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# Geotechnical Investigation and Characterization of intact rocks using destructive and Non-destructive techniques: A Case Study at Gebel El Ramliya-Akheider, Cairo-Suez District, Egypt

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**ABSTRACT :** ***This paper presents the findings of a geotechnical investigation and characterization of intact rocks in Gebel El Ramliya-Akheider, located in the Cairo-Suez district of Egypt. The study area is a strategic economic zone due to industrialization and urbanization and comprises four rock units with different ages, namely Middle Eocene, Upper Eocene, Oligocene, and Miocene. Seven undisturbed rock samples were collected from the exposed intact rocks in the investigated area, and both destructive and non-destructive tests were conducted to identify the geotechnical characteristics of the rocks. The destructive techniques included the Unconfined Compressive Strength and Point Load tests, while the non-destructive methods included the Ultrasonic Pulse Velocity and the Schmidt Hammer tests. The results revealed significant variability in the geological and geotechnical properties of the investigated intact rocks, which is attributed to differences in the lithological characteristics among the rock units. The Middle Eocene rocks comprise very hard limestones, the Upper Eocene rocks are fossiliferous to sandy limestones, and the Oligocene rocks are primarily composed of ferruginous sandstones, while the Miocene rocks include argillaceous limestones. Consequently, the Middle Eocene limestones were classified as medium-strength and stiff rocks, indicating their suitability for geotechnical purposes that require high bearing capacity, such as foundation construction, retaining walls, and slope stabilization. On the other hand, the limestones of the Upper Eocene were classified as having very low to low strength and medium stiffness, while the Oligocene and Miocene rocks were found to have very low strength and low stiffness, highlighting their limited geotechnical potential and the need for caution during engineering activities. These findings provide preliminary information about the geotechnical properties of different rock units, which can be useful for geotechnical and construction projects.***

***KEYWORDS:*** ***El Ramliya–Akheider, Cairo-Suez District, Geotechnical characterization, Intact rocks, Destructive, Non-Destructive.***

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## I. INTRODUCTION

Urbanization in mountainous and desert-land areas has increased significantly, leading to the potentiality of geo-environmental hazards (El Shinawi et al., 2022). As a result, new development areas have encountered issues such as unsuitable bedrock for urbanization, flood hazards, and proximity to faults, leading to structural failures. To address these issues, it is crucial to characterize geological structures and the geotechnical properties of rocks for environmental engineering investigations (Ata et al., 2018). The instability problems that arise are mainly related to the nature of geological structures and the surrounding rocks' geotechnical properties. Therefore, development in mountainous deformed areas should be done cautiously, taking into account the nature and distribution of geological structures (Di Maio et al., 2020; Du et al., 2020;

Kang et al., 2018). Detailed information on the areas under investigation, including the nature of the intact rock, and their geotechnical properties, is required, particularly nearby geologic structures.

The Cairo-Suez District (CSD) represents the northwestern extremity of the Gulf of Suez rift (GOS), Egypt (Fig. 1). The CSD is a strategic economic zone that hosts several important industrial and infrastructure projects. One of the key challenges in the development of these projects is the variability in the geological and geotechnical properties of the rocks in the area. For that reason, several studies conducted by (El Tahan et al., 2021; Elgohary et al., 2022; Harraz et al., 2020; Sakr et al., 2021; Shahien and Ogila, 2022), and others. They highlighted the importance of such investigations in mitigating hazards and ensuring successful development in the CSD. The present study is represented by the Gebel Akheider- El Ramliya which is located in the south-eastern division of CSD. It lies between latitudes 29° 38' 00" N–29° 47' 45" N and longitudes 31° 58' 00" E–32° 16' 48" E and covers an area of approximately 420 km2 (Fig 2). The study area has become a highly strategic economic zone due to industrialization, urbanization, and the presence of several quarries and cement factories. Recent development projects such as New-Suez City and High-speed Railway have further increased the area's importance for future growth and development. As a result, the study area is now considered a hub for all geotechnical applications. From this point on, it is crucial to consider the geotechnical properties of the rocks in the study area for any engineering activities.

The geotechnical characteristics of intact rocks were determined through destructive methods that analyze the deformation and failure modes of rock samples under applied loads. In addition, Non-destructive methods (NDTs) offer an alternative to destructive testing, allowing for the estimation of mechanical properties without the need for excavation or destruction of intact rocks (Moaveni et al., 2022; Yagiz, 2011). Destructive tests include the Uniaxial Compressive Strength (UCS) and Point Load (PL) strength index tests, which are commonly used for rock strength estimation. NDTs include the Schmidt Hammer (SH) and Ultrasonic Pulse Velocity (UPV) tests, which provide information on the intact rock surface hardness and internal structure, respectively.

