Petrographic and Geotechnical Aspects of the River Terraces at the University of Mosul as Buildings Foundations

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Abstract

This study explores the third stage of the Tigris River terraces at the University of Mosul. Due to its importance, most of its buildings, especially the modern ones, were built on these terraces, and some engineering problems appeared in those buildings. The current study aims to know the petrography of the rocks, the emergence of these terraces, and the effects that they obtained as a result of various geological factors, as well as study their geotechnical properties and suggest ways to improve them. A geological map was prepared to distribute the river terraces to show the efficiency of the future build construction sites using a Digital Surface Model (DSM) 1m. The results showed the impact of the new tectonics on these terraces and their exposure to faults in the field and microscopic scales. The study showed the weakness of its geotechnical properties as a result of the high porosity, and the biological effect on it, as well as the weak bonding and cohesion between the gravel and the cement materials. The study suggests engineering treatments to improve the geotechnical properties, including grouting them with easily absorbent materials into the micro-pores and strengthening them by ramming to close them as much as possible.

Keywords: Terraces; Mineralogy; Petrography; Geotechnique; New buildings; Faults

1. Introduction

The terraces of the Tigris River, which are approximately 0.3-12 kilometers wide, furnished the Tigris with five distinct and cartographic stages, including the one currently under study, at a distance of more than 350 kilometers from the Turkish-Syrian-Iraqi border in northern Iraq to Baiji City. The 3rd stage is the most important because it is widespread in the cities of Mosul, Salamiya, Sharqat, and Salah Ad din refinery areas in Baiji. The importance of the 3rd stage comes from the fact that it was used as the foundation for the urban areas of Mosul City built on the eastern bank of the Tigris River (Fig. 1). The 3rd stage concerned is distributed into an elongated discontinuous, isolated conglomerate, infrequently sandstone beds alternated with the conglomerate beds as mentioned by Al-Jubour et al. (2001) arranged parallel to the Tigris River about 12 km wide on the eastern side of the river and showing its periodical lateral migration from east to west. Hagopian and Vejluepek (1977) designed the first map of the terraces east of Tigris with their regional geological maps. Al-Jubouri (1988), completed a detailed study on the geomorphological, structural, and sedimentological characteristics of the terraces furnished on the eastern side of Mosul City. Detailed maps of the three areas, Mosul Dam, Mosul City, and Salamiya village, have been carried out by Al-Dabbagh and Al-Naqib (1991) as well as detailed cross-sections.
The 3rd stage of the Tigris river terraces conglomerate bodies has dispersed as the base rock of the proposed new building foundation in the designated construction area of the University of Mosul using a Digital Surface Model (DSM) with scale 1m. This stage is mapped to cover approximately 3 km². The thickness of the 3rd stage ranges from 5 to 28 m as an elongated huge mass rock body, which restricts broad shallow wading to the south part and sharp deep wadies to the north (Fig. 2A). To complete the evaluation, the new tectonic effects were studied in a geological cut close to the center of university shows sets of faults related to regional tectonic (Fig. 2B). The Late Middle Miocene; upper part of the
Fatha Formation was exposed, as well as gravel quarries (Fig. 3). The graduations of medium-hard conglomerates are clear, where its matrix and cement materials are weak.

The study aims to evaluate certain geotechnical characteristics for the 3rd stage of the Tigris River Terraces by studying geological, sedimentology, petrography, mineralogy, and biological features associated with conglomerate degradation.

1.1. Development and Tectonic History of the Tigris River Terraces

The fluvial Tigris terraces in the entire (Pleistocene and Holocene) interact with two major factors, climate, and tectonic activities. At the Mosul Dam area, the older terrace 1st stage shows few grades of inclination and offers signs of early tectonic activities in the Pleistocene (Stokes et al., 2002; Al-Naqib et al., 2018). Such inclination to the bed terrace in Mosul and Hammam Al-Alil districts is difficult to notice, possibly due to structural position differences between the three areas.

