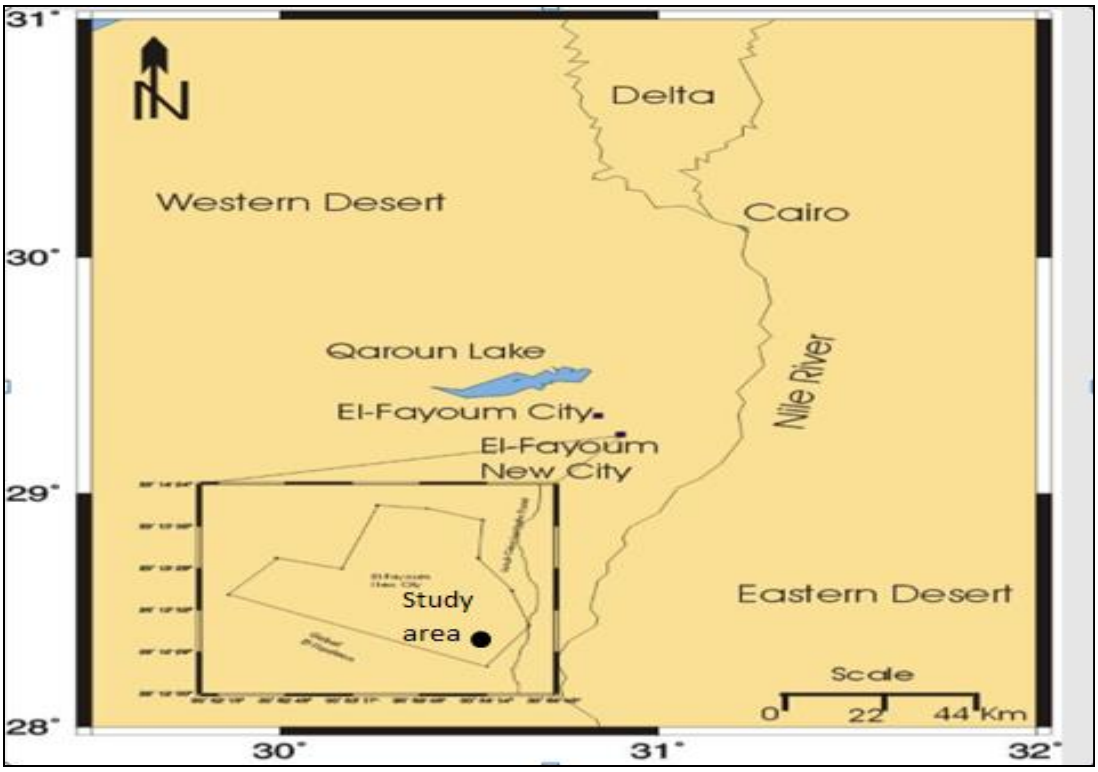


Fig. (1): Location map of El-Fayium New City.

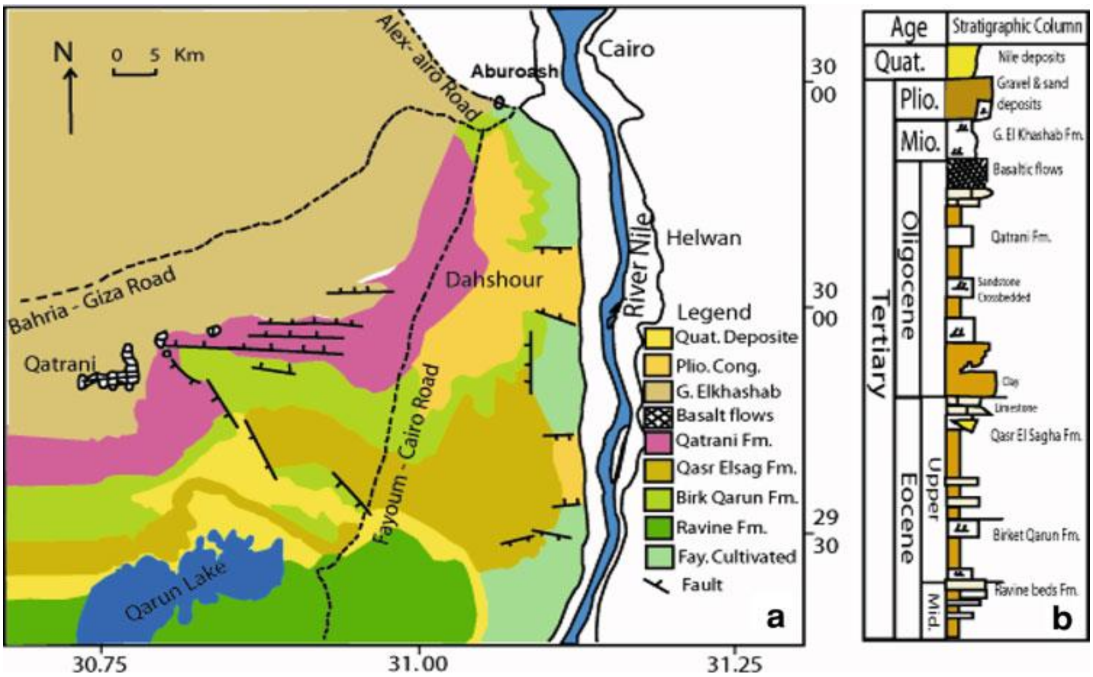


Fig. (2): Geologic map of El-Fayoum area. (After Naim et al., 1993).

Age			Formation	Lithological description
Quaternary	Holocene		-	Sand, sandstone, clay, silt.
	pleistocene		-	Sand, gravel, shale, gypsum, claystone, calcareous material intercalated with ferruginous sandy sandy silt.
Tertiary	Pliocene		-	Sand, gravel, conglomerate.
	Miocene		Gebel El-Khashab	Sand, gravel.
	Oligocene	U.	Widan El Faras	Basaltic flows.
		L.	Qatrani	Sand, sandstone with calcareous clay.
	Eocene	U.	Qasr El Saga	Shale, limestone, sand, sandstone.
			Birket Qaroun	Clay with calcareous sand.
		M.		
			Gar Gehannam	Shale, marl, limestone, sand.
			Wadi El Rayan	Clay, marl, limestone.

Fig. (3): Stratigraphic succession of El-Fayoum area (after Swedan, 1986).

Expansive Soils

Clay soils have a significant hazard, if it is used as a foundation material under buildings founded on them. Among the different types of clay soils, there are many that swell (heave) considerably, when water is added or absorbed to them and shrink with lose of water. This type of soil is termed as expansive soil (Coduto et al., 2010). When these soils are loaded, by a structure or man-made fill, deformation will occur. This deformation may be downward and it called settlement or upward which is then called heave. Heave will result, if the pressure exerted by the pavement or building is less than the swelling pressure. The heave is usually uneven and causes structural damage (Holts and Kovacs, 1981).

Expansive soil can be classified into two main types with respect to the parent rock. The first type comprises the basic igneous rocks, such as basalt, in which the feldspar and pyroxene minerals of the parent rocks have decomposed to form montmorillonite and other secondary materials. The second type has the sedimentary rock that contains montmorillonite as a constituent, which breaks down physically to form expansive soils (Chen, 1975).