Commonly, rock modes of failure are a primary concern in geo-engineering assessments from a rock mechanics perspective. However, understanding and predicting the mechanical behaviour of rocks is a complex and challenging aspect due to varying loading conditions, which can induce different failure modes and patterns, and environmental factors which can alter their properties and behaviour over time. (Basu et al., 2013). Therefore, the present study aims to (i) measure and predict the mechanical behaviour of intact rocks in uniaxial loading conditions and (ii) evaluate their geotechnical properties with a special focus on the suitability of these rocks for engineering purposes. This can be achieved by applying geotechnical destructive and Non-destructive tests.

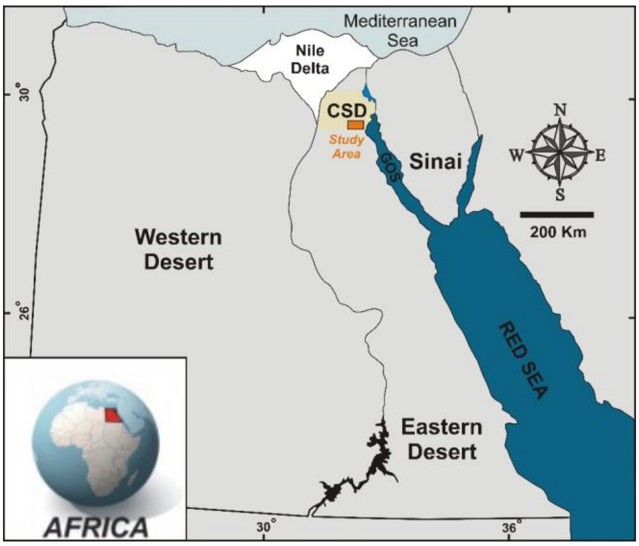


**Fig. 1.** Location map illustratig CSD and the study area's location.

## II. GEOLOGICAL SETTING

The study area is a rhombohedral topographic high which is considered one of the remarkable topographical features in the northern part of the GOS rift. The maximum elevation recorded at the study area is about 395 m (above sea level) at Gebel El-Ramliya. It involves significant surface structures that are well-recognized along asphaltic roads such: Cairo-Ain Sukhna and Cairo-Suez roads. Structurally controlled wadis (i.e., valleys) extended along areas such: as wadi akheider, wadi El-Ramliya, and Wadi Ghoweiba. Moreover, most of the bordering exposures are fault scarps that were obvious later by erosive agents which simplified also the geotechnical investigations of rocks nearby faults (Henaish et al., 2023; Henaish and Attwa, 2018; Henaish And Kharbish, 2020).

