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Geotechnical Properties of Soil at Khan Bani Saad-South West of Diyala Governorate

A Thesis Submitted to the Council of the College of Science, University of Diyala in Partial Fulfillment of the Requirements for the Master's Degree in Geology/ Earth Science

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Abstract

Evaluation of the geotechnical properties of the soil on which heritage buildings were built is essential for efficient maintenance and mitigation. This study aims to evaluate the geotechnical properties of soil at Khan Bani Saad heritage site, southwest of Diyala Governorate, Iraq. Twenty soil samples were collected from the study area. First, the physical properties of soil were identified using the basic index tests and classified using USCS classification following the ASTM standards. Second, the compaction and unconfined compression strength tests were conducted. In addition, some chemical tests on the soil, groundwater, and bricks used to build the heritage building were also performed.

The results showed that the soil in the study area consists of Gravel (0%); Sand (1%-3%) with an average of 2%; Silt (30-57%) with an average of 43.5%, and Clay (40-68%) with an average of 57.9%. Therefore, it was considered as fine-grained. The soil was also characterized by high natural water content and low specific gravity due to the high fine-grained and organic material content. The low depth of groundwater contributes to the capillary action in the soil. The results of Atterberg limits tests showed that the LL ranged between (41%-52%), whereas the PL ranged between (20%-28%), while the PI values were between (18%-27%). Therefore, it can be described as an intermediate liquid limit and medium to high plasticity soil, and according to USCS classification, the soil was classified as type CL or OL. The fine-grained nature and high organic matter content increase the plasticity of the soil. The swell potential of soil was preliminarily evaluated as medium swelling potential using indirect methods based on index properties. The compaction test revealed that the Optimum Moisture Content (OMC) ranged from 12.0% to 22.0%, with an average of 17.2%, and the Maximum Dry Density (MDD) varied from 1.47 gm/cm^3 to 1.79 gm/cm^3, with an average of 1.64 g/cm^3. The Compactin Ratio (R%) ranged from 83.12% to 102.29%, with an average of 93.23%. These values can be used as a guide for future compaction practice. The Unconfined Compression Strength UCS tests showed that it varied from 0.64 kPa to 13.79 kPa, with an average of 9.72

kPa which indicates a low compressive strength and a very soft consistency which is attributed to the high fine-grained, organic matter, and elevated water content. The chemical analyses of soil showed that the soil is characterized by non-gypsum to very slight gypsum presence, while the organic matter content is varied from 0.08 % to 15.3% with an average of 8.62. The high organic content softens the soil, lowering its compressive strength. Furthermore, the chemical tests on soil and groundwater revealed an increase in some salts such as chloride and sulfur which negatively impact soil properties. The tests performed on the bricks showed that they have non-standard dimensions that are non-compatible with the dimensions of Iraqi Standard No. 25 (1988) for clay bricks. However, the values for absorption and compressive strength are close to those of Class A bricks according to the Iraqi standard.

Due to the high fine-grained content, organic material, and some salts, and because of the natural deterioration, the Khan Bani Saad heritage building requires immediate mitigation and maintenance programs. Soil improvement can be achieved using compaction and soil stabilization additives. Finally, further detailed geotechnical tests to evaluate the compressibility, and swelling potential of soil are recommended.

Chapter One

Introduction

1.1 Preface

Engineering geology is a science that focuses on studying the properties of earth materials and their suitability for engineering projects such as tunnels, roads, dams, and buildings. This makes it crucial to select the location of any engineering projects, particularly huge ones. It is also essential to maintain and mitigate these projects. Therefore, it is necessary to characterize the soil on which a structure or foundation will be built to determine its geotechnical suitability and mitigation requirements.

However, the types of soil materials encountered in engineering projects are almost limitless, ranging from hard, dense to soft compressible soils. Addressing the geotechnical properties of these materials and the engineering problems that arise during and after construction is fundamental for designing efficient and economical foundations for almost every engineering structure (Al-Khafaji, 2002).