Factors Causing the Clay Swelling

Changes in the moisture content of the soil may cause changes in the behavior of expansive soils; when an increase in the moisture of expansive soil occurs, it causes the soil to expand (swell) and heave. According to Gromko (1974), Tomilson (1980), Hunt (1984), Hunter (1988) and Murphy (2010), some reasons that responsible for clay swelling are:

- Rainfall and rise in the ground water table,
- Reducing the load condition, such as surcharge loads increases the swell,
- Dry density, dense clays will swell more, when they are wetted than the same clay at lower density with the same moisture content,
- Type of mineral components and their amounts, soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics, and
- Transpiration; the roots of trees and shrubs can extract considerable quantities of water from the surrounding soil which aggravate the swell and shrink problem.

The problem of swelling in the study area, affecting constructions and pavements is a result of increasing of moisture content due to the presence of gardens and parks appended houses and buildings. Also, uncontrolled irrigation of these agricultural areas may increase the amount of water seepage, which causes increasing in the moisture content of the soil.

MATERIALS AND METHODS

Laboratory tests were done for **twenty five samples** for studying their geotechnical properties, seventeen of them were collected from the foundation level at the study area and eight samples at Naalon mountain which lied about 2.7 km due south (Figs. 4 and 5).

Housing and Building National Research Center (November 2010) carried out **twenty boreholes** in El Fayoum New City. The depths of these boreholes are ranging from 15 m to 18 m with total length 340 m. The location map of these boreholes is given in Fig. (6).

Ten shallow seismic refraction profiles were conducted at the site of interest for the generation of seismic waves. Construction of 2D Velocity Models was achieved, after applying the more advanced interpretational methods for our processed seismic data.

RESULTS AND DISCUSSION

- Sample Evaluation of the Study Area: Fig. (6) Illustrates the locations of samples, which are collected from the foundation layers at Fayoum New City and Naalon Mountain. Physical, geotechnical and mineralogical composition of soil materials are evaluated as follows:

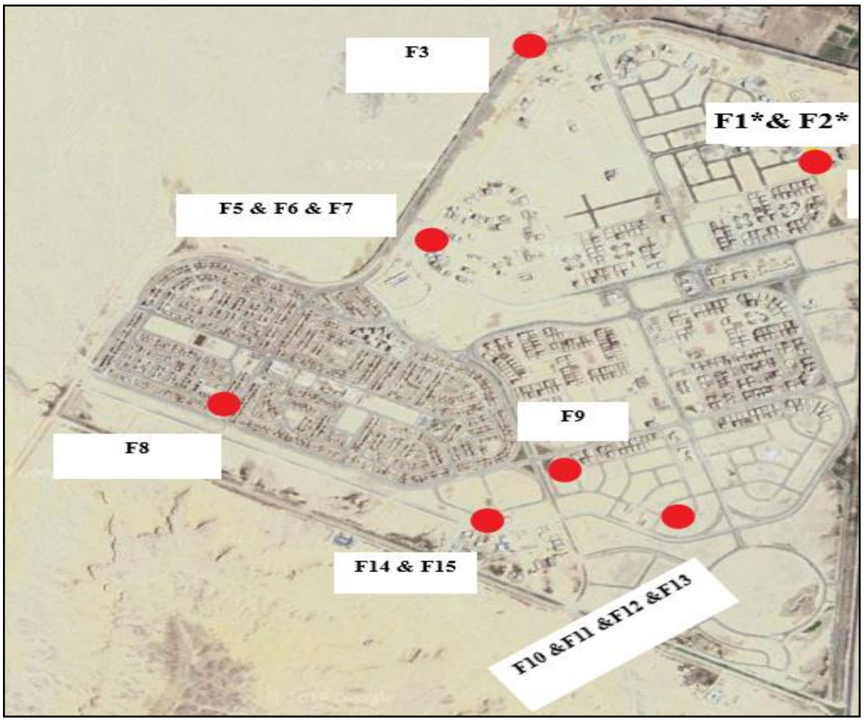


Fig. (4): Sample location map from foundation at Fayoum New City.

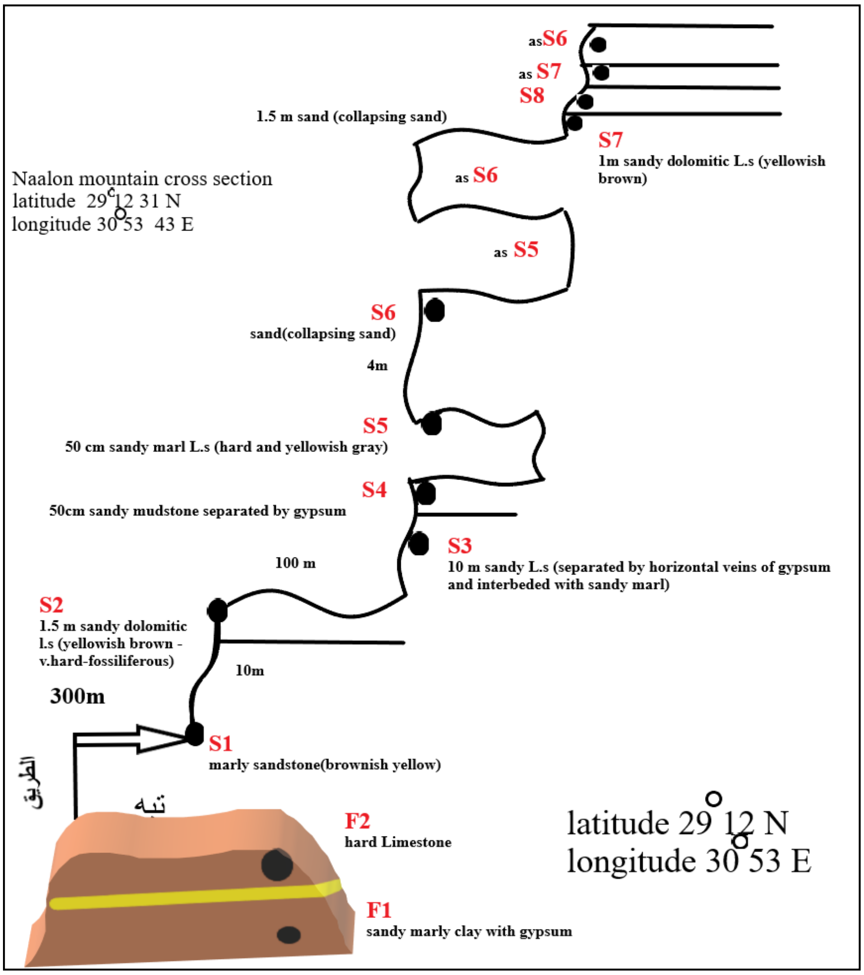


Fig. (5): Cross-section of samples collected from Naalon Mountain.