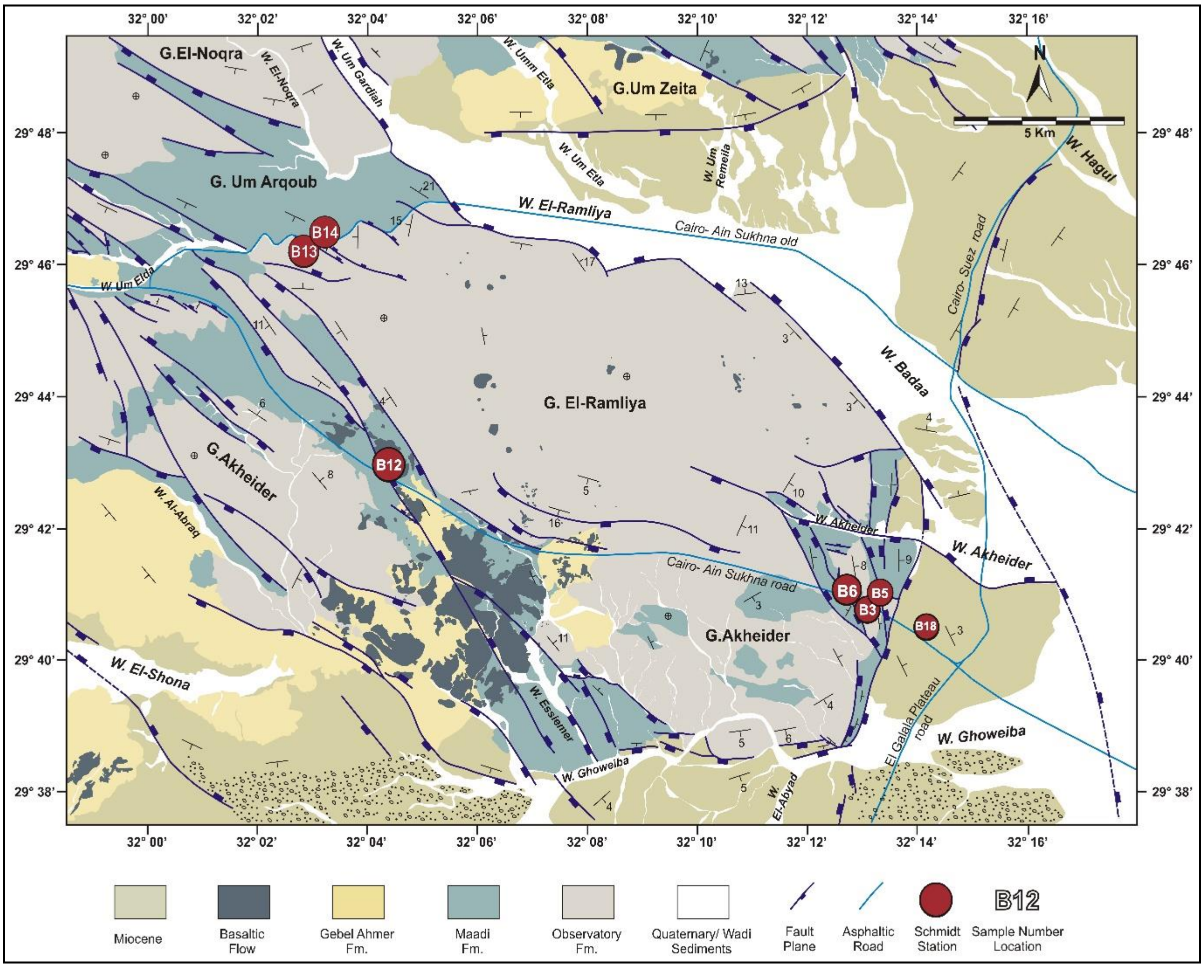


**Fig 2.** Detailed field geological map showing the main structural features and geotechnical investigation of the study area modified after (Henaish et al., 2023).

Tectonically, the study area was affected by several events related to the Neo-Tethys and GOS rifting. Thus, major tectonic structures formed during the Mesozoic to Cenozoic eras resulted from the movements among the African, Eurasian, and Arabian plates (e.g, (Hussein and Abd-Allah, 2001; Moustafa and Abd-Allah, 1991). The regional rifting of the Neo-Tethys during the Jurassic-Early Cretaceous times resulted in E-W to ENE-WSW oriented normal faults. The Late Cretaceous time was characterized by the closure of the Neo-Tethys and resulted in the development of a Syrian arc fold belt trended in a NE-SW direction (e.g, Gamal et al., 2021; Henaish et al., 2023; Moustafa and Khalil, 2017). The CSD witnessed a segment of extension linked up with the GOS rift from the Oligocene to the post-Miocene time, resulting in normal faults oriented in a NW-SE to NNW-SSE direction (Henaish et al., 2023).

Stratigraphically, the study area includes rocks of various ages, namely Eocene, Oligocene, Miocene, and Quaternary, with unconformity surfaces suggesting tectonic events (Fig. 3). The oldest exposed rocks are Middle Eocene, known as the Observatory Formation (Farag and Ismail, 1959). It is composed of a series of limestones with dolostones intercalations. This rock unit is followed by the Upper Eocene, referred to as the Maadi Formation (Said, 1962) including variable lithologies mostly of limestones with some sandstones and shales. This unit is overlain unconformably by a thick layer of ferruginous sandstones attributed to the Oligocene time, known as the Gebel Ahmar Formation (Shukri, 1954). The Eocene and Oligocene rock units are unconformably overlain by Miocene rocks, known as Marine Miocene, including limestones, shales, and sandstones. Finally, the Quaternary sediments consisting of sands and gravels can be found in the wadis floor.

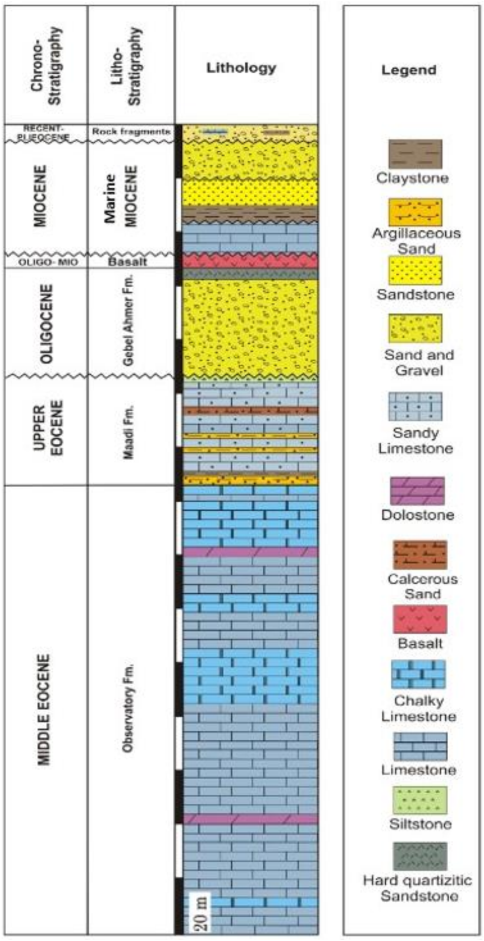


**Fig 3:** Composite stratigraphic section of the study area modified after (Henaish et al., 2023)

## III. MATERIALS AND METHODS

### Field sampling

The geotechnical properties of the exposed intact rocks in the study area were investigated through a combination of field measurements and laboratory tests. Undisturbed rock samples were collected from various locations representing four rock units using field sampling techniques (Figs. 2 and 4). A total of seven undisturbed rock samples were collected, including two samples from the Middle Eocene rocks, three samples from the Upper Eocene rocks, one sample from the Oligocene rocks, and one sample from the Miocene rocks (Table 1).

