

Geotechnical Evaluation and Characterization of Soils from Tobruk City

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Abstract. The spatial variability of soil properties plays a critical role in determining the suitability of sites for construction and infrastructure development. This study presents a comprehensive geotechnical characterization of surface soils collected from ten representative locations across Tobruk City, Libya, to evaluate their engineering suitability. Field sampling and laboratory testing were conducted to determine key geotechnical parameters, including natural moisture content, particle-size distribution, consistency limits, and compaction characteristics. The results indicate that the investigated soils are predominantly sandy, exhibiting low plasticity and negligible clay content. Most samples demonstrated favorable compaction behavior, reflecting satisfactory engineering performance for construction applications. The findings suggest that the soils of Tobruk City are generally suitable for construction, particularly in the Al-Karama and Al-Rasheed areas. Nevertheless, locations characterized by lower densities or greater moisture sensitivity may require appropriate ground improvement measures prior to development. Further investigations, including shear strength testing and seasonal monitoring of soil behavior, are recommended to support safe and sustainable infrastructure development in the region.

Keywords: Geotechnical investigation; Soil characterization; Compaction behavior; Construction materials; Tobruk City.

1 Introduction

Soil serves as the primary foundation medium for civil engineering structures, and its engineering properties directly influence the stability, safety, and performance of infrastructure systems. The design and construction of buildings, bridges, highways, dams, and other engineering facilities require a comprehensive understanding of the geotechnical characteristics of the underlying soils [1]. Since soil properties vary considerably due to differences in geological origin, detailed geotechnical investigations are essential for evaluating site suitability and minimizing the risk of foundation-related failures [2]. Geotechnical investigations play a critical role in identifying subsurface conditions and mitigating risks associated with urban development. Common geotechnical hazards include soil instability, excessive settlement, and liquefaction, all of which can adversely affect the performance of engineering structures [3]. Soil instability may lead to slope failures and ground movement, whereas excessive settlement can result in structural damage and differential foundation deformation. Similarly, liquefaction can significantly reduce soil strength and stiffness, posing serious risks to buildings and infrastructure. Consequently, detailed geotechnical investigations are required to provide reliable data for engineering design and construction.

Several researchers have emphasized the importance of geotechnical characterization in foundation engineering. [Nwankwoala and Warmate \[4\]](#) and [Oke and Amadi \[5\]](#) reported that the assessment of soil properties is necessary for generating reliable design parameters for foundation systems. According to [Shad \[6\]](#), geotechnical investigations provide essential information for the design of foundations, retaining structures, and other engineering systems, thereby ensuring the safety and durability of urban infrastructure. The engineering suitability of soils is commonly evaluated through the determination of key geotechnical

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parameters, including natural moisture content, particle-size distribution, consistency limits, and compaction characteristics. These properties govern the strength, compressibility, permeability, and load-bearing capacity of soils. In general, coarse-grained soils exhibit higher bearing capacities than fine-grained soils, while the plasticity characteristics of cohesive soils significantly influence their engineering behavior [7] and [8].

Tobruk City, located in northeastern Libya along the Mediterranean coast, is characterized by a semi-arid climate and diverse geological formations. The region is predominantly composed of calcareous soils, sandy deposits, and localized clayey layers formed by both coastal and inland geological processes. These variations contribute to spatial differences in soil properties and engineering behavior, which may significantly affect foundation performance and construction practices. Despite the city's ongoing urban expansion and increasing infrastructure demands, comprehensive geotechnical data for Tobruk soils remain scarce. Therefore, this study aims to characterize and evaluate the geotechnical properties of surface soils collected from ten representative locations across Tobruk City. Laboratory testing was conducted to determine the principal index and compaction properties of the soils and to assess their suitability for construction and infrastructure development. The findings of this study provide a valuable geotechnical database for the shallow soils of Tobruk City and support informed decision-making during preliminary site assessment, foundation design, and sustainable urban development.

2 Methodology

The geotechnical investigation in Tobruk City was conducted through a systematic approach combining field sampling and laboratory testing to assess the engineering properties of local soils. The methodology adhered to internationally recognized standards and aimed to generate data suitable for foundational design and construction planning.

2.1 Soil Sampling

Ten representative sites were selected across Tobruk City based on their relevance to existing and planned urban development projects (Fig. 1). One disturbed soil sample was collected from each site (ten samples in total) to evaluate the geotechnical characteristics of the shallow subsurface soils. Sampling was carried out from test pits or shallow boreholes excavated to depths ranging from 0.5 to 1.0 m below ground level (Fig. 2). All samples were carefully labeled, sealed, and transported to the laboratory for subsequent testing and analysis in accordance with standard geotechnical procedures.

