The Shear Strength Parameters as a Function of the Volumetric Water Content of Baghdad City Soils at Tigris River Bank

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Abstract. The capital of Iraq, Baghdad city, is considered one of the regions with a diverse soil composition besides the various characteristics of these soils. The subbase layers can be divided into three zones that are fully saturated, partially saturated, and dry state. This research accomplishes the investigation and assessment of the geotechnical attributes of soil layers of the city, where these characteristics are associated with the ground water elevation. The water level disparity of the Tigris River was correlated with variation of the ground water level and with geotechnical results of more than 260 boreholes. The analysis of the output data revealed that undrained shear strength parameters of soil layers near the Tigris river bank is controlled by the flocculation of the water in the river. New relationships were developed associating the volumetric water content (VWC) with shear strength parameters of these soils (ç and ð). These empirical equations show that predicting strength compounds of partially saturated soils as a linear relation for the angle of internal friction and nonlinear for soil cohesive function with (VWC). Where is an increase of the amount of saturation in the (VWC) results a decrease in strength properties for the soil (c, and ð).

1. Introduction

The Tigris River crosses through Baghdad, with a length of 47 km [1]. The two banks of this river are considered an important region, in which many tourist, commercial, and service facilities are being developed and constructed. This site's subsoil is divided into three zones, i.e., dry, unsaturated, and saturated state. Each layer's thickness depends on the moisture content, which is consequently positively influenced by the elevation of water at Tigris River.

Most of soil engineering, physical, and environmental properties had been exert a predominant affected by the soil moisture content. Water in the soil pore serves either as a lubricant or as a pore pressure within the soil particulate system so that dominating the stability and strength of the soil structure. The soil strength parameters are highly affected by humidity conditions. Usually, in the lab, samples prepare to define the strength parameters of the soil is prepared at particularized moisture content and dry unit weight as in the field conditions, without reverence to the fact, that the moisture content might change in the future. Two approaches had been predicted to estimate the shear strength of unsaturated soil, effective stress approach, and independent stress variables approach. Many studies have demonstrated that both theoretical and empirical equations to predict the unsaturated shear strength provides a nonlinear change with the cohesion of the soil [2, 3]; an empirical formulation based on effective stress concept [4, 5, 6]; a mathematical model based on soil and water characteristic curve [7, 8]; the prediction
of soil strength using hyperbolic function [9]. These traditional models or functions have applied matrix suction (soil pore-air pressure minus pore-water pressure) as a characteristic of soil moisture conditions. Consequently, a prognostication of unsaturated strength surely requires a value for the matric suction of the soil. However, in engineering practice, generally, no sound values for matrix suction are available [10].

Volumetric water content is an essential variable for any soil state; it is correlated with different soil properties such as flow, volume change, suction, etc. [11]; presents a laboratory testing for the performance evaluation of ($v_0$) in a sandy soil, where a new calibration equation was developed. In clay soils, there have been many studies that correlated the volumetric water content values with the engineering properties of clay soils, compacted clayed layers, and remolded cohesive samples [12, 13, 14]; also, related to the analysis of landslide and slope stability [15, 16]. From a review of the previous studies, it becomes clear that most of them were based on studying the effect of a particular case of water content on the engineering properties of the soil of the city of Baghdad [17, 18, and 19]. Thus, in this research, an empirical relationship is proposed to predict unsaturated shear strength as a function of ($v_0$), especially for soils of Tigris river banks, which are greatly exaggerated by the variation of water elevation in the watercourse and the elevation of ground water.

2. Variation of Ground water for Tigris River banks

Irzooki et al. [20], modelled the variation of the ground water of Baghdad city subsoil through the MODFLOW program. The study considered the Tigris River which is the leading reservoir of ground water (Figure 1). The results obtained clarify the variation of the ground water level for Al-Karkh side and the Al-Rusafa side as shown in Figure 2 [21]. This figure considered a zero elevation as a reference line to evaluate the maximum and minimum variation of the ground water elevation, also this line indicates that subsoil herein will not impacted by variation of the water level in the watercourse. In this study, the value of 32.44m considered as the greatest elevation of the Tigris River, and 28.17m is the lowest level.