### Geotechnical investigations

In the present study, Firstly, Intact rocks were identified visually in the field according to NZGS, 2005. Secondly, geotechnical investigations include both destructive and non-destructive techniques (Fig. 4). Destructive techniques involved laboratory tests such as unconfined compressive strength (UCS) and Point load strength index (PL) tests, while Non-destructive techniques involved both field tests such as Schmidt hammer, and lab test such as ultrasonic pulse velocity.

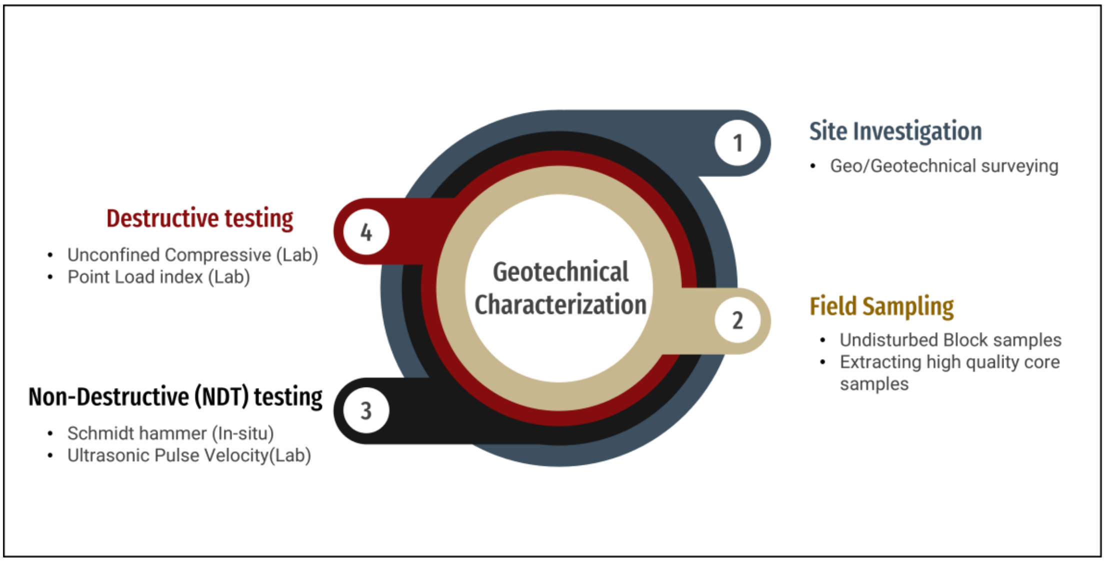


**Fig. 4.** Flow chart for the geotechnical characterization of the study.

## IV. RESULTS AND DISCUSSION

### Unconfined compressive strength (UCS)

The UCS test is a destructive method frequently used to assess the mechanical behaviour of rocks according to (ASTM D7012-14, 2014). UCS measures the intact rock deformation behaviour by subjecting oven-dried cylindrical core samples with flat ends and a length-to-diameter ratio of 2.0 to 2.5 to axial stress. Seven samples were used, and the specimens were vertically placed between steel patents and loaded under uniaxial compression with a constant strain rate of 1.2 mm/min, providing valuable insights into the stability of structures under loads (Fig. 5). The resultant stress-strain curves of samples are illustrated in Figure (6). The corresponding Modulus of Elasticity, E (GPa), represents the slope of stress-strain curves and axial strain, ε (%) at failure is obtained. Also. The resultant compressive strength (UCS) of the samples is presented as the mean value (MPa) as shown in Table 1.

The present study signifies that the UCS values range from 8.44 MPa to 62.81 MPa, indicating a wide variation in rock strength (Table 1). The modulus of elasticity also varies significantly, ranging from 10.53 GPa to 62.81 GPa, suggesting differences in rock stiffness. Additionally, the axial strain values are relatively low, ranging from 0.10% to 0.24%, indicating that the rock samples exhibit brittle behaviour. Among the studied rock units, Middle Eocene limestones show the highest UCS and relatively high modulus, indicating higher strength and resistance to deformation. Conversely, Oligocene sandstones exhibit the lowest UCS and relatively low modulus, while Upper Eocene and Miocene limestones display moderate values.

### Failure under uniaxial compression

Various failure patterns of core specimens were observed. Basu et al. (2013) showed that rock failure modes in a UCS test may be one of these types as shown in Fig. 7. In the present study, observed failure modes in all rock core samples are categorized into four varieties (i.e., axial splitting along a single plane, double shearing, multiple fracturing, and Y-shaped) as shown in Fig. 8. The UCS value along with the corresponding failure mode as well as failure angle of the rock core specimens is given in Table 1. The angle of failure also varies, ranging from 54° to 87°, indicating differences in the resistance of rock material to shear stresses and the variability in the internal structure of rocks (Mardalizad et al., 2018; Sharma et al., 2017).

