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The Role of Seismic Velocity in Evaluating the Proposed Site of the New-Fayoum City, Southwest of Cairo, Egypt

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ABSTRACT. Seismic refraction survey is carried out to evaluate the proposed site of the New-Fayoum City, southwest of Cairo, for constructions. The interpretation of the collected seismic data yields two-dimensional seismic models composed of three main seismic layers; a surface layer of wadi-fill dry clastics and calcareous fragments covering an intermediate layer of sandy calcareous mudstone overlying a bedrock of highly argillaceous calcareous mudstone. The large spectrum of the bedrock seismic velocity at the proposed site is attributed to the difference in the bedrock mechanical and physical parameters. A bedrock seismic velocity contour map for the proposed site reveals three main seismic zones; the first zone, occupies the south-eastern part of the site and is characterized by low seismic velocity (2000 m/s) and is considered as non-eligible for constructions; the second zone, occupying the western and southern parts of the site, is characterized by intermediate seismic velocity (2000-2500 m/s) and is considered less-eligible for constructions; and the third zone, located mainly at the northern part of the site, is characterized by high seismic velocity (>2500 m/s) and considered the most eligible part of the proposed site for constructions.

During the last few years near-surface geophysics, specially seismic refraction survey, have been widely used in Egypt to characterize the subsurface rock mass quality. The reason for the ever increasing application of the seismic refraction technique for rock quality determination is the extensive use of bedrock in Egypt for new urban communities and various underground constructions such as hydro-electric power stations, tunnels, and oil storage. There are some professional papers which discuss the applications of near-surface geophysical techniques to evaluate a site (Dutta 1984, MacGregor 1990, Granger 1990, Fell 1990, Whiteley 1990, Mehanee 1994, El-Behiry *et al.* 1994, Abdel Rahman *et al.* 1994 and many others).

The correlation between the compressional wave velocity (Vp), derived from seismic refraction, and some rock mechanical and physical parameters, such as fracture intensity, rock quality designation (RQD), unconfined compressive strength (UCCS), porosity, clay content, and degree of consolidation has been discussed by Ohkubo and Terasaki (1971), Imai and Yoshimura (1975), Sjögren *et al.* (1979), Savich *et al.* (1983), Dutta (1984) and others.

The main purpose of this paper is to apply the above mentioned close correlations between the compressional wave velocity (Vp), estimated from seismic refraction measurements, and the rock mechanical and physical parameters to evaluate the proposed site of the New-Fayoum City (Fig. 1) for construction.

Location and Geology of the Proposed Site

The proposed site of the New-Fayoum City (Fig. 1) covers an area of 1300 Acres (5.3 Km^2) and is located between latitudes 29° 12'-29° 15'N and longitudes 30° 51'-30° 54'E to the southeast of the city of Fayoum, southwest of Cairo. The rectangular area shown inside the proposed site has been drawn by the planning civil engineers to represent the "housing area" of the site.

The Fayoum area is essentially occupied by sedimentary rocks ranging in age from Tertiary to Quaternary. The regional geology of the Fayoum area was discussed by several workers since the beginning of the present Century. From those are Beadnell (1905), Yallouz and Knetsch (1954) and Said (1962). The geologic setting of the proposed site of the New-Fayoum City was discussed in details by Hemdan (1992).

The proposed site is a part of the desert separating the Fayoum Depression from the Nile Valley. Its northern and southern boundaries are delineated with the Lahun channel and Gebel Na'alun, respectively, whereas its eastern and western sides are surrounded by cultivations of the Nile Valley and the Fayoum Depression, respectively (Fig. 1). Topographically, the area is a wide plain of gentle relief. Intensive field study of outcrops carried out by Hemdan and El-Barkuky (Personal Communications) in the proposed site reveals that the succession consists of the following main lithostratigraphic units, from top to bottom (Fig. 2): 1) Quaternary wadi sediments consisting mostly of gypsiferous sandy silt and friable calcareous sand; 2) Gravely, sandy gypcrete composed of Middle Eocene dolomitic limestone and gravely sandy gypcrete with some fractured marl and argillaceous limestone; and 3) Middle Eocene marl and argillaceous limestone exposed at the footslope of Gebel Na'alun and almost the whole plain area. According to Hemdan (1992), the lower boundary of the third unit, which represents the bedrock of the proposed site, extends in the subsurface to a depth of about 303 m and is characterized by high clay content and gypsum streaks filling the joints and fractures which are abundant in this unit.