The weather in general, was much wetter in time of Early Pleistocene than it is now. Hence, an enormous amount of sediment is produced (Taylor et al., 2017). Boll et al. (1988) combined the two environmental factors to produce the changes in sediment supply and discharge that can cause the river to pass, depending on tectonic factors and climate, from the aggrading stage into an erosional stage. The flood plain can only be transformed into a terrace by some aggrading, climatic, or man-induced change that alters the regime of a river, causing it to entrench itself below its established bed and associated flood plain. Al-Juboury et al. (2001) discussed the development of river terraces of the Mosul area.
Al-Naqib et al. (2018) discussed the relationship of the neo-tectonic of Mosul, Sinjar, and Kirkuk blocks to the terraces of both the Tigris and Greater Zab rivers, and ensured the uplifting of the Mosul Block in Mosul City relative to the Sinjar Block. Al-Azzawi (2013) studied the November 2012 earthquake on the 3rd Mosul Bridge, which ascertained that the Mosul Block was being uplifted compared to the Sinjar Block. Consequently, each Tigris terrace stage may represent a distinctive seismic activation. Therefore, there were at least five major seismic activities occurred and the two Mosul and Sinjar blocks rejuvenated during Pleistocene-Holocene, leading to five terraces for Tigris. Another conclusion was that at the beginning of deposition or initiation of the 3rd stage of the Tigris River, the Mosul and Kirkuk blocks had been separated. The interaction between the inherited vertical basement fault and the horizontal movement of the Alpine Orogeny formed pre-Middle Miocene. This interplay reshaped the boundaries of the Mosul and Kirkuk blocks forming the present zone of the Tigris and the Greater Zab River. The period between the shaping of the Tigris River and the Greater Zab River was approximately equal to the age of formation and migration of the 1st stage and 2nd stages of the Tigris River terraces (Rafeeq et al., 1995). Al-Naqib et al. (2018) added that latter, the basement blocks have been retwisted again and reprocessed to shape the present zone of Greater Zab and its existing river terrace stages by relatively uplifting the southwest boundary of the Kirkuk Block. This conclusion depends upon a comparison of both terraces; the five stages of Tigris and the three stages of the Greater Zab River, although they differ in stage elevations. The latter two conclusions were approved in the field by Al-Naqib (2006) who related the formation of ninivite rock to the intersections of the Tigris River and Greater Zab River, as well as major structural elements such as faults.

1.2. Geology and Terraces Occurrences in Mosul City

In Mosul City, there are two geological formations outcropped: Fatha and Injana formations. Fatha Formation is a widely spread formation in Iraq divided into two members; the study area of the outcropped upper part includes a cyclic series of green and red mudstones and gypsum (Jassim and Goff, 2006). The formation had been covered by most of the area with river terraces, soil, and rock fragments. The oldest buildings of the University of Mosul built on the flood-plain and the new buildings are situated on hilly areas of the 3rd terraces stage.

The Tigris fluvial terraces are mostly situated on the left bank of the river in Mosul. The 3rd stage in Mosul University is widespread (Fig. 2B). On these terraces, most of the Mosul University buildings were constructed. For geotechnical engineers and engineering geologists, river terraces are very important. In terms of Civil Engineering their characteristics, disjoints, ground proximity, and high compressibility make quaternary deposits very important (Culshaw et al., 1991). The erosion and deposition processes were responsible for most of the river terraces, depending on the load of a river (Schumm, 1977). On either side of the river, the terraces extend for over ten kilometers (Jassim and Goff, 2006), as appeared in the study area, and twelve kilometers extension reached in Kokjalli as documented in the hand-dug well at a depth of two meters (Rafeeq et al., 2002). The integration of more than one independent process, including tectonic, climate, and geomorphology, controls the deposition of the fluvial terraces and their landforms (Schumm, 1977; Pazzaglia, 2018). The three processes control the deposition of Tigris terraces at the left bank of Mosul City. Until now, tectonic activity has been still occurring and a northwest anti-clockwise rotation of the Arabian Plate contributes to higher uplift northeast than southwest (Sissakian et al., 2014; Thannoun et al., 2022). Climate change over the Last Interglacial-Glacial Period affects the middle river terraces (Macklin et al., 2002). Nowadays, the climate in the study area has been from semi-arid to arid. During the deposition of the fluvial terraces, the climate was completely different from the present.
Fatha is the main formation that occupied the Tigris River on both sides. Al-Juboury and McCann (2008) carried out a comprehensive study of the Fatha Formation on the western side of the Tigris River represented by the lower member whereas the eastern side was displayed by the upper member of the formation. The Injana Formation is exposed to the east about 6 to 8 km from the present river channels.