In particular, evaluation of the geotechnical properties of soil at the heritage sites is an essential but challenging task for maintaining and mitigating these sites. Khan Bani Saad site (Fig. 1-1), is an old heritage building located on the Baghdad-Baquba old road built in 1688 for travelers who preferred to spend the night resting in Khan Bani Saad (Al-Azzawi 1969). The building was severely damaged during the terrorist attack conducted by ISIS in 2015. This terrorist operation targeted the markets and residents of the Bani Saad area with a car bomb 20 meters away from the building. The corners, foundations, and basements of the building were demolished (Fig. 1-2a and b). This event and the natural deterioration of the building have triggered the alarm for permanent maintenance work to mitigate the building.

Recently, a new campaign was scheduled to mitigate the heritage building of Khan Bani Saad. Any engineering evaluation process for the site demands detailed data about the site's geotechnical properties. This can be achieved by conducting a geotechnical site investigation to assess the physical, engineering, and chemical properties of the soil as well as the chemical properties of the groundwater at the site.

Figure (1-1):The heritage building of Khan Bani Saad.

Figure (1-2): (a) The impact of the terrorist attack, 2015 (b) the deterioration of the heritage building of Khan Bani Saad.

1.2 Aims of Study

The main objectives of this study is to evaluate some of geotechnical properties of soil at Khan Bani Saad heritage site southwest of Diyala Governorate. Specific objectives can be listed as follows:

1. Evaluating the physical properties of soil such as natural moisture content, grain size distribution, specific gravity, Atterberg limits, etc. These properties are required to identify and characterize the soil at the site. These tests are also essential to classify the soil following the ASTM standards.
2. Conducting engineering tests, such as compaction and unconfined compression strength tests, to evaluate the soil's engineering behavior.
3. Assessing some of the chemical properties of soil, such as Sulphate Content, Organic Content (ORG%), Total soluble salts (T.S.S), Gypsum Content, and Chloride Content, in addition to the basic chemical analysis of groundwater in the area. These tests are fundamental to evaluating the chemical activity of soil and water at the site.
4. Performing some basic engineering tests on bricks used for building the Khan Bani Saad heritage site to evaluate their physical characteristics.

The results of this study provide preliminary geotechnical data required for future efficient maintenance and mitigating procedures of Khan Bani Saad heritage building.

1.3 Location of Study Area

The studied area is located in Khan Bani Saad, which is situated southwest of Diyala Governorate approximately 43 km northeast of Baghdad City. The site is flat with an altitude of approximately 43m ASL. Soil samples were collected from four Borehole around Khan Bani Saad heritage building labeled as B1, B2, B3, and B4 Figure(1-3). The table(1-1) indicates the drilling coordinates in the study area.In addition, groundwater samples were taken from groundwater well drilled at the site. Furthermore, bricks used in the construction of the building were also collected. After collection, the samples were tightly secured and transported to the laboratory for testing. Further details on sample collection, preparation, and testing methods will be provided in Chapter 2.

The table(1-1) indicates the drilling coordinates in the study area.

NO.	Coordinates in the study
B1	33° 34' 21.66"N, 44° 32' 29.71"E
B2	33° 34' 18.76"N ,44° 32' 32.72"E
B3	33° 34' 20.30"N,44° 32' 32.91"E
B4	33° 34' 20.34"N,44° 32' 29.8"E