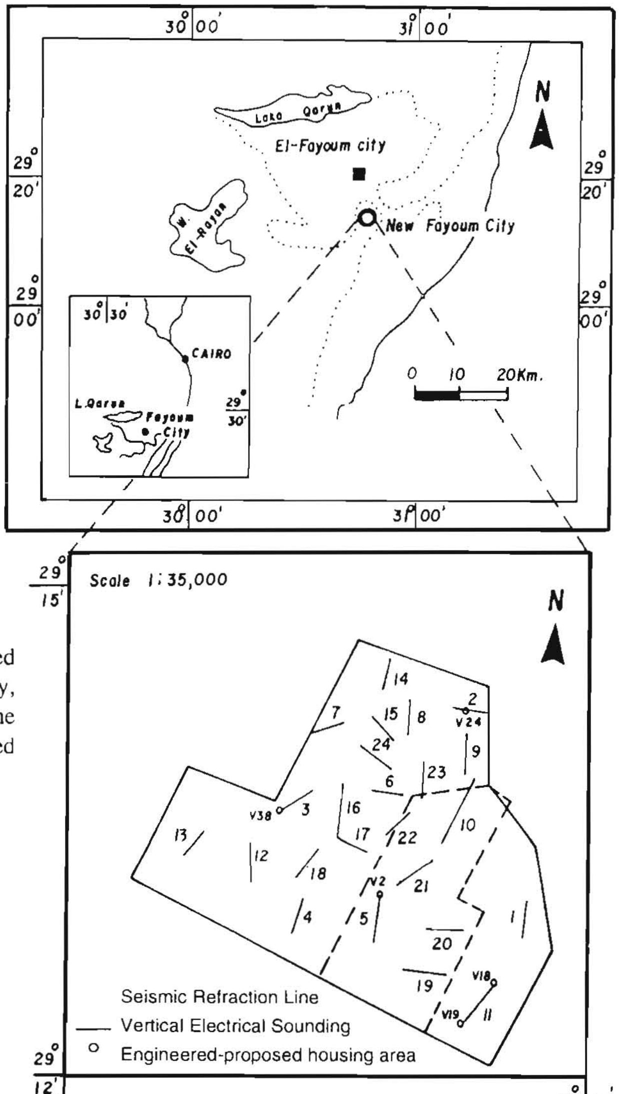

Fig. 1. Location map for the proposed site of the New-Fayoum City, Southwest of Cairo, and the locations of the conducted seismic refraction lines.

Figure (1)

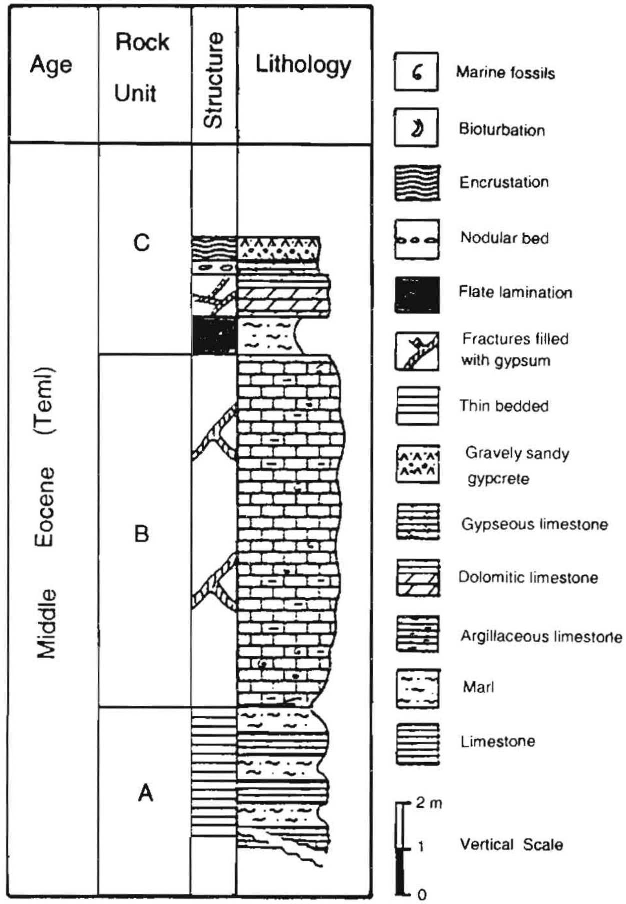

Fig. 2. Stratigraphic columnar section for the proposed site of the New-Fayoum City.