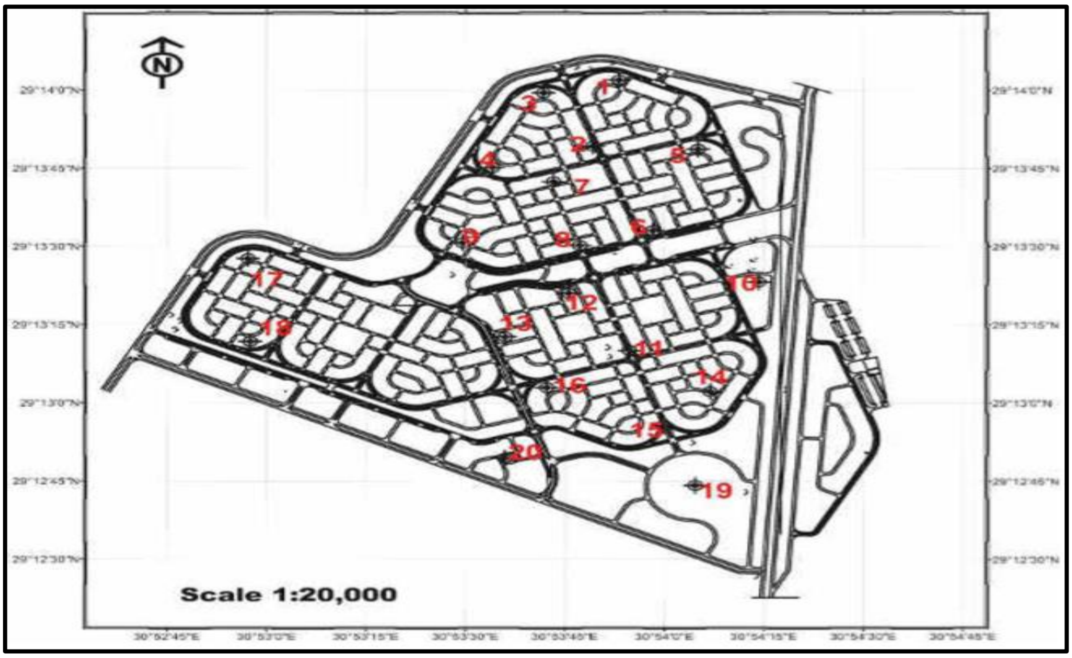


Fig. (6): Locations of the boreholes at Fayoum New City.

Table (1): Soil property of the studied clay samples.

Soil property / Description of soil	No. of soil sample							
	F1	**S4**	**F1***	**F5**	**F7**	**F10**	**F12**	**F14**
	Sandy marl clay with gypsum	**Sandy mudstone separated by gypsum**	**Sandy clay**	**Claystone**	**Claystone**	**gray brownish clay**	**gray brownish clay**	**Marly clay**
Free Swelling (%)	**70**	**60**	**160**	**100**	**50**	**100**	**170**	**30**
Liquid limit (%)	**53.7**	**58.7**	**70.9**	**45.7**	**40.8**	**66.2**	**78**	**30.2**
Plastic limit (%)	**32**	**31.2**	**39.9**	**41.5**	**25.6**	**45.8**	**53.8**	**18.1**
Shrinkage limit (%)	**22.7**	**20.6**	**25**	**38.8**	**20**	**32.7**	**36.3**	**15**
Plasticity index (%)	**21.8**	**27.6**	**31.1**	**4.2**	**15.2**	**20.4**	**24.2**	**12.1**
Water Content (%)	**3.6**	**3.3**	**3.7**	**7.1**	**1.7**	**2.3**	**5.9**	**3.3**
Bulk density (gm/cm^3)	**2.1885**	**1.739**	**1.95**	**1.788**	**1.81**	**1.95**	**2.139**	**1.96**

1) **Physical Properties** of studied soil samples are represented by water content and bulk density.

✓ **Water content**: it is the ratio of the weight of water to the total weight of the sample after drying (oven drying method). The results of the water content of studied samples given in Table (1) were measured according to ASTM; D 2216 (1994), that is ranged from 1.7 % to 7.1 % with an average 3.86 %.

✓ **Bulk Density:** the density of a sample is the ratio of the weight of a given sample to its volume which is calculated according to ASTM; D 2937 (1994). The results range from 1.74 gm/cm^3 to 2.19 gm/cm^3.

2) **Geotechnical Properties** of studied soil samples are represented by Atterberg limits, consistency indix and swelling potentiality.

- ✓ **Atterberg Limits:** They are the water contents at which the soil material behavior passes from one state to another through four stages. These states include solid, semi-plastic solid, plastic and liquid. Water content greatly affects the engineering behavior of the fine-grained soils. The water contents at the boundary of these states are known as Atterberg limits. These limits include liquid, plastic, and shrinkage limits.

Liquid limit (L.L) is the moisture content at which any increase in the moisture content will cause a plastic soil to behave as a liquid. By using the standard liquid limit device (Casagrande, 1958) the results of the liquid limit of studied samples (ASTM; D4318, 1994) range between 30.2 % and 78 % with average 55.47 % as shown in Table (1). Most of soil samples results fall in the marginal to high swelling potential according to Snethen et al. (1977) classification.

Plastic limit (P.L) is the water content at which the soil begins to crumble when rolled into threads of specified size. The plastic limit like the liquid limit depends on the types and amounts of clay in the soil (Arora, 1988). The results of the plastic limit of some of studied samples are ranging from 18.1 % to 53.8 % with average 35.98 %. These soils are considered as high plastic soil due to their high clay contents.

Shrinkage limit (S.L) is the maximum water content at which a reduction in water content will not cause a decrease in the volume of soil mass. It can be approximately determined graphically, if the plasticity index and liquid limit are known (Das, 1994). This is done by plotting the data of liquid limit and plasticity index on the plasticity chart (Fig. 7). Soils with low shrinkage values are characterized by presence of high amount of montmorillonite mineral, while soils with high shrinkage values have high amount of kaolinite mineral (Mitchell, 1976). The results of shrinkage limit range from 15 % to 38.8 % with average 26.4 % as shown in Table (1). Sample F14 has lower shrinkage limit (15 %) and 100 % montmorillonite mineral, while sample F12 has higher shrinkage limit (36.3 %) with only 76% montmorillonite mineral and 23% kaolinite mineral.

- ✓ **Consistency Indices:** The plasticity index is the range of water content, over which the soil exhibits a plastic behavior, and can be calculated as follows (Nelson and Miller, 1992):

P.I = L.L – P.L

Where P.I: Plasticity Index, L.L: Liquid Limit and P.L: Plastic Limit.

The results of plasticity index of some of studied samples are in the range of 4.2 % and 31.1 % with average 19.5 % as listed in (Table. 1). According to the soil classification by Holtz and Gibbs (1956), the plasticity index of the collected samples is ranged from low to high expansive soils. Most of collected samples lie under A-line; the studied soils are classified as inorganic clays of low to medium plasticity, silty clays, lean clays, and inorganic silt and inorganic clays of high plasticity according to the Unified Soil Classification System (USCS), ASTM D2487-2011.

- ✓ **Swelling Potentiality:** The swelling potential of the expansive soil can be identified in the laboratory either by direct or indirect methods. The direct methods which used to identify expansive soils are more reliable and depend on the use of several types of swelling devices. Indirect methods include free swelling, mineralogical composition, and plasticity index.

- **Free swelling:** is the increase in volume of soil without any external constraint when subjected to submergence in water according to Holtz and Gibbs (1956). The results of free swelling are ranged between 30 % and 170 % with average 92.5 % as shown in (Table. 1). Some samples with free swelling below 50.0 % do not mean that these samples are not having change in its volumes. Dawson (1953) reported that some of clay samples of Texas with free swelling values in range of 50.0 % have caused significant damage through expansion, due to the extreme climatic conditions in combination with the expansion characteristics of the soil.