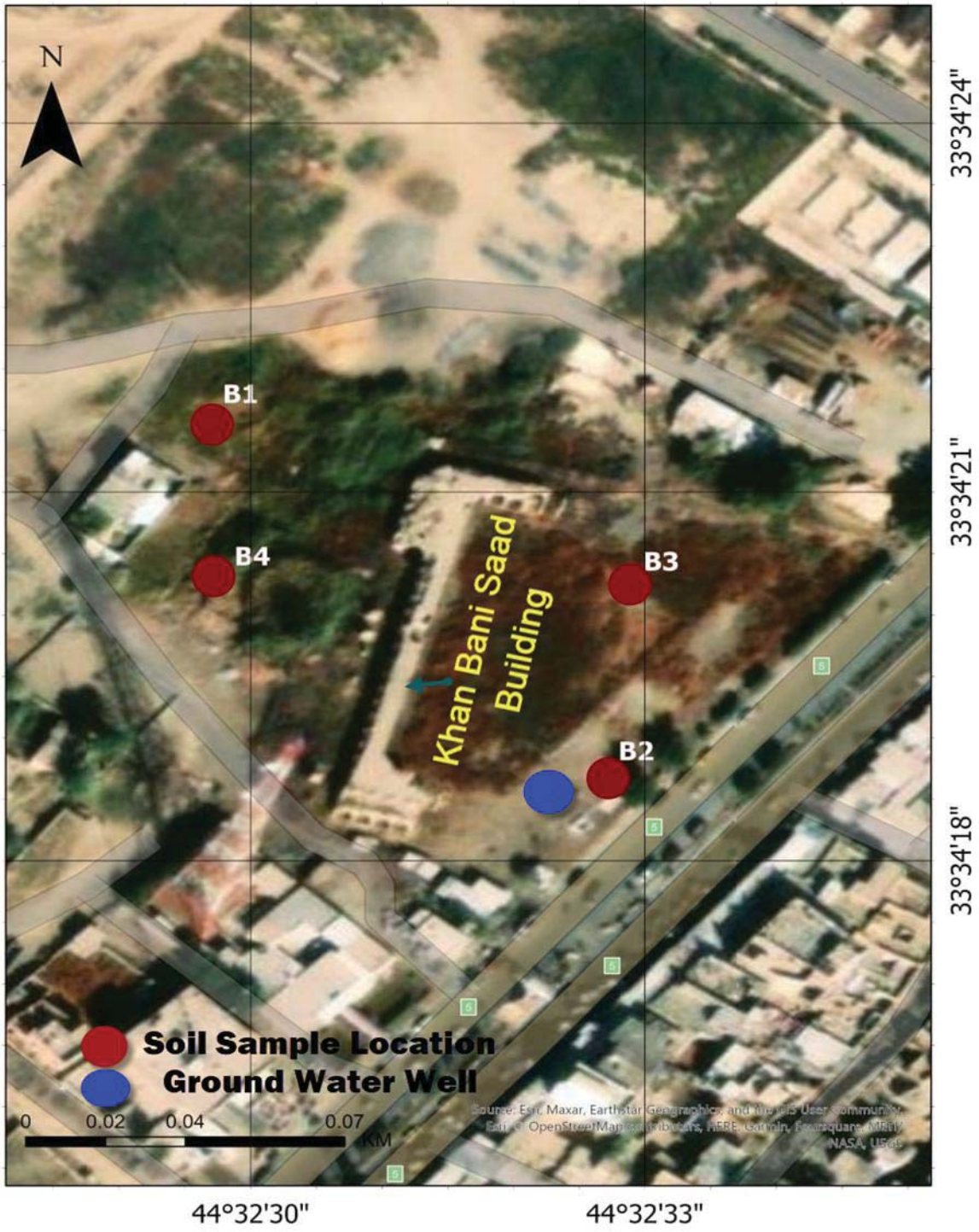

Figure (1-3): A map showing the studied area and the sampling locations.

1.4 Geological Background

Tectonically, the northeastern part of the Diyala governorate lies within the low folded zone, while the southwestern part lies within the Mesopotamia Foredeep (Fouad, 2012). The study area (Figure 1-4) lies in the later zone.