**Table 1.** The resulted geotechnical data characterizing the collected Rock samples and their representative rock units of study area.

| Site sampling | | | UCS test | | | | | | PL test | SH test | UPV test |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rock unit | Sample No. | Lithology | UCS (MPa) | *E* (GPa) | E/UCS $*10^3$ | Ɛ (%) | Mode | Angle | IS50 (MPa) | SH No. (R) | Vp (Km/s) |
| Miocene | B18 | Argillaceous LS | 19.04 | 16.83 | 884 | 0.16 | Multiple fracturing | 72° | 0.63 | 24 | 2.95 |
| Oligocene | B12 | Ferruginous Sandstone | 8.44 | 10.53 | 1247 | 0.23 | Y-shaped failure | 63° | 1.08 | 24.8 | 5.1 |
| Upper Eocene | B3 | Sandy LS | 36.05 | 29.44 | 817 | 0.24 | Axial Splitting | 81° | 1.86 | 29 | 7.65 |
| | B5 | Fossiliferous LS | 14.6 | 38.66 | 2648 | 0.13 | Double shear | 78° | 0.81 | 23.6 | 6.67 |
| | B6 | Sandy LS | 16.21 | 31.29 | 1931 | 0.13 | Double shear | 54° | 1.83 | 26.7 | 6.95 |
| Middle Eocene | B13 | V. hard LS | 57.63 | 46.59 | 809 | 0.13 | Axial Splitting | 83° | 2.82 | 37 | 8.23 |
| | B14 | V. hard LS | 60.78 | 62.81 | 1033 | 0.10 | Axial Splitting | 87° | 3.42 | 39.6 | 8.66 |

* These results are presented as average values obtained from multiple measurements

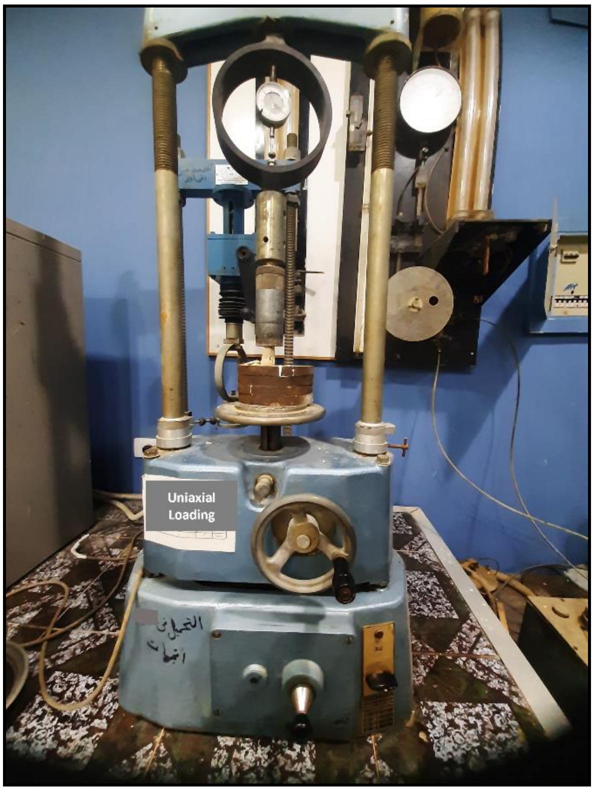


**Fig. 5.** An experimental setup for UCS test. The device model: ELE-international Inc. for UCS tester supplied with load frame 4 speed 50KN, Proving Ring, 28 KN, Dial Gauge, 0.01x 25 mm and plain platens.