- **Mineralogical Composition of Clay in El Fayoum New City:** Mineralogy of clay can cause a soil to increase in volume in case of accompanying by water. Three main clay minerals can be detected from X-ray diffraction analysis:

Smectite group is represented by Montmorillonite, which is considered as an expansive soil and has a wide range of plasticity index values. Its mineralogical structure allows water molecules to penetrate between their sheets causing the expansion. By increasing water content, the structure of mineral became unstable.

Kaolinite group is considered as non-expansive clay mineral which has lower plasticity index values than the expansive soil and resist water to penetrate its mineralogical structure.

Illite group can be expansive but when compare it with montmorillonite, its structure tends to attract less water and so it has less swelling-shrinking characters (Beavis, 1985).

Table (2) shows the percentage of clay fraction in the study area and Fig. 8 shows three run charts of three clay samples (F5, F12 and F14) by X-ray diffraction.

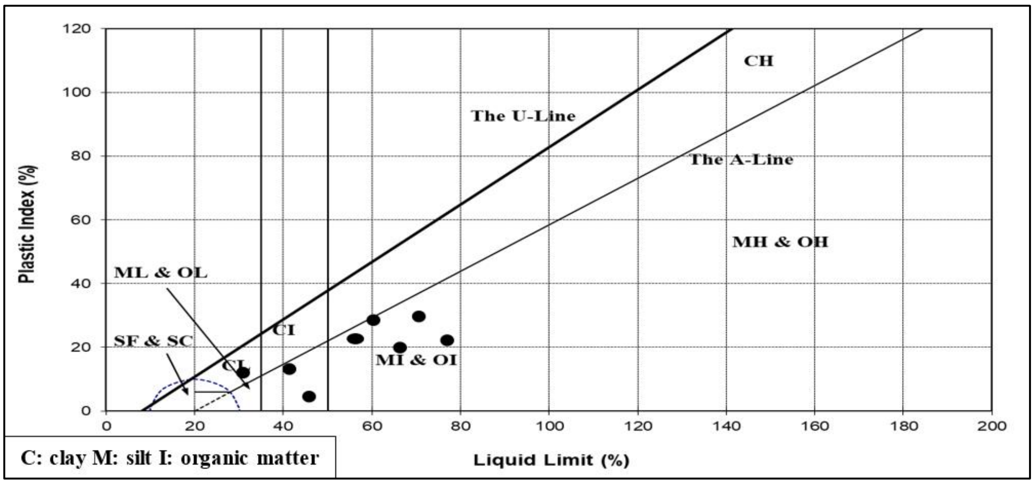


Fig. (7): Unified soil classification of the studied samples using the chart of Casagrande (1948).

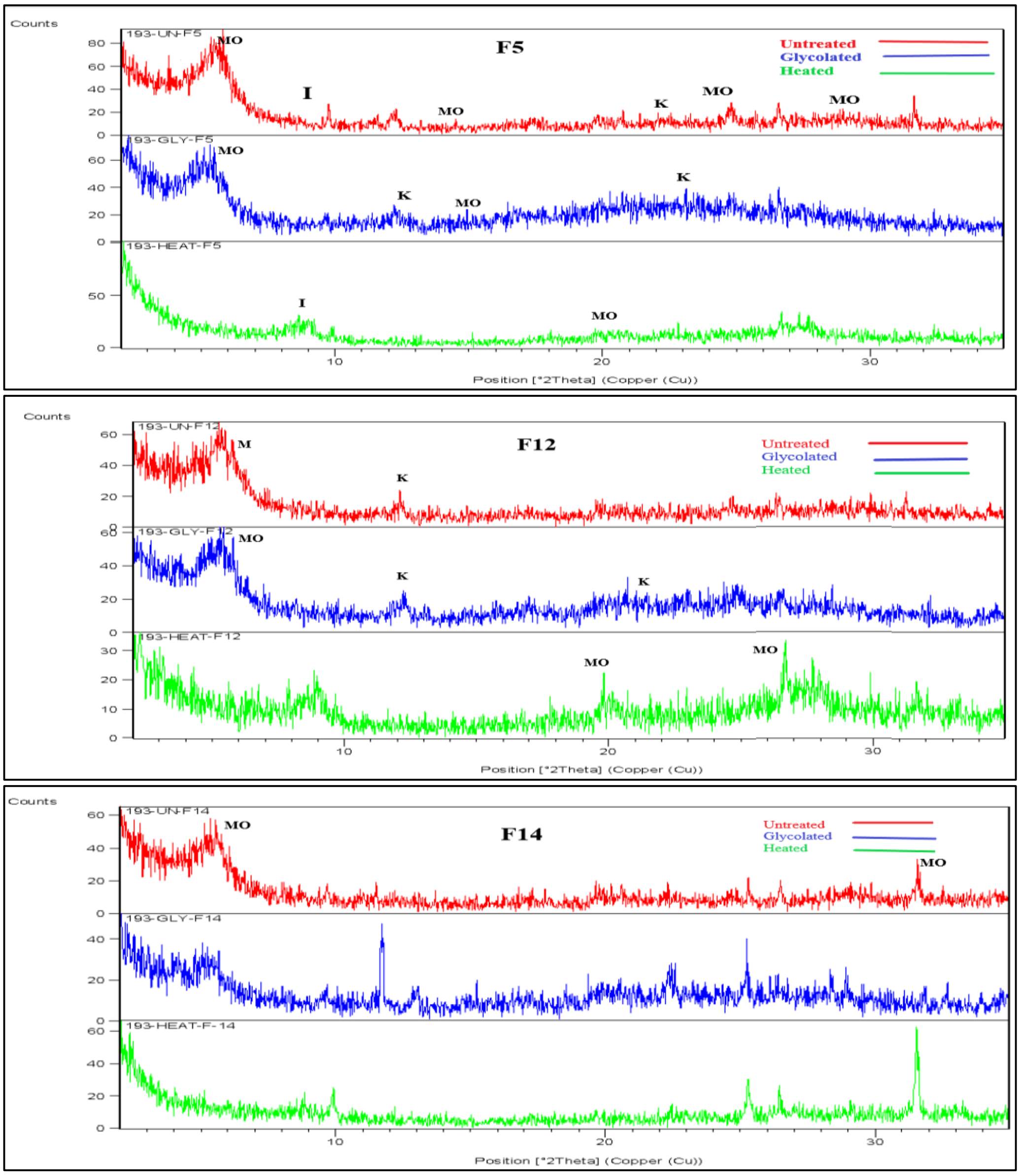


Fig. (8): X-ray diffracts grams of the powder and treated clay fractions of different samples (F5, F12, F14), MO: Montmorillonite, K: Kaolonite and I: Illite.

Table (2): XRD patterns of the studied clay samples.

Samples	Clay Minerals	Ref. code	Chemical formula	Equivalent (%)
F5	Montmorillonite-calcine	00-058-2008	Ca0.2 (Al , Mg)2 Si4 O10 (O H)2 ·x H2 O	70.45 %
	Kaolonite-1A	00-058-2005	Al2 Si2 O5 (O H)4	5.636%
	Illite	00-002-0056	K Al2 Si3 Al O10 (O H)2	23.85%
F12	Montmorillonite-calcine	00-058-2008	Ca0.2 (Al , Mg)2 Si4 O10 (O H)2 ·x H2 O	76.2%
	Kaolonite-1A	00-058-2005	Al2 Si2 O5 (O H)4	23.78%
F14	Montmorillonite-calcine	00-058-2009	Ca0.2 (Al , Mg)2 Si4 O10 (O H)2 ·x H2 O	100%

The mineralogical analysis has shown that all samples were essentially montmorillonite in addition to some kaolinite and illite as clay minerals in a descending order.