Recent quaternary sediments cover large areas of the Diyala governorate, especially the lower parts. These deposits can be summarized as follows (Jassim and Goff 2006) :

1. Slope deposits: These sediments are found on the slopes of a gentle incline that form narrow belts at the base of rocky ridges. The deposits are mixed and consist of particles of silty sand, gravel, and rock fragments of varying thickness, which suggest the origin of the rocks.
2. Valley fill deposits: These deposits were formed by the erosion of hills and mountains caused by rainfall. The rainwater then transported the sediments, consisting of gravel, sand, silt, and clay to the valleys. The thickness of the sediments varies, and their composition reflects the source rocks.
3. Floodplain deposits: The lower part of the Diyala governorate is covered by a type of sedimentation that takes the form of a floodplain. The plain is made up of silt and clay and extends on both sides of the Diyala river course.

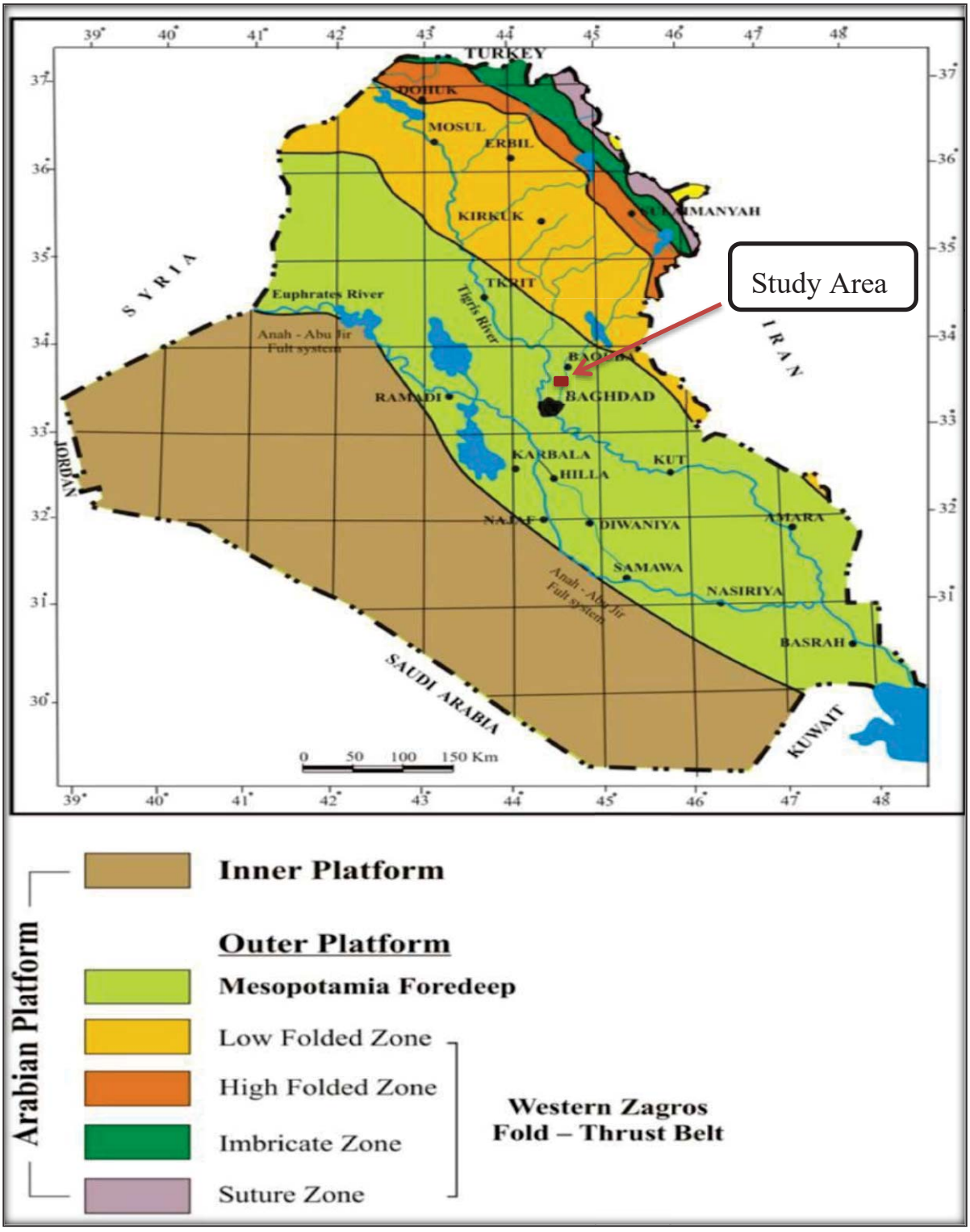

Figure (1-4): Tectonic map of Iraq (Fouad, 2012).