Seismic Refraction Data Acquisition and Results

Twenty four compressional (P)-wave seismic refraction lines, with a maximum length of about 330 meters, are carried out covering the area of the proposed site of the New-Fayoum City (Fig. 1). A sledge hammer and steel impact plate is used as the P-wave source. For most refraction lines, distances of one meter and five meters are used as the shot-first-geophone and the inter-geophone spacings, respectively. Despite the high ambient noise caused by heavy traffic on the Cairo-Asyut Desert Highway crossing the eastern part of the site, quarrying, and other man-made noises, acquisition parameters are optimized to collect good quality seismic data as is evident in Fig. (3). First arrival times are picked with accuracy of the order of 10^{-3} milliseconds using an advanced PC-software (Seismograph Application Software, Scintrex, Canada).

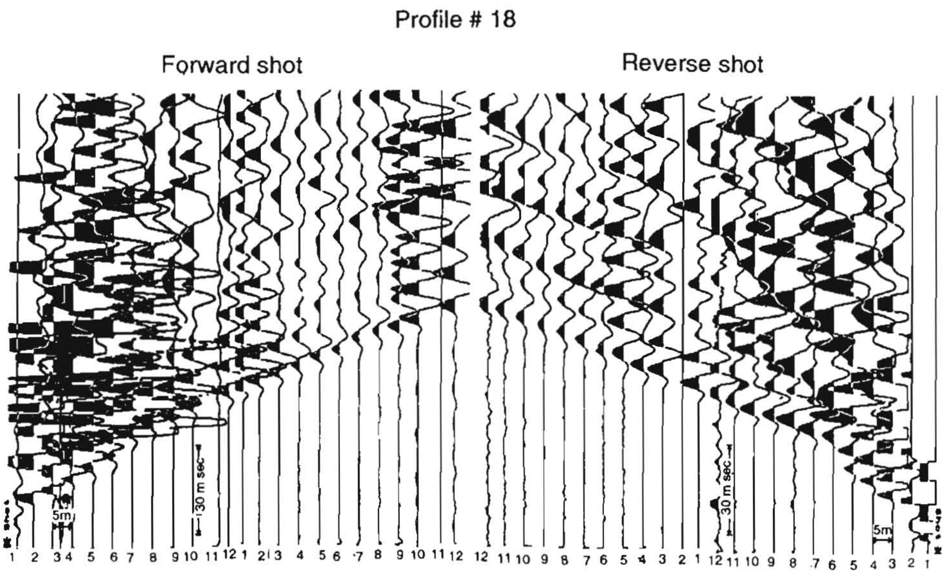

Fig. 3. Some compressional (P)-wave seismograms demonstrating the quality of the recorded seismic data.

The collected travel time data are inverted to yield velocity-depth models through a computer software which combines the Intercept-Time (Ewing *et al.* 1939), the Plus-Minus (Hagedoorn 1959), and the Split-Spread (Johnson 1976) interpretation schemes in one main program. The resulting two-dimensional depth models demonstrate the topography of each seismic interface, along with the medium compressional wave velocity. Fig. (4) show some examples for the obtained models with the travel time curves at the top and the interpreted depth sections at the bottom.