Borehole Lithological Description:

Fig. 9 is a borehole (B.H.20) log showing a soil classification as: calcareous siltstone, calcareous clayey silt and calcareous siltstone with clay intercalations according to Housing and Building National Research Center (November 2010).

Twenty boreholes were carried out to investigate the underneath soil properties, three of them found that the swelled soil layer was in wet case. Free swelling index readings were in the range of 30 % and 170 %. After building the constructions, it is noticed that houses are suffering from cracks appeared in the concrete structures (beams and columns). The swelling soil in this area was observed in sample F14 which has montmorillonite mineral as 100 %, from XRD analysis as shown in Table (2). Thus, any change in underneath moisture content of soil will cause soil expansion and move the footings up arising severe building cracks, as shown in Fig. (10). This figure shows one of the buildings suffering from cracks where the same location of B.H. (20).

Also, a horizontal soil movement may occur, leading to widening of cracks at the upper floors of building, as shown Fig. (11). In most cases, cracks due to shrinkage and expansive clay usually run from corner towards the adjacent openings and are uniform in width or v-shaped (Abdel-Latif, 2008), Fig. (12) shows the cracks observed at the light structures.

Treatment Methods of Expansive Soils

Several techniques have been suggested to minimize the swelling effect of the expansive soils on the structural elements at El-Fayoum New City depending on the engineering experience such as chemical admixtures, soil replacement, electrochemical soil treatment methods, surcharge loading system and sand cushions.

In Egypt, one of the most common techniques is used of replacement soil by different granule beneath shallow foundations. Particularly, if this layer has a thin thickness and shallow, it is easy to remove. Also, backfilling soil can be used as a foundation. Choosing the different backfilling materials and their depths are related to the problematic expansive soil formation depth and its properties. Control water fluctuation and suitable drainage system for surface and subsurface water are essential in collecting water away from homes. Irrigation water in parks and gardens, particularly near the structures should be minimized in order to avoid the water leakage under foundation.

- Seismic Refraction Measurements

Seismic refraction technique is the most powerful method in the near-surface geophysical investigations. Seismic refraction data interpretation is usually used for depth determination and true velocities calculation under the shot points, as well as beneath each geophone. Interpretational methods, based on the delay time, plus-minus, generalized reciprocal time and ray-tracing are well explained in the literatures, (e.g. Hagedoorn, 1959; Redpath, 1973; Palmer, 1980 & 1986; Zhu and McMechan, 1989; Matsuoka et al., 2000; and Palmer and Jones, 2003).

Seismic Acquisition

During the seismic field measurements, a multi-channel seismograph (OYO McSeis 1500 - 24-Channels Seismograph) was used. This device is used for recording, filtering and stacking of the seismic data. A sledgehammer (18 kg) was used as a source of energy in this survey and seismic waves were generated by repeating impacts (stacks) on a steel plate.

Stacking was always done through several impacts for signal enhancement, till a good data quality is reached. Twenty-four vertical component geophones with natural frequency of 14 Hz were planted into the ground to convert ground movements (displacements or vibrations) into electrical pulses (voltages). The raw data in the form of travel time-distance curves are manipulated to convert them into the format of velocity variations with depth as velocity-depth models or Velocity Models.

Ten shallow seismic refraction profiles were conducted at the site of interest for generation of seismic waves, as shown in seismic profiles location map (Fig. 13). The length of each seismic profile was 187.5 m with a geophone interval equals only 7.5 m for all profiles, the distance between the two end shot points and the nearest geophone was 7.5 m and the distance between the middle split-spread shot point and their nearest geophones were half geophone interval 3.75 m. Some selected shot gathers (seismograms) are shown in Figs. 14 and 15.

Scale	Depth (m)	Lithology	Soil Classification of B.H.20	Thickness (m)	Free swelling (%)	Clay type	RQD (%)
	3		Calcareous siltstone with gypsum pockets and silt joints, yellowish brown	3	-		-
	6		Calcareous clayey silt with gypsum pockets, yellowish brown	8			-
	9				80-130	CH	
	12						
	15		Calcareous siltstone with clay intercalation, yellowish brown	4	-		-

Legend: According to the Unified Soil Classification System (USCS), ASTM D2487-2011 Classification of clay is: CH (Inorganic clays of high plasticity), CL (Inorganic clays of low to medium plasticity, silty clays and lean clays).

Fig. (9): Borehole (B.H.20) log.

Fig. (10): Borehole (B.H.20) was drilled near the defected building.

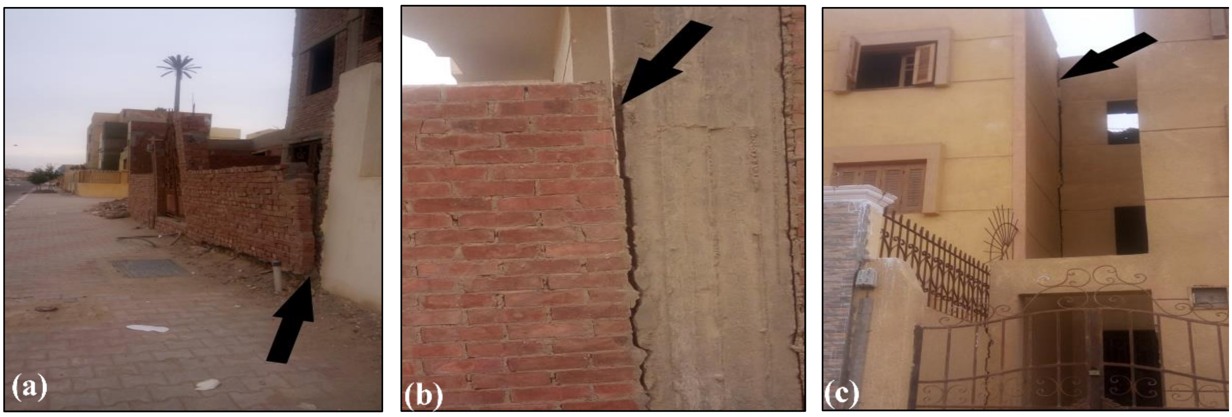


Fig. (11): Cracks observed at foundation elements.

Fig. (12): Cracks observed at light structures.