1.5 The Previous Studies

1.5.1 Geotechnical Studies of Soil in Iraq

Many studies have been conducted to evaluate the geotechnical properties of soil in different regions of Iraq.

Al-Badran and Muhammad (2002) evaluated the quaternary sediments of Basra City, southern Iraq. The study revealed that the sediments can be classified into two types; some are clayey soil, while others are noncohesive soils.

Al-Marsoumi et al (2008) investigated the engineering properties of soil in Khor Al-Zubair, located in southern Iraq. They discovered that the soil is primarily composed of gypsum and sand. Their findings indicated that as the gypsum content increased, the soil's cohesion also increased, which in turn affected shear strength and the angle of internal friction.

Muttasha.8r (2010) conducted a study on the geotechnical properties of the soil on the western bank of the Khor Al-Zubair Canal, south of Basra. He utilized five marine wells and three land wells for his research. He discovered two distinct layers in the bank of the canal. The first layer consists of marly silty clay, also known as fat clay, which is 18 meters thick and varies in consistency from very soft to hard. The second layer is composed of sandy soil.

Hassan (2011) conducted an assessment of soil suitability in selected sites in the Dhi Qar Governorate for brick manufacturing. The study found that most of the region's sediment is clayey, with some being silty or sandy. The plasticity of the sediment ranges from high to low plasticity, which increases with the percentage of silica among the oxide components. Tests on ordinary brick samples showed that adding sand to all study areas improved the properties of the bricks. The properties of the bricks met the requirements of Iraqi standards.

Al-Jabban (2014) conducted a geotechnical evaluation of some test pits in the city of Hilla and he found the permeability of underground soil varies depending on the sand content. The soil consists mainly of silty clay to clay silt with some sand. The study revealed that the soil has a low swelling and contains a high dissolved salts percentage, in addition to gypsum and sulfate contents and groundwater contains harmful amounts of sulfates, especially for any concrete work.

Hussein (2016) evaluated the geotechnical properties of the soil in Wasit Governorate. He found that the subsoil consisted of cohesive, brown silty clay to silty and sometimes sandy with medium to high plasticity with low compressibility, and high organic matter. Additionally, high sulfate and chloride contents were noticed in the groundwater.

Al-Zubaydi et al. (2016) conducted a study on the stability of the slopes along the banks of the General Main Drain Canal's middle section in central and southern Iraq. They found that the soil contains a higher percentage of clay as compared to silt and sand. The clay is of two types: one with low plasticity and the other with high plasticity. The soil also has varying levels of salinity, ranging from low to high, and the pH value falls within the range of low to moderate basicity. Grain size distribution indicates higher clay content than sand and silt in Al-Massab Al-Aam Channel stations.

Omar et al. (2016) assessed the soil at Koya City, North Iraq. The results showed that the test stations mainly contained coarse-grained soils, with only a few fine-grained soils present. The clay soils in the test area have weak clay activity, which means they have a low tendency to swell. There is also a significant variation in the percentage of gravel, sand, and fines from one station to another,

and the permeability varies widely depending on its breadth and the different soil types and formations within the region.

Abboud et al. (2016) evaluated the soil at selected sites in Kirkuk City. The results of the physical tests showed that the soil is silty and has low plasticity. Through chemical analyses, the gypsum and organic content are low and basic with a low soluble salt content.