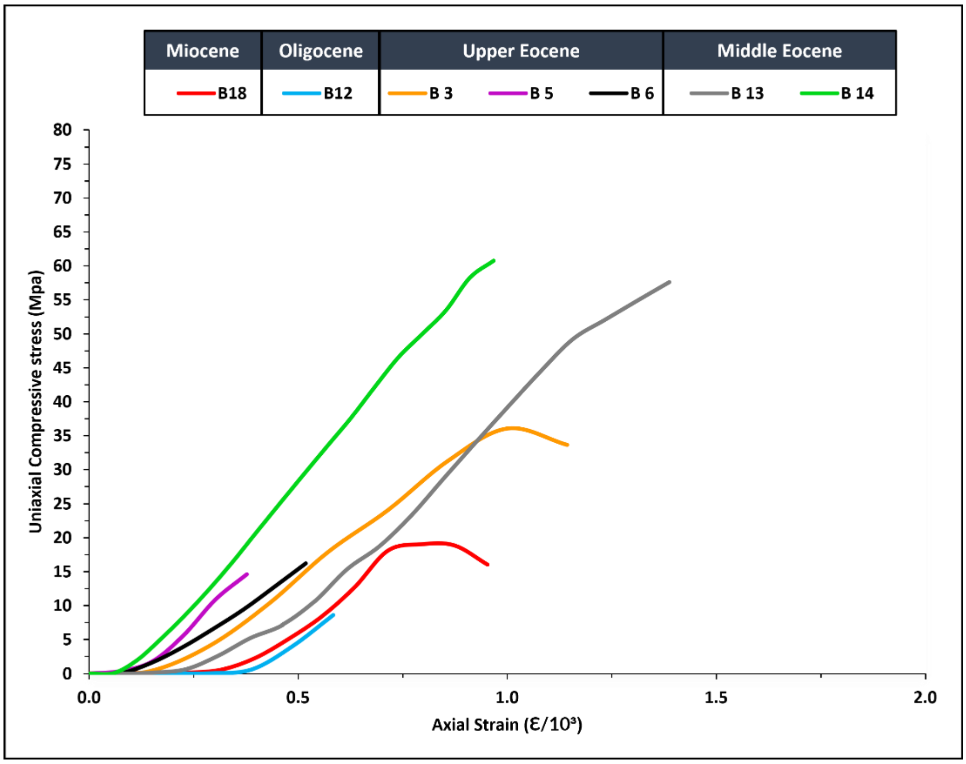


**Fig. 6.** Stress–strain curve of UCS test on rock core samples and their representative rock units

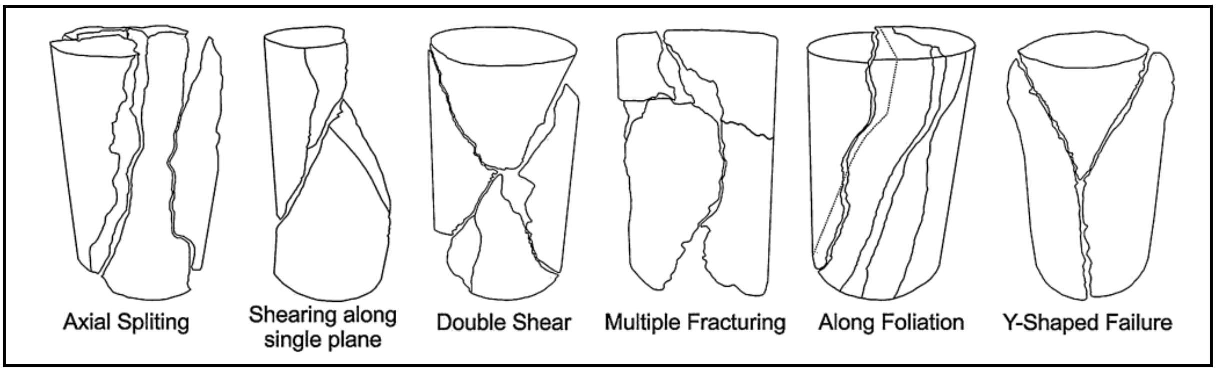


**Fig. 7.** Schematic representation of different failure modes under uniaxial compression proposed by Basu et al. (2013).


**Fig. 8.** The observed failure modes and angles in the UCS test (a) Miocene, (b) Oligocene, (c) Upper Eocene, and (d) Middle Eocene. Note: beta ($\beta$) refers to failure angle of the fractured plane.

**Point Load strength index (PL)**

The PL is the second type of geotechnical destructive test and is considered a quick indicator of compressive strength. The PL testing procedure was conducted following ASTM standards (ASTM D5731-16, 2016). This standard implies that PL testing requires little sample preparation. For that reason, the PL test was conducted on irregular lump specimens (Fig. 9). The resulting data of corrected PL values (Is50) show that the rocks in the study area have a wide range value of 0.63-3.42 MPa (Table 1). Significantly, the Middle Eocene limestones have the highest PL values of 2.82 – 3.62 and the Miocene limestones have the lowest values of 0.63. These results provide important information for assessing the strength of rock units under various loading conditions. As a result, the Middle Eocene rocks are observed to exhibit the highest strength among the studied rock units, as evident also from the UCS test.

**Fig. 9.** An experimental setup for PL test on irregular lump specimen. The PL device model: ELE- International Inc. PL tester supplied with load frame for applying loads up to 55 KN.

**Schmidt Hammer test (SH)**

The Schmidt hammer (SH) test is used as a non-destructive method to measure the hardness and strength of rocks. The test followed a set of standards based on a combination of ASTM D5873-14 and ISRM, 2015. The SH test is portable and can be conducted in situ by measuring the rebound number (R-value) of a spring-loaded hammer that strikes the rock surface. Frequently, Higher rebound values indicate a harder and more compact rock surface, while lower values indicate a weaker and less compact surface (Basu and Aydin, 2004; Bruno et al., 2013).

In the present study, SH tests were conducted at 7 stations, Fig. 2, on polished outcrops of rock surfaces (Fig. 10). The resulting data of rebound numbers (R) shows that Middle Eocene limestones have the highest rebound range values of 37 – 39.6, indicating that they have the hardest and most compact rock surfaces. On the other hand, the Oligocene vuggy limestone and Miocene limestone samples have the lowest rebound values of 23.6 and 24, respectively, indicating that they have the weakest and least compact rock surfaces among the tested samples.