Figure 2 indicated that there is 3-4m topsoil layer thick will not be influenced by the variation of water height in the river, and it can be almost in the dry state. The foremost part is the subsoil within the range between the maximum and minimum ground water levels. These soil layers can be considered unsaturated soil and will be affected by the amount of water in pores, which, in consequence, will affect the shear strength parameters in soil. It is clear that any soil below 5m down the maximum ground water elevation is fully saturated. It will not impacted by the changes of ground water elevation. Note that the above layers recognized this discussion extended within 550m from the edge of the river.

3. Data Obtainment and Assessment

To relate the impact of ground water influence on the subsoil attributes, the characteristics of the city soil was re-enacted utilizing GIS soft-ware. It is permits demonstrating the common variety of subsoil states and different components on material permanence. An aggregate of more than 260 boreholes dispersed in Baghdad city from different sort of activities were considered as the principle information gathered from site examination reports (NCCL [22], Research NCCLR, and AETL [23]), also the data gathered from [24, 25]. Figure 1 illustrates the distribution of the pits location in the analysis area. The geotechnical database related to boreholes was arranged and added in Arc Map10.2 and then converted to shapefile. Only the data of the unsaturated zone were considered (from 1.0 to -4.0) in Figure 2, where this layer is divided into three layers with an interval of 2m, considering that from (1.0 to -1.0m) is layer 1, from (-1.0 to -3.0) is layer 2 and from (-3 to -5) is layer 3.
Figure 1. The coordinates of the boreholes location observed in the study at Baghdad city, [20].

Figure 2. Max. and Min. ground water level at Al-Khawkh and Al-Rusafa regions, [21].

4. Baghdad City Unsaturated Subsoil Properties

4.1. Subsoil type
The fat clay (CH) is the most wide in the top layer under a definitive ground water level, where it covers about over 60% of the investigation territory, while the lean clay (CL) covers the remainder of this layer. Also, the layers of sand and silty soils pronounce to a small amount of the district (Figure 3A). In the subsequent layer, the clayey soil is controlling at the investigation area; the lean clayey and fat clayey soils spoke to be most extent of layer in the region, and of modest quantity of cohesionless layer (Figure 3B). The last layer shows the degree of clayey soil in the most layer (Figure 3C). Nonetheless, silt-sands and sands soil are starting to appear more, particularly at Karkh side.

4.2. Moisture content (M.C) %
The important parameter in the calculation of (VWC) is soil moisture percent. The soil moisture content can be considered as the relevant parameter in the calculation of the volumetric water content. This characteristic may be change with time consequently upon properties and situations. Figure (4) shows variation of moisture content and soil layer in the city of Baghdad. At the upper subsoil, the magnitude varying between 20% and 30%. Consequently valid for the next layer. In the 3rd deposit, the amount of moisture water content varied from 23% to 33%. Additionally, the dispersal of the values of (o9%) as shown in Figure (4), the value of moisture content built up with depth was taken into account.
4.3. Dry unit weight of the soil ($\gamma_d$)
The distribution of the values for the dry unit weight of the unsaturated subsoil in city of Baghdad are shown in Figure (5). At the first deposit, the amount found to vary from 15 kN/m$^2$ to 17 kN/m$^2$. It reduces as reported for the second subsoil and varying from 15 kN/m$^2$ to 16 kN/m$^2$ in utmost investigated area, considering that for the east part where the value is more than 16 kN/m$^2$. Less 15 kN/m$^2$ was demonstrated in the northern and southern parts. At the third layer, the value became within 14 kN/m$^2$ to 16 kN/m$^2$ excluding for the eastern part from Al-Rusafa side that amount was greater. At part of subsoil in the north-west and south-west, the value is less than 14 kN/m$^2$. The above variation in the dry unit weight is reliable and logical where the clay subsoils contribute values advanced than the silt-sand soils.

4.4. Initial void ratio ($e$)
Figure (6) shows that the void ratio tends to be high to intermediate value in northwest and southeast at the first layer. In the next subsoil, the value appears more appropriate in the all-region and third layer; it shows that intermediate value in the Al-Karkh region and less value in the Al-Rusafa region.
5. Correlations between the Ground Water level Variation and Engineering Soil strength

The strength of the soil and the amount of water in it are closely related, as changing the amount of water will lead to a variance in the strength characteristics of the soil. The selection of soil characteristics, such as density, Gs, etc., these parameters are undependable on the water volume in soil. Therefore, the defined volumetric water content ($\theta_v$) can correlate moisture content with the soil strength properties, and it can be defined as the following equation (1), [26]:

$$\theta_v = \frac{\gamma_t e s}{Gs \gamma_w}$$  \hspace{2cm} (1)

where: $\theta_v$: Volume water content, $\gamma_t$: Unit weight of soil, $e$: void ratio, $s$: saturation degree, $Gs$: specific gravity, and $\gamma_w$: water unit weight.