1.3. Distribution of the Terraces on the Eastern Bank of Nineveh

In the fieldwork, approximately 95 m elevation differences were observed in Mosul City between the 1st stage and the 5th stage to the east. Also, 12 km from the present stage of the Tigris River to Kokjalli, where the 1st stage rests unconformably on the Injana Formation, which is covered with approximately 2 m thick soil that was found in a hand-dug well (Al-Jabbari et al., 2002).

The 2nd stage occupying relatively high aerial extents, around six kilometers long and about thirty-three meters thick, also rests unconformably on the final appearance of the Fatha Formation and the aerial extent of the Injana Formation. It is difficult to recognize because most civil buildings of the town in its eastern countryside were laid down on it and most of the flat areas existed covered by agricultural activities.

In the eastern bank of the Tigris River, the 3rd stage forms large continuous and isolated conglomeratic entities in the NW-SE direction parallel the river. It is mostly confined between the hilly elongated terrain of Al-Kafaat (the second), Al-Hadbaa, Al-Jamiaa (Fig. 4), Al-Masairif along Al-Khusar River for about five kilometers Al-Muthana, and the area between the two archeological hills, Al-Refaq extending to Al-Zuhur and Al-Noor sectors that have about two to three kilometers wide zone, (Fig. 1). This stage generally has approximately 20 m maximum thickness of subrounded, moderate sorting pebbles, clay, and calcareous cement clayey conglomerate. Subordinate silica cement was found as patchy surfaces formed of Ninivite rock, probably formed due to biogenic creatures besides H2S and methane gases, and finally, cross-bedding of large and medium-sized were documented in Fig. 5.

![Fig. 4. Location map of quarters in the eastern bank of the Tigris River](image-url)

Karstification is found within conglomeratic bodies forming the destruction of bedding (Fig. 6). Photo interpretation of the Google map on a scale of 1:100 and field interpretation mainly in the study area revealed tectonically, the presence of at least 3 sub terraces stages separated from each other by step type faults, which are inclined toward the east forming graben within S3 as shown in Fig. 6.

The 4th stage continues from the 3rd stage to the present stage in the Tigris River. It is limited to the Tigris narrow belt with a maximum 15-20 m, maximum thickness of a clayey conglomerate which is unconformably overlying red claystone of the upper members of the Fatha Formation, with red
claystone overland it. The conglomerate displayed medium to fine pebble sizes with subordinate coarse pebbles, mostly rounded to sub-rounded with good sorting of common clayey matrix and calcareous cementing materials.

![Fig. 5. The documentation of cross-bedding in the terraces.](image)

![Fig. 6. Typical cross-section in the terraces, the contour map of the study area showing the karstification distribution, and the 1m DSM of the University of Mosul.](image)

2. Materials and Methods

New cuts were made in fluvial terraces during the construction of new buildings at Mosul University. These cuts had been examined in detail and documented extensively with photographs and drawings. Petrographic and geotechnical samples were collected. In the field survey, Schmidt Hammer was used to test the cementing material rebound number for predicting strength. Thin sections for petrography and samples for XRD and SEM analyses were taken and cylindrical and cubical samples are prepared for geotechnical tests. Swift polarized microscope is used to study thin sections, while the SEM is conducted using Quanta FEG 250 SEM affixed with energy dispersive spectrometry (EDS) and XRD using a PANalytical X-ray Diffractometer at laboratories of the National Center for Research, Egypt. Finally, a comprehensive geotechnical map was developed for the University of Mosul, showing the distribution of engineering properties and their validity for the construction of university buildings.
3. Results and Discussion

The results of the current study were divided into a number of sections related to each type of investigation, their discussion and their relationship with other sections.

3.1. Petrography

The sandstone consists of three primary compounds: quartz, feldspar, and rock fragments in addition to common algae. In the analyzed samples, quartz is typically medium-sized. The entire sequence contains both monocrystalline quartz (MQ) and polycrystalline quartz (PQ). The MQ is normally medium to extremely fine and sub-rounded to angular, while some are well rounded, implying a suggested plutonic igneous origin. The PQ grains are medium-grained, sub-rounded to angular, consisting of more than three crystals; the contacts between the sub-grains are sutured to straight (Fig. 7A).