2.2 Laboratory Testing Program

Natural Moisture Content: The natural moisture content of the soil samples was determined in accordance with BS1377-2 [9]. Representative specimens were oven-dried at $105 \pm 5^\circ\text{C}$ for a minimum of 24 hours, and the moisture content was calculated as the ratio of the mass of water lost during drying to the mass of the dry soil, expressed as a percentage.

Particle Size Distribution: It was determined by mechanical sieve analysis following the procedures specified in BS1377-2 [9]. Air-dried soil samples were passed through a series of standard sieves arranged in descending order of aperture size. The proportions of gravel, sand, silt, and clay fractions were subsequently determined and used for soil classification.

Consistency Limits: The consistency limits were determined in accordance with BS1377-2 [9]. The liquid limit (LL) was measured using the Casagrande method, where the water content corresponding to 25 blows was obtained from the flow curve. The plastic limit (PL) was determined by rolling soil threads until they reached a diameter of approximately 3 mm and began to crumble. The plasticity index (PI) was calculated as

the difference between the liquid limit and plastic limit ($PI = LL - PL$). For samples exhibiting non-plastic behavior due to insufficient cohesive fines, PL and PI values were not determined.

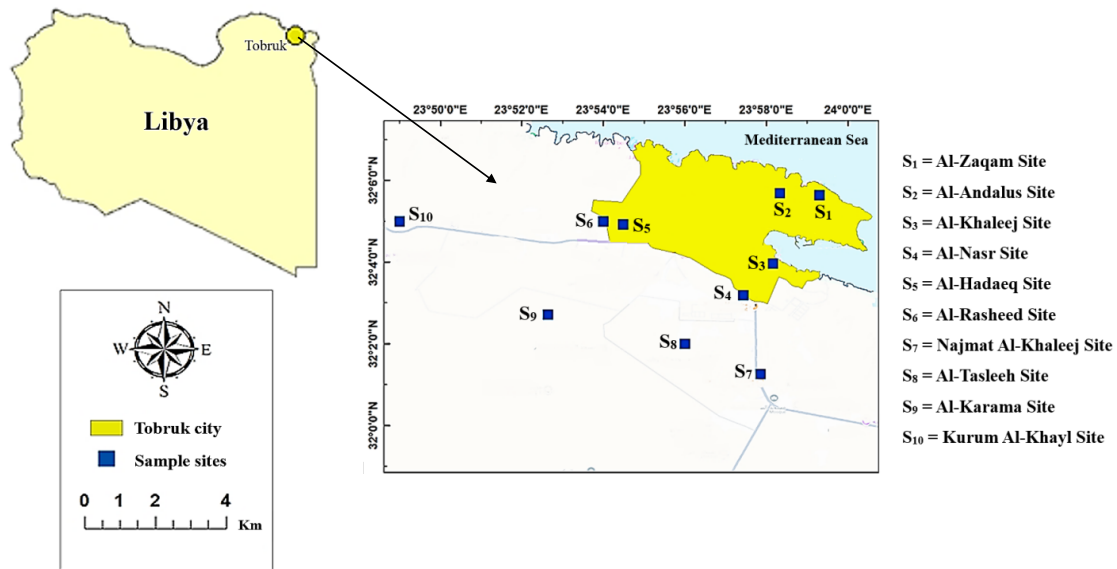


Fig.1 Geographical distribution of the study sites in Tobruk City.



Fig. 2 Field sampling and excavation of test pits at the selected locations.

Standard Proctor Compaction Test: The compaction characteristics of the soils were evaluated using the Standard Proctor test in accordance with [BS1377-4 \[10\]](#). Soil samples passing the 4.75 mm sieve were prepared at varying moisture contents and compacted in a standard mold using a 2.5 kg rammer dropped from a height of 300 mm. The dry unit weight corresponding to each moisture content was determined, and compaction curves were developed to establish the maximum dry density (MDD) and optimum moisture content (OMC) of each soil.

3 Results and Discussion

3.1 Natural Moisture Content

The natural moisture contents of the investigated soils are presented in Fig. 3. The measured values ranged from 1% at the Al-Khaleej and Al-Karama sites to 11% at the Al-Rasheed site, indicating noticeable spatial variation in the moisture conditions across the study area. Such variability may be attributed to differences in local drainage conditions, soil composition, topography, and environmental exposure. The generally low moisture contents recorded at most sites are characteristic of the semi-arid climatic conditions prevailing in Tobruk City and suggest relatively dry subsurface conditions.