Al-Furaiji et al. (2016) studied the geotechnical properties of the soil of Abu Ghraq city in Babylon Governorate and found that the surface soil is silty clayey and then silty sandy and classified it as low plasticity clayey. Laboratory investigation showed that the region's soil needs engineering treatments to establish engineering facilities.

Al-Mayahy et al. (2019) conducted a geotechnical evaluation of soils in Al-Mashrah area in Maysan Governorate and found that the soils are cohesive, silty clay and clayey silt, and were classified into four layers: silty clay and clayey silt of medium strength, a layer of silty clay and clayey silt of very strong structure, and another layer of silty clay and clayey silt of hard structure.

Sayhud and Rashid (2020) evaluated the geotechnical characteristics of the soil along both banks of the Euphrates River in the Kufa Al-Mishkhab region of central Iraq. Their study found that the grain size of the silt is greater than that of the clay and sand. The soil samples were classified according to the Unified Soil Classification System (USCS) standard. The results indicated the presence of silt with a low plasticity ratio, as well as areas with a high plasticity ratio. Both the dry and saturated densities of the soil were found to be within the ideal limits.

Muhammad (2023) conducted a study on the engineering and environmental characteristics of the sediments in dam reservoirs. His findings showed that the soil in the reservoirs is mainly alluvial and clayey, with silt being more prevalent than

sand and clay. The plasticity of the soil varied between the dams, with the Samarra Dam having low plasticity and the Al-Wand and Mandali dams having medium plasticity. The cohesion values were found to be high at the Mandali Dam site and low at the Samarra Dam site. In terms of the production of clay bricks, the deposits of the Samarra Dam were found to fall outside the limits of the Iraqi standard for brick manufacturing. However, the raw materials from the Al-Wand Dam and the Mandali Dam were suitable for making clay bricks according to the Iraqi standard.

In Diyala governorate, however, few geotechnical studies were conducted in different parts of the governorate. For instance, Al-Ani (2001) constructed initial geotechnical maps of the western and central regions of Diyala and concluded that the soil in these parts is fine-grained with different geotechnical properties. The study did not cover the south of Baqubah city due to lack of data.

Similarly, Al-Shakraji and Turki (2011) provided soil maps for Diyala, in addition to Baghdad, Wasit, and Babil governorates. They found that the soil of Diyala Governorate is characterized by fine-grained soils that are diverse in their geotechnical properties due to their origin from recent sediments.

An extensive geotechnical site investigation was conducted at the campus site of the University of Diyala by Al-Ebdaa Company in 2015. The soil profile, as per the geotechnical boring logs, comprises a 13m thick layer of low plasticity, light to dark brown clayey soil (CL) overlaying a layer of dark gray silty sand (SM) (Al-Ebdaa, 2015)

Alhadad and Najeh (2020) evaluated the geotechnical properties of soil samples collected from the Al-Ghalabiya area in the Diyala governorate. The study showed that the soil in the area is categorized as fine-grained type (CL-ML, CL) and it was concluded that the soil is suitable for various engineering projects.

In the south of the city of Baqubah, Hassan et al. (2022) conducted physical and mechanical assessments of soil, and it was classified as fine-grained inorganic clay soil with low to moderate plasticity based on the USCS classification.

Dada (2023), conducted geotechnical and geoelectrical tests for soil, at the Diyala University campus site south of Baqubah. Geotechnically, the soil was described as a fine-grained type CL of low to moderate plasticity. The geotechnical parameters were also compared with the electrical resistivity values.

In selected locations (Qara Tappah, Baqubah, Khanaqin, and Al-Muqdadiya cites) in Diyala Governorate, Hussein (2023) evaluated the compaction characteristics of soil at these sites. The results indicated that the soil in Qara Tappah was coarse-grained, while in the other sites, it was fine-grained, and the values of maximum dry density and optimum moisture content were determined.