Feldspar has been observed, both plagioclase and K-feldspars. Plagioclase grains have been reported in sub-angular, euhedral grains forming zoned crystals. Twinning K-feldspar is common, while, it is much less common than plagioclase (Fig. 7B), and displays varying degrees of roundness. Sedimentary, igneous, and metamorphic rock fragments include lithic fragments, few carbonates, chert and argillaceous rock fragments are common. The carbonate rock fragments were persisting as mosaic sparry calcite, and some were found as micritic fragments. Chert rock fragments occur as angular to sub-rounded and fine to medium-sized, and chert fragments are mostly micro- to crypto-crystalline (Fig. 7C). The radiolarian chert (Fig. 7C) comes from the Cretaceous Qulqula sequence in northeastern Iraq and the nearby Sanandaj-Sirjan region of Iran (Stöcklin, 1968). Argillaceous fragments are composed of fissile shale, which is coarse grains and sub-rounded. The metamorphic rock fragments include serpentine, slate, phyllite-schist, and metasedimentary fragments of poly-crystalline quartzitic clasts (Fig. 7D). Intermediate acid-plutonic and andesitic fragments are the most common fragments of the igneous rock. The matrix, as crushed lithic grains displayed as small quartz grains. Cementing materials is a pore-filling and patchy carbonate, as identified with the use of Alizarin Red Solution (colored red, see Figs. 7 A-B) in most of the samples examined. The dominant accessory minerals are opaque or non-opaque, chlorite, anhydrite, and gypsum, rhombic dolomite, as well as iron oxide spots and veins, and few fossils replaced by calcite and some of them by iron oxide.

![Fig. 7. (A) PO quartz showing straight and sutured contacts (arrows), (B) Plagioclase (arrows) (C) Radiolarian chert (arrow) (D) Metamorphic rock fragment (schist), note carbonate cement is common (colored red A-B).](image)

Algae has been found as, red, green, and very rare greenish-blue, with a significant portion of the thin section, overlying the original deposits. Aspartic algae, often present as a multiple filament, oval, circular, stick, crescent, and network tend to have micritic groundmass (Fig. 8). The *Pseudotetraspora gainii* is a widespread freshwater algae species diagnosed in the current research. They appear as a single cell, *Palmellopsis gelatinosa korsch.*, *Ankistrodesmus convolute corda*, *Gonyostomum semen (Her.)*, *Schizomeris Leibleinii Ktz* (Fig. 9).
Fig. 8. Three types of colored algae (A) red (B) green (C) greenish-blue

Fig. 9. Five species of freshwater algae (1) Ankistrodesmus convolute corda, (2) Gonyostomum semen (Her.), (3) Palmellopsis gelatinosa korsch, (4) Pseudotetraspora gainii, (5) Schizomeris Leibleinii Ktz.

X-ray diffraction technique (Fig. 10) showed that the main minerals in the bulk samples studied are calcite and quartz, whereas, the clay minerals that appeared in the form of hump due to non-separating the clay minerals by sedimentation method may include kaolinite and illite.

Fig. 10. X-Ray diffractogram of the selected bulk sample (N5); C=Calcite, Q=Quartz; K= Kaolinite; I=Illite

Scanning electron images (Fig. 11) illustrate that calcite is dominated in the form of interlocked crystals (Fig. 10A) supporting the results from XRD (Fig. 10) that calcite is the abundant mineral in the studied rocks that may present as rock fragments or cementing materials, while flakes of illite and degraded hexagonal kaolinite flakes are also observed (Fig. 11B).

Various forms of algae are also observed in the SEM images (Fig. 11C-D), they present in unicellular with spherical shaped. These fresh water algae are micro algae, which are one of the most
abundant organisms in the world that can grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure (Elumalai et al., 2011; Pankaj and Awasthi, 2015)

Fig. 11. SEM photomicrographs, A. Interlocked calcite crystals B. illite flakes (white arrows) and degraded kaolinite (red arrow). C-D. Unicellular and spherical microalage.