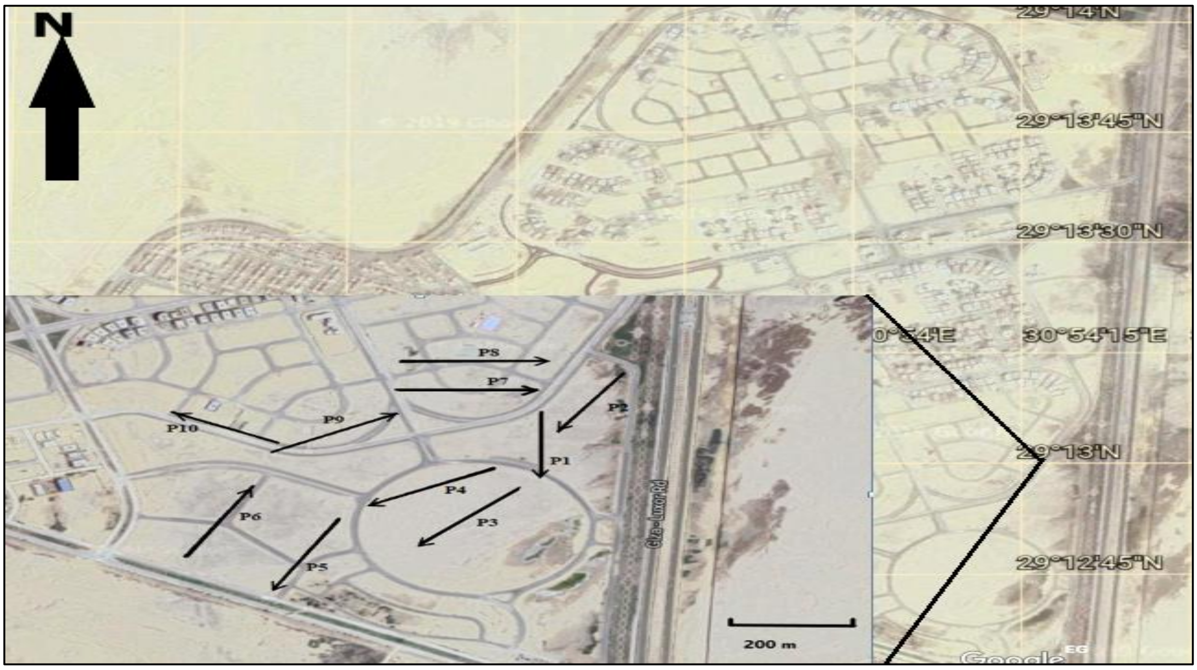
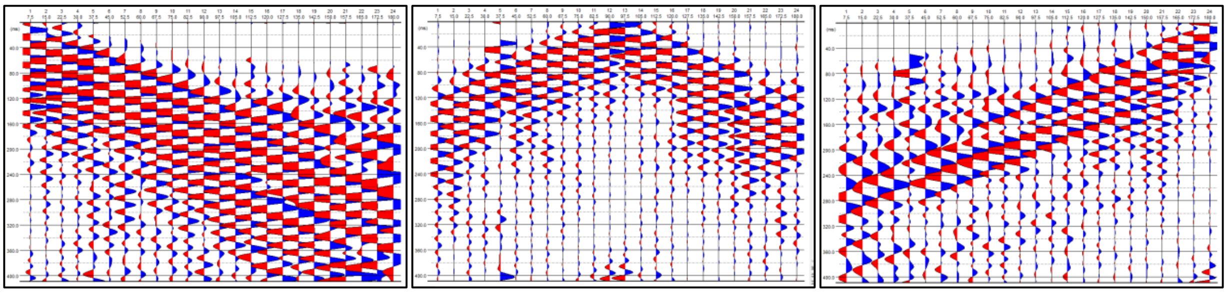
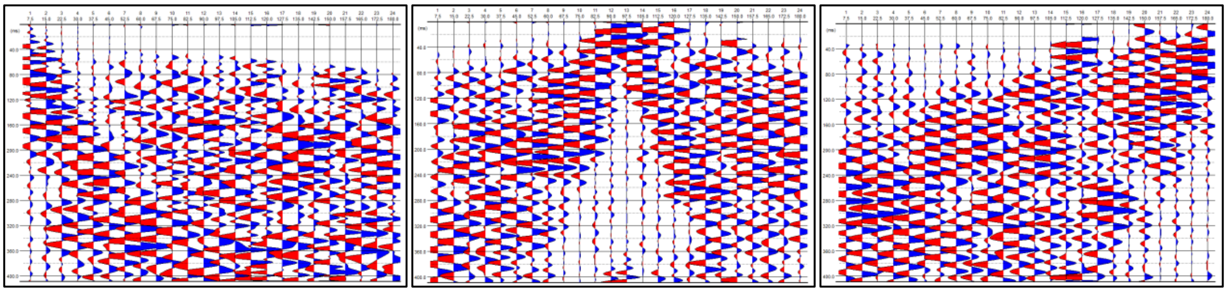


Fig. (13): Seismic profiles location map.



Normal shot **Middle shot** **Reverse shot**

Fig. (14): Shot gathers of profile 7.



Normal shot **Middle shot** **Reverse shot**

Fig. (15): Shot gathers of profile 9.

Seismic Processing

Recent software packages (ZondST2D, 2017 and Geogiga Seismic Pro 7.1) have been used for seismic data processing and interpretation. The used filters were band reject, band pass, low pass and high pass, to pass the frequency band width (15-100 Hz), which expresses the real data.

Seismic Interpretation

After filtering the data picking of the peaks of the first arrival times of the P-waves, the next step is to get the time-distance curves, that are used for seismic interpretation and building the 2D velocity models or geo-seismic sections. Some selected time-distance curves were established along the acquired profiles, as shown in Figs. 16 and 17.

Building of 2D Velocity Models was achieved after applying the more advanced interpretation methods for our processed seismic data that were measured in the study area. **Smoothed inversion** was carried out for all profiles under study and 2D smoothed velocity models were built. By applying **the layered inversion** algorithm on the smoothed model using the geological information of the area a new-layered 2D velocity model would be producted; which is more reliable and matched to geologic features than the smoothed velocity model.

Four sedimentary layers have been identified in the suggested geoseismic cross sections Figs. 18 and 19. At the depth range of about 50 m, with widely variable layer thicknesses and velocities. The shallower part of the sedimentary section in this area is represented by the following layers, that are confirmed by the borehole drilling results:

Layer 1: Topsoil calcareous sandy silt, with compressional wave velocity in the range of 400-800 m/s and its thickness ranges between 1 m and 5 m.

Layer 2: Calcareous clayey siltstone, with compressional wave velocity in the range of 910-2200 m/s and its thickness ranges between 2 m and 16 m.

Layer 3: Calcareous clayey silt, with compressional wave velocity in the range of 1490-2560 m/s and its thickness ranges between 15 m and 34 m.

Layer 4: Ferruginous sandy silt, with compressional wave velocity in the range of 1630-3530 m/s and unknown thickness.

Seismic Resolution

Seismic resolution is defined as the ability to separate two features, which are very close together (Brown, 2004). Resolve means to separate into two parts. Determination of resolution within seismic surveying depends on: 1) Quality of the raw data, 2) Frequency bandwidth, 3) Source response characteristics, and 4) Nature of the vertical sequence of the possible reflectors present within the subsurface "i.e. Flat-lying, widely spaced reflectors are much easier to image than those closely spaced steeply dipping".

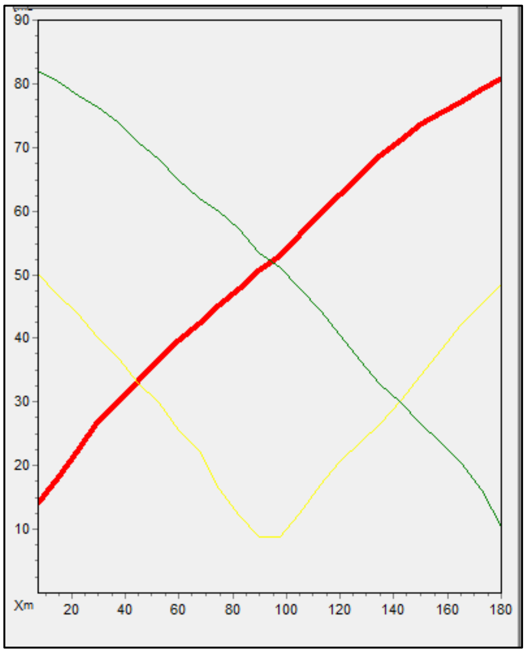


Fig. (16): Time-distance curves of profile 7.