From an engineering perspective, soils with low natural moisture content typically exhibit greater stability and are less susceptible to moisture-induced reductions in strength. In contrast, the relatively higher moisture content observed at the Al-Rasheed site may influence the soil's load-bearing behavior and compaction characteristics, particularly under changing environmental conditions. Overall, the results indicate that the investigated soils possess relatively low in-situ moisture contents, which is advantageous for construction activities. Nevertheless, local variations in moisture conditions should be considered during site preparation and foundation design, as elevated moisture levels may necessitate appropriate drainage or moisture-control measures to ensure satisfactory engineering performance.

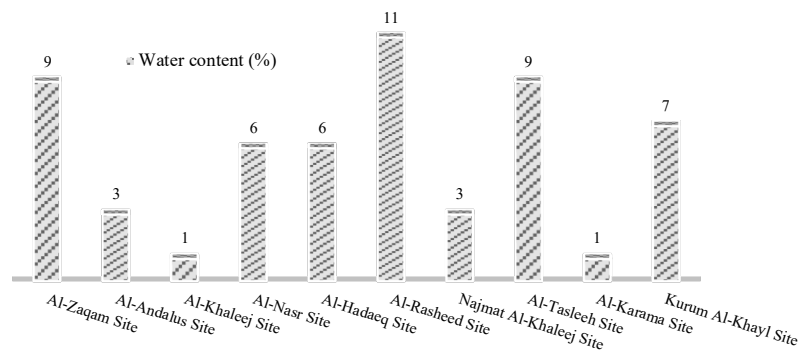


Fig. 3 Natural moisture content of soil samples collected from the investigated sites in Tobruk City.

3.2 Particle-Size Distribution

The particle-size distribution curves of the investigated soils are presented in Fig. 4. The results indicate that the soils are predominantly coarse-grained, consisting mainly of sand with varying proportions of gravel and silt, while clay-sized particles were negligible in all samples. The sand fraction represents the major component of the soil matrix, accounting for approximately 70-90% of the total soil mass. Medium sand (0.425-2.0 mm) was identified as the dominant sub-fraction, contributing approximately 40-50% of the overall particle-size distribution. Fine sand constituted the second most abundant fraction, representing 20-35% of the soil mass, particularly in the Al-Rasheed and Kurum Al-Khayl sites. In contrast, coarse sand (>2.0 mm) occurred in relatively small proportions and generally did not exceed 15%. Gravel was present primarily as fine gravel (4.75-9.5 mm), with the highest concentrations observed in the Al-Zaqam, Al-Khaleej, and Al-Tasleeh sites. The gravel content in these locations ranged from approximately 5% to 15%, reflecting localized variations in depositional conditions. Silt was detected in all samples at relatively low percentages, averaging around 10%, and was predominantly composed of coarse silt particles. The near absence of clay-sized particles indicates a lack of cohesive fines and confirms the essentially nonplastic nature of the investigated soils.