The EDS results (Fig. 12) shows that the analyzed samples contain elements C, O, N, Ca, Si and Mg with approximately higher C than O and N, and less than Si, Ca and Mg.

Fig. 12. Energy dispersive spectrometry (EDS) results showing the main elemental composition and ratios of representative samples

The presence of carbon, oxygen, and nitrogen is an indication that their source is organic materials, such as algae, whereas, silica, calcium, and magnesium refer to the common presence of calcite, quartz and clay minerals since no dolomite was recorded in the XRD analysis.
3.2. Geology

The 3rd stage of the Tigris River terraces consists of different sizes of sediments, clay, silt, sand, pebbles, and boulders. The heterogeneous texture distribution of these sediments complicates the illustration of geotechnical properties within the localized sites (Fig. 13A). The contact between different sizes of sediments was undulated or fractured, open in general, and empty (Fig. 13B). Secondary deposition and alteration interpenetrate through the terraces, the deposition sometimes reaches to be collapsed and the alteration produces the Ninivite, due to a series of different conditions of evaporation and alkaline/salinity (Fig. 13C) (Voigt et al., 2017). Climate change and the change from erosion to deposition of the fluvial system for a long-time led to these characteristics of terrace deposits (Mather and Harvey, 1995; Stokes et al., 2002; Ivanovic et al., 2016; Voigt et al., 2017).

![Fig. 13. Heterogeneous texture distribution of sediments (A), the openness of empty fractures (B), and the ninivite rock seam along joints (C).](image)

The karstification marked in the study could be formed due to; bedrock type, joints, and faults happened contemporaneously to river channel activities. Some biological degradations like micro-organisms and algae nutrition during river channel life (Figs. 2, 8 and 9). Then, this karstification filled later by gravels derived by the river channel through flooding periods (Fig. 2). Consequently, the difference in the rock strength between karstic areas and their adjacent positions causes disharmony in stress-strain distribution of proposed building sites. Therefore, inhomogeneous building settlements take place.

3.3. Geotechnical Characteristics

Field geotechnical investigations include strength, degree of weathering, water seepage, and discontinuity characteristics. Although the discontinuities probably do not occur by tectonic activity, the local stresses construct by gravity, physical characteristics (swelling and shrinkage), and weather. The strength of the material as a whole seems to be weak to very weak, while that’s attributed to gravel appearing moderately to very strong. The certain matrix of carbonates between grains may perhaps be the major reason to decrease in the strength (Fig. 7). In addition, the alteration and dissolution of parent rock materials and the matrix is exceeding the weakening of terraces.

The majority of the rock fragments or pebbles found in cement have smooth surfaces and are circular to subcircular in shape. The adhesion and cohesiveness between it and the cement material are limited as a result of this phenomenon. Because most of it is carbonate, the cement material is characterized by fragility, weakness, and high porosity, as well as high solubility. Due to the presence of initial planes of weakness, pre-fracture, weathering, and their previous exposure to stresses in them, some of the rock fragments are prone to weakness (Fig. 14). Several new buildings have been constructed on river terraces, many problems of settlement and cracks have occurred in their walls and floors. The reason for this is due to the poor bearing of river terraces for these loads, in addition to the presence of the Fatha Formation under them, which is known as karst (Al-Heety et al., 2022).
Fig. 14. Pores caused by poor cohesion between the grains and the cementation material and the occurrence of dissolution

Field observations and measurements revealed the presence of planes of weakness and fractures caused by a variety of reasons, including the development of cliffs, which caused pieces of various sizes to separate and fall (Fig. 15). All scales, including the field scale, the hand specimen scale, and the microscopic scale, represented these levels of weakness. These fractures are not only joints but also displacements, indicating that they are a reflection of the new tectonic processes that caused faults to form (Figs. 6, 15 and 16).

The dry bulk density of river terrace bulk samples ranged between 1.946 and 2.124 gm/cm$^2$, the porosity was between 11.4 and 14.2 %, and the water absorption ratio was between 7.9 and 12.4 % (Table 1). Since the cement material has poor geotechnical properties, the values of its physical properties became lower than those of the bulk samples (Table 2). The rock represented by pebbles has high original geotechnical properties, although they have decreased slightly due to weathering processes prior to deposition and during the terrace period.

Table 1. Physical properties of bulk materials of terraces.