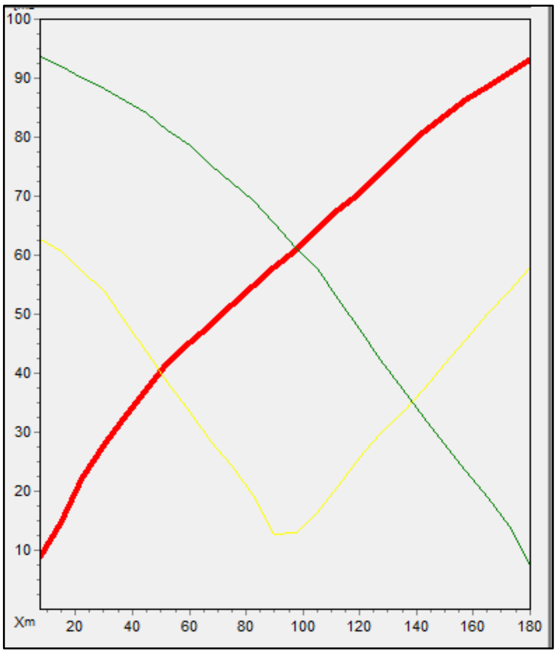


Fig. (17): Time-distance curves of profile 9.

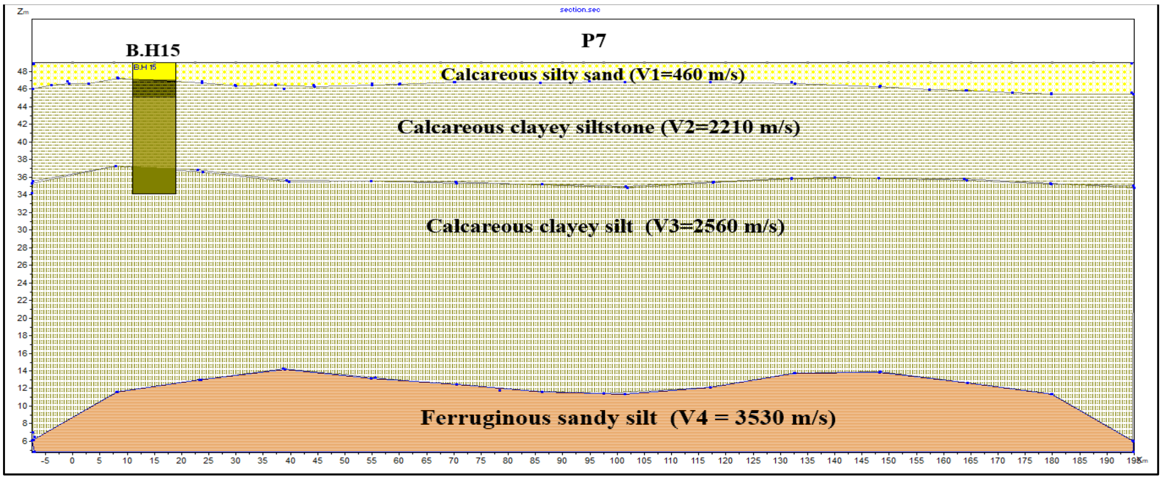


Fig. (18): Geoseismic cross sections for profile P7.

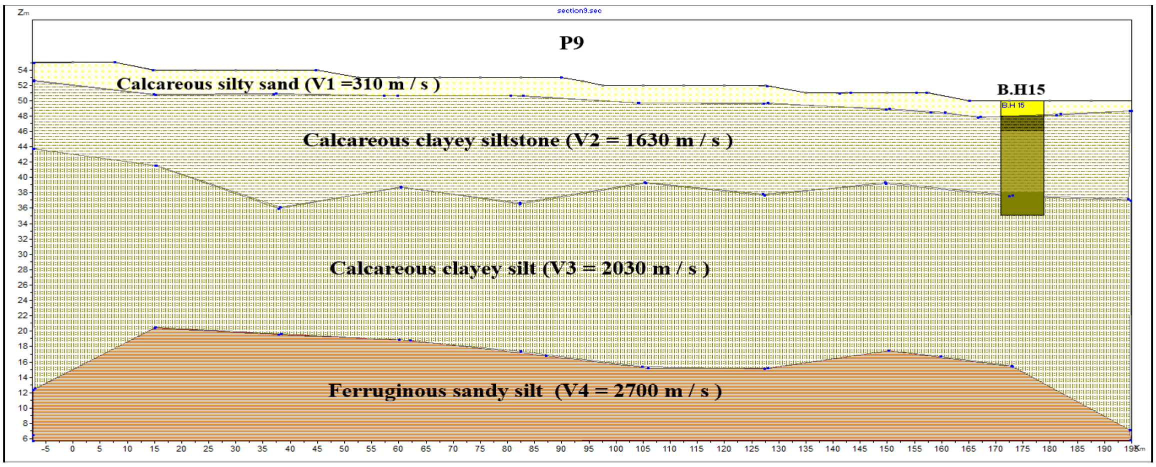


Fig. (19): Geoseismic cross sections for profile P9.

Vertical resolution means: how thick must a layer be, to discern the top and bottom of the specific layer? Theoretically, a layer can be distinguished when it has a thickness of 1/4 wavelength. The wavelength is determined by: wavelength (λ) = velocity (v) x period (T) = velocity (v) / frequency (f) of the seismic wave: λ = v/f. Vertical resolution (Tuning thickness) is equal to λ/4 = v/4f.

In engineering seismic surveys, there are several types of seismic energy sources in use (Yilmaz, 2015); a popular vertical-impact source is a sledgehammer (5-9 kg weight) and a steel plate (30 x 30 cm in size and 2.5 cm thick). This type of source is adequate to record P-wave data with bandwidth up to 100 Hz to pick first breaks and estimate P-wave velocity-depth models. Explosive charges commonly used in engineering seismic release seismic energy within range of 100 to 200 Hz, some of them reach even 400 Hz (Brom and Stan-Kłeczek, 2015)

P-wave velocities (Vp) in the near-surface typically range between 400 and 2000 m/s and generally increase in depth. Whereas the dominant frequency of the seismic signal typically varies between 100 and 20 Hz and decreases in depth. Therefore, typical seismic wavelengths associated with P-waves within the near-surface range from 4 to 100 m and generally increase with depth (Yilmaz, 2015). For example, a shallow layer with a 400 m/s velocity and 100 Hz dominant frequency potentially can be vertically resolved if it is as thin as 1 m (λ/4 = v/4f). A thinner layer, however, cannot be resolved. Similarly, for a deeper layer with a velocity as high as 2000 m/s and dominant frequency as low as 20 Hz, the thickness must be at least 25 m for it to be resolvable.

In the present study, the following Table (3) shows the obtained velocities, frequencies and vertical resolutions within the studied three layers. The seismic traces of these layers are separated in marked rectangulars and their dominant frequency spectra given in Fig. (20) for profiles 7.