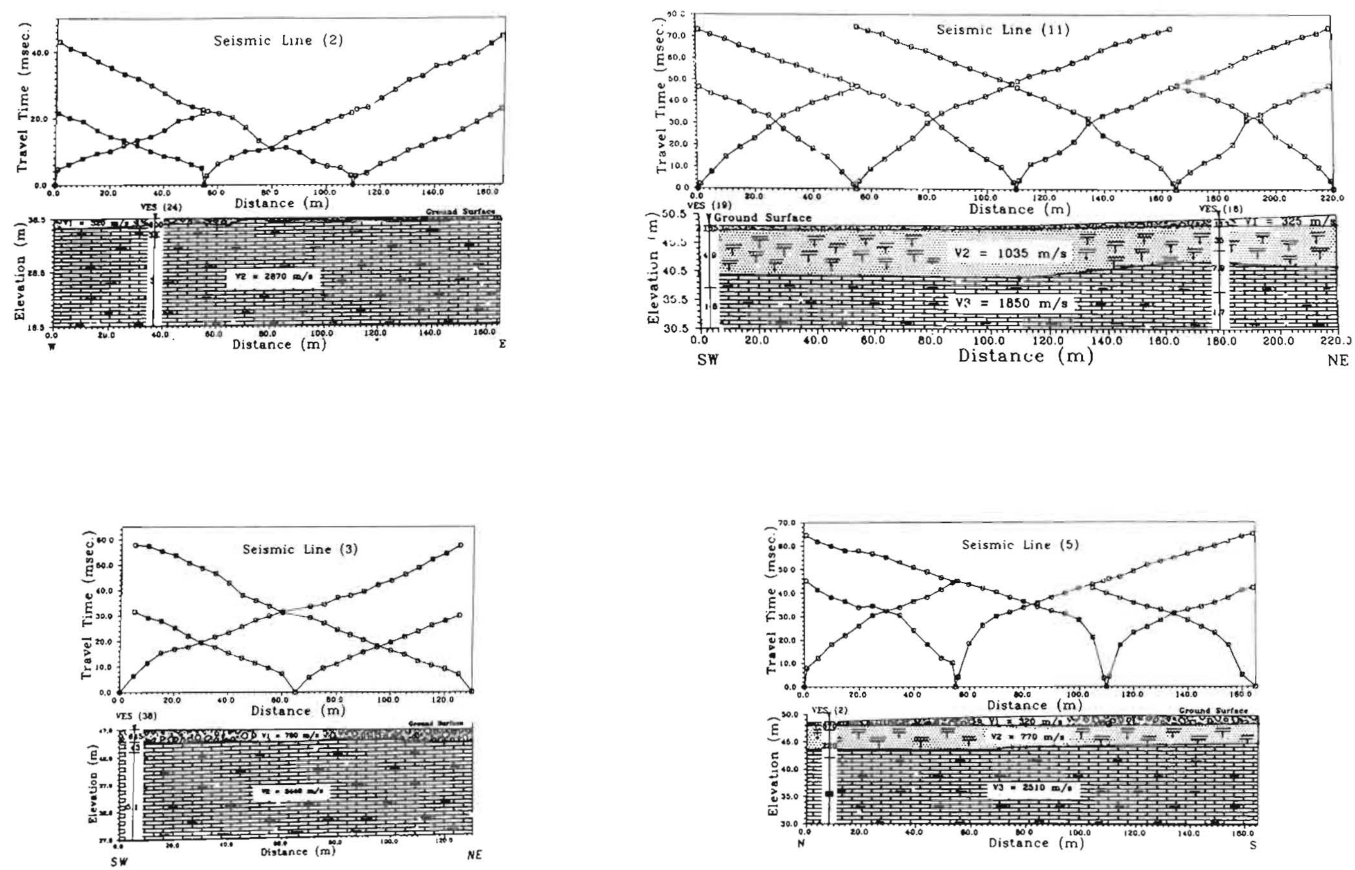

Fig. 4. Travel time curves and interpreted depth sections of some refraction lines.

The resulting depth sections show three main layers which are from top to bottom:

1) A surface layer characterized by low seismic velocity of 350-780 m/s corresponding to wadi-fill dry clastics and calcareous fragments. The thickness of this layer ranges between 0.2 m at the northern part of the site and about 2.5 m at its south and southeastern parts,

2) An intermediate layer characterized by seismic velocity of 770-1500 m/s corresponding to sandy calcareous mudstones. Its thickness is about 8.0 m at the southeastern part of the site and approaches a few centimeters at its northern and western parts, and

3) A bedrock characterized by high seismic velocity of 1950-3100 m/s corresponding to calcareous mudstones with high clay content. The depth of this layer reaches about 2.0 m at the northern part of the site and increases to about 10.0 m at its southeastern part. Fig. (5) shows a three-dimensional presentation for the thickness of the first two seismic layers and the topography of the bedrock.