Recently, AL-Ahmed for Engineering Consultancy and Construction Testing (Al-Ahmed, 2024a) evaluated the geotechnical properties of soil in the Makkah Al-Mukarama Mosque located in Khan Bani Saad . The report revealed a homogenous soil profile of Silty Clay (CL) extending to 10m depth. The soil exhibited high fines content (87% - 98%), medium to high natural water content (20.2% - 28.8%), liquid Limit (32% - 46%), Plasticity Index (17-31%) indicating medium to high plasticity and it showed moderate compressibility (Compression Index Cc 0.174-0.208) with shallow groundwater table at 2.5m below the ground surface. Similarly, Al-Ahmed (2024b) evaluated the geotechnical properties of soil in Om Al-Qura site situated in Khan Bani Saad. The report also indicated a homogeneous soil of silty clay (CL) up to depth of 10.0m with fines content >80%. The soil was characterized by moderate natural water content (19.6 – 25.2%), and medium to high plasticity (Plasticity Index 15-32%). It also exhibited moderate swelling

potential (swell pressure 99-138 kPa) and moderate compressibility (Cc=0.165-0.220) suggesting that the swelling and compressibility characteristics should be considered in the foundation design to reduce the swelling and settlement potential.

1.5.2 Previous geotechnical archaeological studies in Iraq

Several studies were presented to evaluate the archaeological sites in different regions of Iraq.

Al-Omari et al. (2015) assessed the physical properties of stones of the Ziggurat walls of the city of Nimrud, northern Iraq. They found that the stone surface of the Ziggurat walls is affected by salt weathering.

In northern Iraq, Khorshid (2018) detected the archaeological sites located in the Tuz Khurmatu region of Saladin Governorate. They are hill ranges in varying sizes, and the buildings were constructed from mud, making them weak to resist the climate. All of the buildings were probably buried underground.

Saleh (2018) studied the reasons for the deflection of the minaret of the Caliph's Mosque in Baghdad by conducting a geophysical survey. It was found that there were widespread caverns and soft areas underneath and around it and that the area had a high groundwater level. Through conducting a numerical analysis, it was found that the area had been exposed to many explosions, especially in the years preceding 2013.

Nahaba (2019) investigated the archaeological features at the site of Tel Zuna, located in Babylon Governorate. They used the GPR method (GPR) to study the ancient Babylon. The geophysical investigation focused on the buried archaeological structures and the study area was divided into three zones. The first zone consisted of dry sandy and clay soil, crushed archaeological materials, broken bricks, and ruins mixed with rock core. The second zone had relatively low

resistance due to humidity, while the third and deepest zone contained buried archaeological foundations and walls.

Abed et al. (2022) conducted a study on the geometric characteristics of ancient fire clay bricks found in the archaeological site of Dalbat, located in the south of Hilla city. The study focused on properties such as the ratio of porosity, density, and compressibility, as well as ultrasound examination in the Al-Kifl neighborhood of the south Babylon Governorate.

Al-Jubouri and Fakhr Al-Din (2022) analyzed the soil present in the Kufa Mosque's foundations. They discovered that due to the cracks in the mosque wall, it is important to consider the values and locations of the settlement and shear forces to maintain the wall properly. Archaeologists relied on investigation reports to determine the properties of the foundations, including their dimensions, materials, and depths. Soil investigation reports were used to determine the properties and standards of the soil. Additionally, a finite element program was utilized to assess the deformations of the soil layers beneath the brick foundations and walls of the mosque.

In Al-Abbas Holy Shrine in Holy Karbala, Al-Kafaji (2022) assessed the grouting works carried out to fill the cavities present in the soil beneath the old foundation of the exterior wall of the Al-Abbas Holy Shrine. The evaluation was done using a transverse seismic survey, and the results showed that the soil injection process was successful and effective in filling the cavities.

Also, Al-Khafaji (2023) conducted geotechnical characteristics at three sites in Karbala, Iraq, based on the cross-sectional survey completed at the Al-Abbas Holy Shrine, the pure water complex, and the tent hotel project and sites.