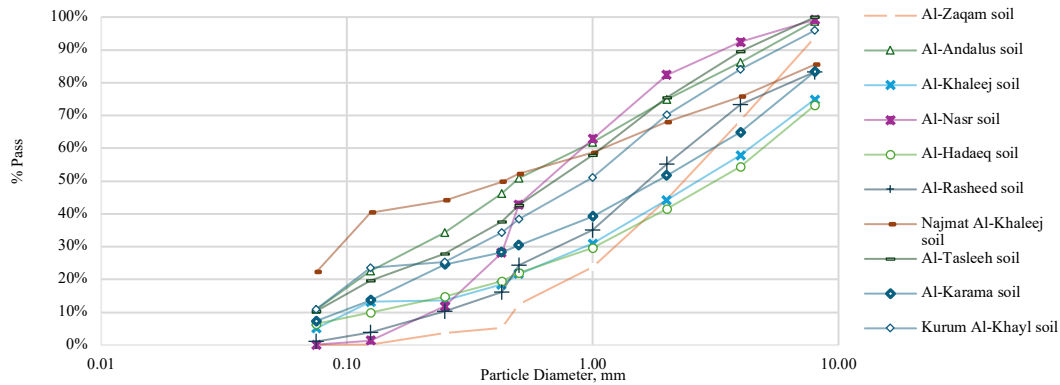


Fig. 4 Grain-size distribution curves of the collected soils

From an engineering perspective, the predominance of sand and gravel fractions suggests favorable geotechnical characteristics, including high permeability, low compressibility, and relatively low susceptibility to volume change. The appreciable gravel content recorded in sites such as Al-Zaqam and Al-Khaleej is expected to improve interparticle friction and enhance the shear strength and stability of the soil mass [11]. Conversely, soils containing relatively higher proportions of fine sand and silt, particularly at Al-Rasheed and Kurum Al-Khayl, may exhibit greater sensitivity to moisture variations and compaction conditions, which should be considered during construction and earthwork operations. Overall, the particle-size distribution characteristics indicate that the soils of Tobruk City are generally suitable for foundation and infrastructure applications. Their coarse-grained nature promotes efficient drainage and reduces the potential for excessive settlement. However, the limited presence of cohesive fines may reduce natural resistance to erosion and slope degradation, necessitating appropriate stabilization or protection measures where required.

3.3 Consistency Limits and Soil Plasticity

The consistency limits of the soils investigated are presented in Table 1. The liquid limit (LL) values range from 20.6% to 34.05%, while the plastic limit (PL) values vary between 14.3% and 17.7% for soils exhibiting measurable plasticity. The calculated plasticity index (PI) ranges from 6.27% to 10.52%, indicating generally low plasticity characteristics. For the Al-Zaqam, Al-Khaleej, Najmat Al-Khaleej, and Al-Karama sites, the plastic limit could not be determined because the soils lacked sufficient cohesion to be rolled into threads of 3 mm diameter. Consequently, plasticity index values were not calculated for these samples. This behavior is attributed to their predominantly coarse-grained composition, characterized by high sand and gravel contents and a negligible clay fraction. Accordingly, these soils are classified as non-plastic (NP).

Table 1. Consistency limits of the investigated soils.

Site	LL	PL	PI
Al-Zaqam	34.05	-	-
Al-Andalus	20.6	14.33	6.27
Al-Khaleej	33.6	-	-
Al-Nasr	27	17.3	9.7
Al-Hadaeq	26.2	17.7	8.5
Al-Rasheed	21.5	14.3	7.2
Najmat Al-Khaleej	23.5	-	-
Al-Tasleeh	24.7	16.86	7.84
Al-Karama	22.4	-	-

The relatively low liquid limit and plasticity index values obtained for the remaining samples indicate limited plastic behavior and low susceptibility to moisture-induced volume changes. These findings are consistent with the particle-size distribution results, which revealed a predominance of sand and minor amounts of silt with negligible clay content. Overall, the consistency limit results confirm that the investigated soils are predominantly non-plastic to low-plasticity materials. The absence of significant clay fractions and the relatively low plasticity indices indicate a low potential for shrink–swell behavior and support the suitability of these soils for a wide range of construction and infrastructure applications.

3.4 Soil Classification

The investigated soils were classified using the Unified Soil Classification System (USCS) based on particle-size distribution and consistency-limit results. The resulting classifications indicate that the investigated soils are predominantly sandy materials, with varying amounts of nonplastic or low-plasticity fines. The USCS classifications are summarized in Table 2.

Table 2. USCS classification of the investigated soils

Site	USCS Classification
Al-Zaqam	SW
Al-Andalus	SP-SC
Al-Khaleej	SW-SM
Al-Nasr	SP
Al-Hadaeq	SW-SC
Al-Rasheed	SP
Najmat Al-Khaleej	SM
Al-Tasleeh	SP-SC
Al-Karama	SW-SM
Kurum Al-Khayl	SP-SC

The classification results show that SP and SP-SC soils occur at several locations, indicating predominantly sandy materials with either minor fines or low-plasticity clayey fines. The SM and SW-SM classifications indicate sands containing nonplastic silty fines, whereas the SW classification indicates well-graded sand with a negligible amount of fines.

3.5 Compaction Characteristics

The compaction characteristics of the investigated soils, determined using the Standard Proctor test, are presented in Fig. 5. The results indicate that the optimum moisture content (OMC) varies from 12.5% to 23.0%, whereas the maximum dry density (MDD) ranges between 1.612 and 1.956 g/cm³. The observed variability reflects differences in soil gradation, particle arrangement, and fine-content distribution among the investigated sites. Al-Karama soil exhibited the highest maximum dry density, indicating a dense particle packing arrangement and a high degree of compactability. Such characteristics are generally associated with improved load-bearing capacity and reduced compressibility, making the soil favorable for foundation and pavement applications. In contrast, the Al-Tasleeh soil recorded the lowest maximum dry density and one of the highest optimum moisture contents, suggesting a greater water demand to achieve effective compaction and comparatively lower resistance to deformation under loading. The compaction behavior observed in this study is consistent with the predominantly coarse-grained nature of the soils. Sandy soils typically attain relatively high dry densities at moderate moisture contents due to efficient particle rearrangement during compaction. Variations in OMC among the sites can be attributed to differences in the proportions of fine

sand and silt fractions, which influence water retention and lubrication between soil particles during densification.