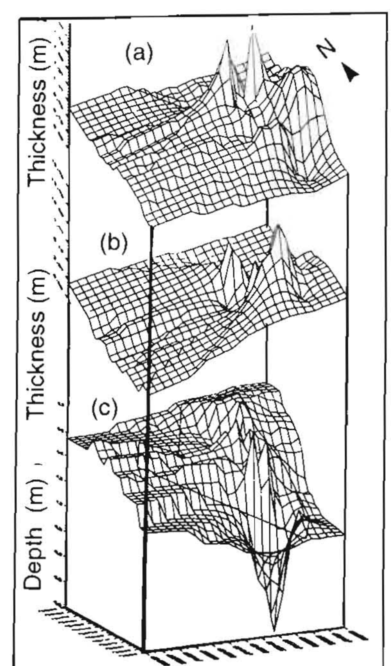

Fig. 5. Three-dimensional presentation for the areal and vertical distribution of the interpreted seismic layers at the proposed site of the New-Fayoum City.

The above-mentioned results are in good agreement with the results obtained from geoelectric resistivity soundings conducted, with Schlumberger electrode array, at the same locations of the seismic lines (see Fig. 1). The calculated resistivity models show three main layers; a surface layer characterized by high true resistivity of more than 800 Ωm, an intermediate layer characterized by true resistivity of about 50-200 Ωm, and a bottom layer characterized by very low true resistivity of 1.5-8 Ωm.

A bedrock compressional wave velocity (Vp) contour map is constructed for the proposed site (Fig. 6). It can be seen that the northern part of the site is dominated by high bedrock seismic velocities which decrease gradually towards the southeastern side. Three seismic velocity zones (Fig. 7) could be delineated from this map; the first zone occupies the southeastern part of the site and is characterized by low seismic velocity (Vp ≤ 2000 m/s); the second zone is located at the western and southern parts of the site and is characterized by intermediate seismic velocity (2000 < Vp ≤ 2500 m/s); and the third zone lies at the northern and central parts of the site and is characterized by high seismic velocity (Vp > 2500 m/s).

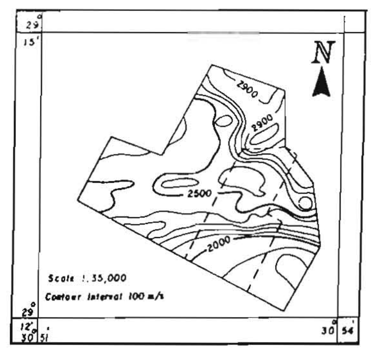

Fig. 6. Compressional wave velocity (Vp) contour map for the bedrock at the proposed site of the New-Fayoum City.

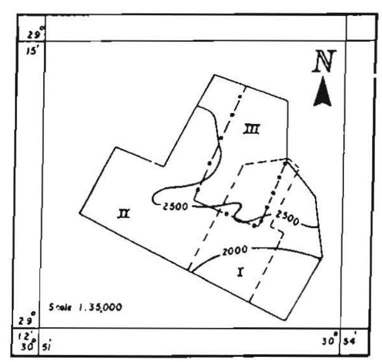

Fig. 7. Geophysical-based evaluation of the proposed site of the New-Fayoum City with the proposed lcoation of the housing area before (-----) and after (–•–•–•–) seismic investigation.

Discussion

Studying the relationship between the compressional wave velocity (Vp) and the mechanical and physical parameters of the rock mass is useful in characterizing engineering sites. Ohkubo and Terasaki (1971) have concluded, via laboratory tests, that in hard rocks, there is a direct relationship between Vp and the rock unconfined compressive strength (UCCS) as well as the degree of consolidation. They have also stated that, in soft rocks like mudstones, increasing porosity decreases Vp. Sjögren *et al.* (1979) have derived a correlation between Vp and the rock fracture frequencies and the rock quality designation (RQD) for various rock types. They have concluded that the decrease in the rock fracturing (i.e. crack/meter) and the increase in RQD increases Vp which indicates the suitability of rocks for construction. Dutta (1984) used the conclusions of Sjögren *et al.* (1979) to study the foundation rock of a dam in India. He also concluded that low Vp corresponds to low elastic (Young's, Bulk, and Shear) moduli, low RQD and high fracture intensity which consequently results in the non-eligibility of the rock for construction.