**Ultrasonic Pulse Velocity (UPV)**

The UPV test is another non-destructive testing method used to evaluate the quality and integrity of rock materials. The test was performed in accordance with a developed set of standards based on a combination of guidelines (ASTM D2845-08, 2008; ISRM, 2013). Seven core rock samples were used to measure the speed of sound waves (Vp) passing through rocks (Fig. 11). The Vp (Km/s) is influenced by various factors, such as rock density, porosity, and mineral composition. In the present study, the Vp values range from 2.95 km/s for the Miocene limestones to 8.66 km/s for the Middle Eocene limestones. The Vp values generally increase with the increased hardness and density of the rock (Jedidi, 2022). Based on this fact, it can be predicted that Middle Eocene limestones represent the densest and highest among other rock units as the Vp values are the highest range values of 8.23 – 8.66 Km/s. This is attributed to the low porosity, high cementation and compaction of limestone which enable the Vp to pass fast through core samples.

**Fig. 10.** SH testing on Upper Eocene rock surface. SH testing on Upper Eocene rock surface. The SH device model: Proceq N-type Schmidt hammer.


**Fig. 11.** Performing the UPV test on a known length of an oven-dried core sample. The UPV device model: Matest (C369N) Ultrasonic pulse velocity tester.

**Engineering Classification for intact rocks**

It is crucial to establish engineering classification for intact rocks to determine their suitability for engineering applications. Deere and Miller (1966) proposed a classification system based on two parameters elastic modulus (E), a measure of rock stiffness, and unconfined compressive strength (UCS), a measure of the rock's strength. Accordingly, the present study established the engineering classification of intact rocks based on UCS (Mpa) and E (Gpa) values obtained from the UCS test. These values were also plotted on a log scale graph, Fig. 12, and the modulus ratio (E/UCS) was calculated and listed in Table 1. The modulus ratio is an indicator of rock ductility and is inversely related to rock strain.

The present study signifies that all rock units have high modulus ratios, but their strength and stiffness vary based on their composition and porosity. The Miocene limestones and Oligocene sandstones are classified as very low strength and low stiffness due to the predominance of clay minerals and high porosity, respectively. The Upper Eocene limestone samples are classified as low to very low strength and medium stiffness due heterogeny of limestones, while the Middle Eocene limestone samples are classified as having medium strength and stiffness due to the mineral composition, mainly calcium carbonate, and resistance to compression.

However, the samples have a similar modulus ratio (high modulus ratio), their strength and stiffness values differ significantly due to other factors such as composition, porosity, grain size, and mineralogy (Spross et al., 2020). Therefore, while a high modulus ratio suggests a certain level of ductility, it does not necessarily mean that all rocks with a high modulus ratio will exhibit the same behaviour under stress. These findings provide insights into the geotechnical properties of different rock units, which can be useful for geotechnical and construction projects.

Table 2. The Engineering classification of the investigated rock samples and their representative rock unites.

| Rock unit | Sample No. | Lithology | Rock Strength | Rock stiffness | Modulus ratio |
|---|---|---|---|---|---|
| Miocene | B18 | Argillaceous LS | Very low | Low stiffness | High Modulus Ratio |
| Oligocene | B12 | Ferruginous Sandstone | Very low | Low stiffness | |
| Upper Eocene | B3 | Sandy LS | Low | Medium stiffness | |
| | B5 | Fossiliferous LS | Very low | | |
| | B6 | Sandy LS | | | |
| Middle Eocene | B13 | V. hard LS | Medium | Stiff | |
| | B14 | V. hard LS | | | |

## V. Conclusion

The present work concerned the geo-engineering characteristics of four rock units including Miocene, Oligocene, Upper Eocene and Middle Eocene rocks. These rocks represent the surface exposures of the Gebel El-Ramliya-Akheider, facing the Cairo-Ain Sukhna Road. Geotechnical properties of the exposed rock in the study site were investigated using both field/Lab destructive and non-destructive tests. The analysis of seven stations from different exposures at the study area showed that the Middle Eocene limestones registered appear to be the most suitable rock unit for applications that require medium strength and stiffness, while the other rock units (i.e., Upper Eocene limestones, Oligocene sandstones, and Miocene limestones) may require caution depending on the specific application. For instance, the Oligocene rocks exhibit very low strength and low stiffness, which may pose challenges for construction or mining activities. Similarly, the Miocene and Upper Eocene rocks also exhibit low rock strength.Therefore, the study emphasizes the importance of carefully selecting rock units based on their mechanical properties for engineering and geological applications. Low strength and stiffness in rocks should be approached with caution when designing structures or assessing rock formations. The data presented in the study can be a valuable resource for informed decision-making by engineers and geologists. However, more research is needed to better understand rock properties and develop more accurate models for predicting their behaviour in various applications.