The relations where predicted concerning the subsoil type found nearby the banks of Tiger River, namely, lean clayey (CL), fat clayey (CH), and silt-sand soil (SM).

For the lean clay soil layer, the correlation of the data of undrained shear strength to the volumetric water content gives a dependable nonlinear relationship as defined in Eq. (2) and Figure 7. The coefficient of determination ($R^2$) was found to be equal to 0.91.

Figure 4. Moisture content below the below Max. and invariable groundwater level. (A) Layer 1. (B) Layer 2. (C) Layer 3.
Figure 5. Dry unit weight below the below Max. and invariable groundwater level. (A) Layer 1. (B) Layer 2. (C) Layer 3.

\[ \theta_v = 0.6464 c_u^{-0.121} \] (2)

For the same soil above, (CL) Figure 8 demonstrates the correlation of the VWC and (\( \phi \)). A good linear relationship has been found with a coefficient of determination (R²) like to be 0.8, as shown in Eq. (3).

\[ \theta_v = 0.3758 - 0.0014 \phi \] (3)

Figure 9 shows the relation between the VWC and undrained shear strength for unsaturated subsoils of fat clayey (CH) nearby the banks of Tiger River; the information poised gives a function as shown in Eq. (4), the (R²) equal to 0.7158.

\[ \theta_v = 0.4177 - 0.007 c_u + 2^{-6} c_u^2 \] (4)

The soil friction angle can be estimated by Figure 10. The correlation (Eq. 5) found to be:

\[ \theta_v = 0.5281 - 0.00934 \phi \] (5)
Figure 6. Void ratio below Max. and invariable groundwater level. (A) Layer 1. (B) Layer 2. (C) Layer 3.

Figure 7. Undrained shear strength ($c_u$) and volumetric water content for lean clay soil (CL) in Baghdad city at Tigris River banks.

Figure 8. Internal friction angle ($\phi$) and volumetric water content and for lean clay soil (CL) in Baghdad city at Tigris River banks.
For the silt-sand soil sublayer (SM), an agreement connection is found as the VWC and the angle of soil friction ($\phi$), (Figure 11) and Eq. (6), where the obtained coefficient of determination ($R^2$) is equal to 0.9014.

$$\theta_v = 0.0003\phi^2 - 0.0165\phi + 0.5851 \tag{6}$$

The present observational functions to anticipate the soil strength for unsaturated soils as an exponential capacity of (VWC) is by all accounts sensible. It can be noticed that a decrease in the designing properties of the soil (i.e., $c_u$ and $\phi$) with the level of immersion considered in the (VWC) expanded. This technique depicted in this examination gives helpful option in contrast to the quantitative assessment of unsaturated soil shear quality, as not lattice pull information will requisite.

6. Conclusions

This study displays a distribution of soil types and properties for Baghdad city by simulating 262 pits information in the Geographic Information System program. The figures presented illustrated that the engineering characteristics for the unsaturated soil layer, which are exaggerated by the variations of the groundwater elevation, are expressively different. The undrained shear strength for this unsaturated soil change between 50 to 125 kN/m$^2$ and the angle of friction range ranges between 15° to 32°, for lean clay
soil. As for fat clay soil, thevariation was found to be from 50 to 175 kN/m² for undrained shear strength and from 15 to 23° for the angle of internal friction. This alteration attributed to the amount of moisture water percent in soil due to the fluctuation of the ground water; thus, a correlation among the volumetric water content with the shear strength parameters were established. These empirical equations indicate reasonably that a reduction in the undrained shear strength and angle of internal friction as the volumetric water content increases. The amount of water found to be a significant parameter affect the angle of internal friction in the cohesionless layer soil, where it found a reduction from 32° to 17°. The conditions anticipated from this research gives a suitable option in contrast to the quantitative appraisal of unsaturated shear strength. The main advantage of this formulation is that the shear strength parameters required can be estimated without any elaborate soil testing.

7. References
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