Using the advantages of the close correlations between the compressional wave velocity (Vp), derived from seismic refraction, and the rock mechanical and physical parameters discussed earlier (Ohkubo and Terasaki (1971), Sjögren *et al.* (1979), and Dutta (1984)), the bedrock of the proposed site of the New-Fayoum City could be classified as follows:

1) A highly fractured and porous calcareous mudstones which are of low consolidation, low unconfined compressive strength (UCCS), and low rock quality designation (RQD) at the southeastern part. The general increase in porosity may be due to the increase in the clay content and presence of fractures and joints filled with gypsum streaks.

2) An intermediate zone of consolidated calcareous mudstones is characterized by moderate mechanical and elastic (RQD, UCCS, and fracturing) parameters at the western and southern parts.

3) A highly consolidated non-fractured, slightly jointed, limestone is characterized by higher RQD and UCCS and lower clay content at the central and northern parts of the site.

Consequently, the southeastern, southern-western, northern-central parts of the proposed site of the New-Fayoum City may be classified as non-eligible, less-eligible, and preferred for construction, respectively, and therefore, the housing area should be relocated at the northern part (zone III) of the site (Fig. 7).

Conclusion

24 seismic refraction lines are conducted at the proposed site of the New-Fayoum City, southwest of Cairo to evaluate this site for constructions. The areal distribution of the calculated bedrock velocity (Vp) reveals three seismic zones: the first zone occupies the southeastern part of the site and characterized by low seismic velocity (2000 m/s); the second zone, which is located at the western and southern parts of the site, is characterized by intermediate seismic velocity ($> 2000 \leq 2500$ m/s); and the third zone, located at the northern and central parts of the site, is characterized by high seismic velocity (> 2500 m/s). Utilizing the close correlation between the compressional wave velocity (Vp) and the rock mechanical and physical parameters such as fracturing, rock quality designation (RQD), unconfined compressive strength (UCCS), porosity, clay content, and consolidation, the obtained seismic zones could be classified as non-legible, less legible, and preferred areas for construction, respectively. Therefore, it is recommended that the proposed housing area should be relcoated at the northern part of the site rather than its southern parts.

Acknowledgements

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دور السرعة السيزمية في تقييم الموقع المقترح لمدينة الفيوم الجديدة ، جنوبي غرب القاهرة ، مصر

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تم إجراء أربعة وعشرين خطاً سيزمياً انكسارياً بالموقع المقترح لمدينة الفيوم الجديدة والواقع جنوبي غرب القاهرة وذلك لتقييمه بغرض الإنشاءات . بعد تفسير البيانات السيزمية ، تم حساب قيمة السرعة السيزمية للموجات الانضغاطية المميزة لصخور الأساس (Bedrock P-Wave Velocity) . من التوزيع الأفقي لهذه السرعة السيزمية أمكن تقسيم صخور الأساس بالموقع إلى ثلاث نطاقات سيزمية :

النطاق السيزمي الأول يشغل الجزء الجنوبي الشرقي من الموقع ويتميز بسرعة سزمية منخفضة (أقل من أو تساوي ٢٠٠٠ متر/ ثانية) .

النطاق السيزمي الثاني يمتد في الأجزاء الجنوبية والغربية من الموقع ويتميز بسرعة سزمية متوسطة (اكبر من ٢٠٠٠ متر/ ثانية وأقل من ٢٥٠٠ متر/ ثانية) .

النطاق السيزمي الثالث الذي يشغل الجزء الشمالي من الموقع فيتميز بسرعة سزمية عالية (أكبر من ٢٥٠٠ متر/ ثانية) .

في ضوء العلاقة الوثيقة المعروفة بين السرعة السيزمية للموجات

الانضغاطية وبعض خواص الصخر الميكانيكية والفيزيائية والتي تبين منها التناسب الطردي بين السرعة السيزمية للموجات الانضغاطية ومعامل جودة الصخر (RQD) ، مقاومة الصخر للانضغاط الغير محدود (UCCS) ، ودرجة اندماج الصخر (Consolidation) وكذلك بعض معاملات المرونة مثل معامل يانج (Young's) ومعامل القص (Shear) والتناسب العكسي مع شدة التقسر (Fracture Intensity) . ونتيجة لذلك تم تقسيم النطاقات السيزمية الثلاث إلى مناطق غير صالحة ، وصالحة ، ومفضلة للإنشاءات على التوالي . وعليه تمت التوصية بتخصيص الجزء الشمالي من الموقع المقترح لمدينة الفيوم الجديدة للمناطق السكنية وذلك لملائمة صخور الأساس به للإنشاءات .