Based on the compaction test results, the investigated soils display generally favorable engineering characteristics, as reflected by their MDD and OMC values, supporting their potential use in construction projects. Higher dry densities are commonly associated with increased shear strength, reduced settlement potential, and improved foundation performance. However, soils exhibiting lower dry densities and higher moisture requirements may require stricter moisture control and compaction procedures during construction to achieve the desired field density and engineering performance. Furthermore, the comparison between natural moisture content and optimum moisture content provides valuable information for construction planning. The natural moisture contents measured at most sites were lower than the corresponding OMC values, indicating that moisture conditioning through controlled water addition would likely be required during field compaction. Such measures are essential to ensure the achievement of maximum dry density and to optimize the long-term performance of earth structures, pavements, and shallow foundations.

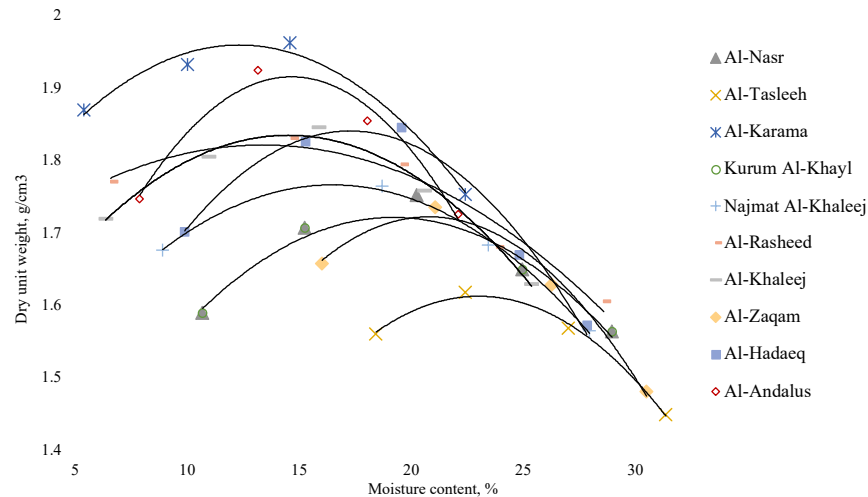


Fig. 5 Standard Proctor compaction curves of soils collected from the investigated sites in Tobruk City

4 Conclusions

This study presented a geotechnical characterization of surface soils collected from ten representative locations within Tobruk City. A comprehensive laboratory testing program was conducted to evaluate the physical and index properties of the soils. Based on the results obtained, the following conclusions can be drawn:

- Natural moisture content values ranged from 1% to 11%, indicating generally dry in-situ conditions consistent with the semi-arid climate of Tobruk City.
- Particle-size distribution analysis revealed that the investigated soils are predominantly coarse-grained, consisting mainly of sand with minor proportions of gravel and silt and negligible clay content.
- Consistency limit tests showed that the soils are non-plastic to low-plasticity materials, as reflected by the low liquid limit (LL) and plasticity index (PI) values. Several samples were classified as non-plastic due to the absence of sufficient cohesive fines.
- Compaction test results indicated optimum moisture contents ranging from 12.5% to 23.0% and maximum dry densities between 1.612 and 1.956 g/cm³, demonstrating generally satisfactory compaction characteristics.

The overall findings demonstrate that the surface soils within the investigated areas of Tobruk City possess generally favorable geotechnical characteristics for construction purposes. Nevertheless, the observed spatial variability highlights the importance of conducting site-specific investigations to support the design and implementation of engineering projects.

5 Recommendations

Although this study provides a baseline understanding of the near-surface soil conditions in Tobruk City, further investigations are recommended to expand the geotechnical database and provide more comprehensive information for engineering applications. Based on the findings of the present study, the following recommendations are proposed:

- Additional tests, including direct shear, triaxial, and consolidation tests, should be conducted to evaluate soil strength and settlement behavior.
- Soils with higher plasticity or poor compaction characteristics should be investigated for potential stabilization using materials such as lime or cement.
- Seasonal sampling is recommended to assess the effects of moisture variations on soil properties and engineering performance.
- Since sampling was limited to 0.5–1.0 m depth, deeper subsurface investigations are recommended to characterize underlying soil layers and provide reliable information for site-specific foundation and infrastructure design.

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