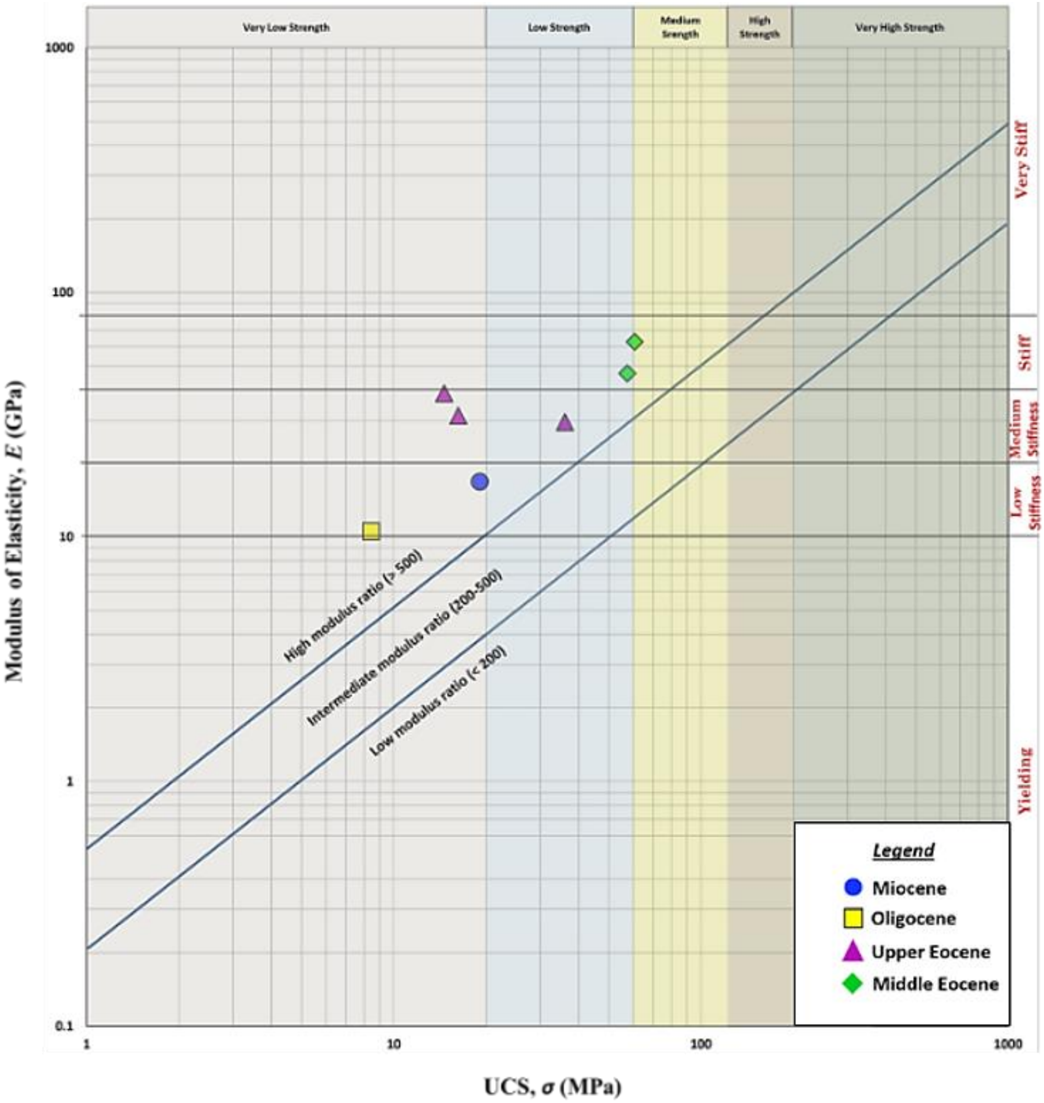


**Fig. 12.** Engineering classification of the study area rock units (Deere and Miller, 1966).

## VI. RECOMMENDATIONS

1- The investigated area has varying properties and characteristics of rocks, and hence, a site-specific investigation and characterization is crucial for successful geotechnical design and construction of infrastructure projects.

2- The UCS and elastic modulus of the rock units in the area were found to be relatively low, indicating their susceptibility to failure and deformation. Therefore, proper slope stability analysis and reinforcement measures are recommended to ensure the safety and stability of the slopes.

3- The rebound numbers of the rocks varied significantly depending on the weathering condition, highlighting the importance of assessing the degree of weathering of rocks before any construction activity is carried out.

4- The geotechnical investigation should also include a detailed assessment of the groundwater conditions in the area, as it could have a significant impact on the performance and stability of the foundation soils and structures.

5- It is suggested to carry out comprehensive geohazard assessment to identify any potential risks associated with natural hazards and develop appropriate mitigation measures to minimize the potential impact on the infrastructure and surrounding communities.

6- Finally, it is crucial to ensure that the geotechnical investigations and characterization are conducted by experienced professionals using the latest technologies and methodologies to ensure accurate and reliable results.

These recommendations aim to enhance geotechnical performance, mitigate hazards, and contribute to the overall success of infrastructure development in the region.

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