<table>
<thead>
<tr>
<th>Location</th>
<th>Dry Bulk Density gm/cm$^2$</th>
<th>Porosity %</th>
<th>Water Absorption %</th>
<th>Strength MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.946</td>
<td>14.2</td>
<td>12.4</td>
<td>8.7</td>
</tr>
<tr>
<td>2</td>
<td>2.031</td>
<td>11.4</td>
<td>8.3</td>
<td>11.3</td>
</tr>
<tr>
<td>3</td>
<td>2.124</td>
<td>11.7</td>
<td>8.7</td>
<td>12.3</td>
</tr>
<tr>
<td>4</td>
<td>2.101</td>
<td>12.2</td>
<td>7.9</td>
<td>12.0</td>
</tr>
</tbody>
</table>

Table 2. Physical properties of cementing materials of terraces

<table>
<thead>
<tr>
<th>Location</th>
<th>Dry Bulk Density gm/cm$^2$</th>
<th>Porosity %</th>
<th>Water Absorption %</th>
<th>Strength MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.178</td>
<td>47.2</td>
<td>45.3</td>
<td>9.4</td>
</tr>
<tr>
<td>2</td>
<td>1.096</td>
<td>52.9</td>
<td>47.8</td>
<td>14.2</td>
</tr>
<tr>
<td>3</td>
<td>1.211</td>
<td>48.4</td>
<td>44.1</td>
<td>23.6</td>
</tr>
<tr>
<td>4</td>
<td>1.105</td>
<td>47.3</td>
<td>44.7</td>
<td>24.5</td>
</tr>
</tbody>
</table>

Equations 1 and 3 were used to calculate the dry bulk density, porosity, and water absorption ratio, respectively. In addition to the accumulation of carbonates, which represent cement materials, the physical properties of the soil vary significantly laterally and vertically, particularly at depths of less than 2 meters (Dengdz, 2010). The river terraces above the level of water inundation have high porosity, and the porosity increases with the increase of vital activities and organic matter in them (Kercheva et al., 2017). The situation in strength differs from that in physical properties because the strength of cementing materials was estimated in the field using a Schmidt hammer, whereas the compressive strength of the entire samples was determined in the laboratory. This implies that the compressive strength is low due to poor bonding between the rock pieces and the cement material. The large variation in geotechnical properties is attributed to the large variation in texture, lithology, and carbonate content (Coultas and McCracken, 1952).
\[ \gamma_d = \frac{\omega_d}{(\omega_{sat} - \omega_{sub})/\rho_w} \quad (1) \]
\[ n = \left(\frac{\omega_{sat} - \omega_s}{\omega_{sat} - \omega_{sub}}\right) \times 100\% \quad (2) \]
\[ w_{abs} = \left(\frac{\omega_{sat} - \omega_d}{\omega_d}\right) \times 100\% \quad (3) \]

where,
- \( \gamma_d \): Dry bulk density (gm/cm\(^2\))
- \( \omega_d \): Dry weight (gm)
- \( \omega_{sat} \): Saturated weight (gm)
- \( \omega_{sub} \): Submerged weight (gm)
- \( \rho_w \): Unit weight of water
- \( \omega_s \): Solid weight (gm)

**Fig. 15.** The fractures and cracks common on the terraces (A) tension cracks (B and C) fracture and crack due to new tectonics respectively.

**Fig. 16.** The fractures in thin section (A) Arrows refer to the direction of displacement, (B, C) Arrows refer to the fractures in the cementing material, (D) Arrow refers to the fractures in the rock fragments.

**4. Conclusions**

Field description supported by sedimentologic and mineralogic studies and investigations of geotechnical characteristics for the 3\(^{rd}\) stage of the Tigris river terraces at the site of Mosul University has been conducted. The thickness of terraces is exceeding seven meters in general in the Mosul University site. The weakness in geotechnical properties is due to high porosity, and biological effects in addition to weak bonding and cohesion between gravel and cement materials. These terraces spread over thousands of square meters, and most buildings of the university were built on these terraces and near the cuts of there. The current study concludes to treat each site of the building before any construction operations by pressing hard and preventing the water from entering through the terraces. Erect concrete retaining walls in front of natural and man-made cuts before construction.
References