A great match is shown between the results obtained from lithological description of the five boreholes (BH 14, BH 15, BH 16, BH 19 and BH 20) and the ten interpreted seismic profiles (P1-P10) as follows:

1) The total vertical depth (TVD) of the boreholes is 15 m and it is about 50 m for the interpreted geo-seismic sections (velocity-depth models).
2) The number of layers penetrated by the boreholes is 4 and sometimes 3, and it is 4 layers interpreted in the geo-seismic sections.
3) The seismic wave velocities of the first superficial layer are ranged between 410 m/s and 800 m/s, 910-2210 m/s for the second layer, 1490-2560 m/s for the third layer and 1630-3530 m/s for the fourth layer.
4) The frequencies of seismic waves within the first layer are varied from 48 Hz to 104 Hz, 29-85 Hz in the second layer, 17- 46 Hz for the third layer. Note that, the frequencies decrease with depth.
5) The wavelengths of seismic pulses are varied from 3.33 to 10.9 m in the first layer, from 10.7 to 43.4 m in the second layer and from 55.6 to 92.6 m in the third layer. Note that, the wavelength increases with depth.
6) The vertical seismic resolutions of the first, second and third layers are 0.83-2.65 m, 2.67-10.86 m and 14.49-21.91 m, respectively. Note that, the vertical resolution decreases with depth.
7) The first layer thickness in the boreholes is ranged between 1 and 3 m, and it is almost matched with the velocity-depth models. The vertical resolution of this layer is ranged in all seismic profiles between 0.83 m to 2.65 m e.g. 1.28 m in profile 7.
8) The second layer thickness in the boreholes is in the range of 2-8 m, while is ranged between 2 m and 12 m in seismic velocity models. This layer is almost hidden in seismic profiles because it is too thin to be resolved, where the vertical resolution calculated from seismic data for the second layer in profile 7 is 7.3 m and its true thickness in borehole BH 15 is only 2 m which is lower than the vertical resolution 7.3 m, that is why it is undetected or blind zone. In such case, this layer (2 m) was combined with the third layer in borehole (8 m) and appears as only one layer (10 m) in the second segment of seismic data of profile 7.
9) The fourth layer in most of the boreholes is only penetrated by 3 m and these holes were not continued to its base. This layer appears as a third layer in the velocity-depth model with thickness in the range of 20-32 m and its vertical seismic resolution between 13.9 and 23.15 m.
10) The fourth layer in all of the seismic velocity-depth models is found till the maximum depth of seismic wave penetration which is about 50 m.
11) Clay swelling in boreholes data analysis is wide variable in both vertical and lateral directions. It is ranged from10 % to 40 % at depth 1-4m, 70 % to 130 % at depth 6 – 8 m, 10 % to15 % at depth 10-11 m and 60 % to 80 % at depth 13-15 m.
12) Classification of the clay is CH (inorganic clay of high plasticity) and CL (inorganic clay of low to medium plasticity, silty clays and lean clays) according to the Unified Soil Classification System (USCS), ASTM D2487-2011.

Table (3): P-wave vertical seismic resolution.

Layer No.	Vp (m/s)	Frequency (Hz)	Vertical resolution (m) = λ/4
1st layer	400-800	48-104	0.83-2.65
2nd layer	910-2200	29-85	2.67-10.86
3rd layer	1490-2560	17-46	13.91-23.16

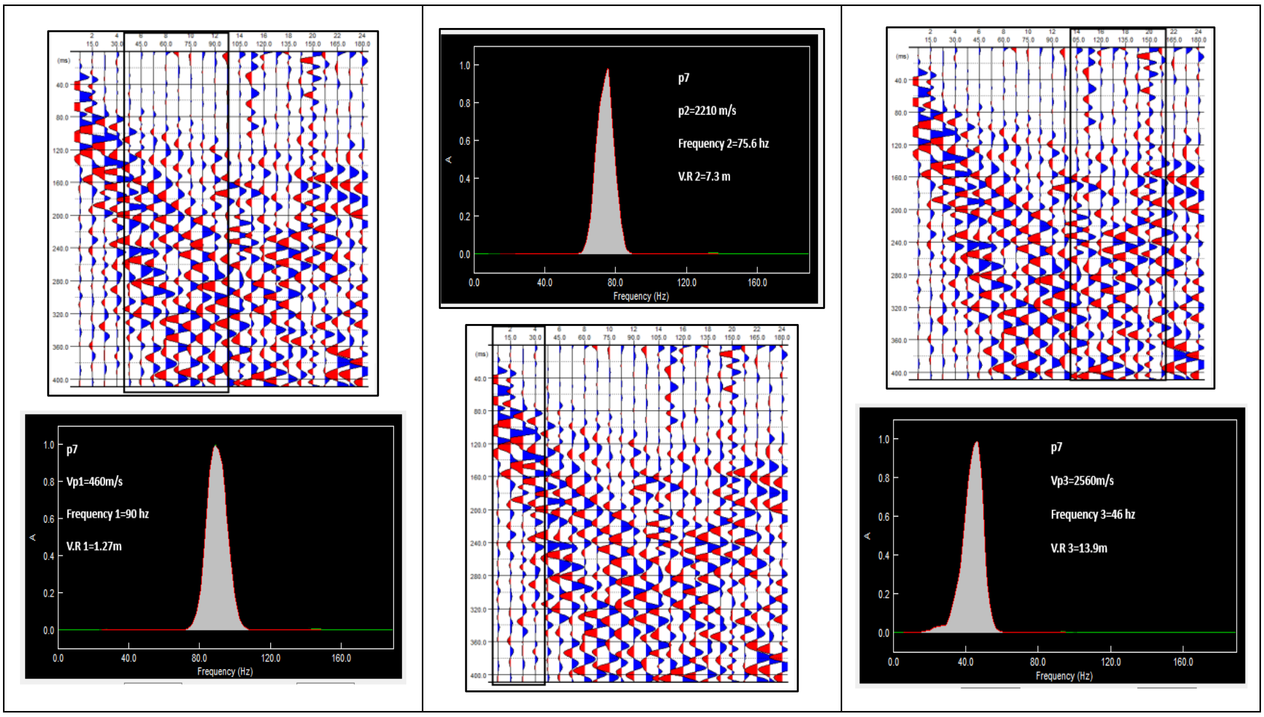


Fig. (20): Frequency spectrum of profile 7.

SUMMARY AND CONCLUSIONS

El-Fayoum New City represents one of the new urban settlements recently founded on expansive soils which are considered as difficult foundation materials that expand upon wetting. These soils are problematic for architectural and civil engineers because they originate minor to major cracks to pavements and structural buildings.

Many laboratory tests were carried out to determine the clay swelling behavior reflecting higher values. Liquid limit test indicates that most of soil samples fall in the marginal to high swelling potential. High plastic limit values reflect the presence of high clay contents. Low shrinkage limit confirms the presence of high amount of montmorillonite mineral. High free swelling values of clay severely damage foundation and crack building structures. X-ray diffraction (XRD) revealed that the type of clay minerals is montmorillonite. Sand and thin clay layer intercalations are shown in borehole lithological description. These thin clay layers are non-detectable in seismic sections because they are below seismic resolution.

Special kind of foundation material was recommended to solve this problem such as replacement soil or backfilling soil. Also, irrigation water for the parks and gardens should be minimized to avoid the water leakage under foundations.

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