Evaluation of Soil Compaction Characteristics at a Construction Site in Al-Khalis City, Northeast of Iraq

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Abstract. Soil compaction characteristics namely optimum moisture content and maximum dry density are frequently used as criteria to control field compaction specifications. This study aims to evaluate the compaction characteristics of soil at a construction site located in Al-Khalis City, northeast of Iraq. Ten soil samples were collected from the study area; five samples were augured to perform the Standard Proctor compaction tests to investigate the relationship between the moisture content and the dry density of the soil. A core cutter method was implemented to collect additional five samples used to determine the field dry density of soil and to calculate compaction ratio. The results showed that optimum moisture content values were ranged from 15.4 to 22.5% while maximum dry density values were ranged from 1.63 to 1.83 g/cm$^3$. The effect of the compaction effort on the compaction curves was investigated. Increasing the compaction effort increases the maximum dry density and decreases the optimum moisture content of the soil. In addition, a linear relationship between the maximum dry density and optimum moisture content (correlation coefficient $R^2$=0.937) is noticed. This relationship is compared with similar relationships from the literature. Finally, compaction ratio, commonly used to evaluate compaction specifications, was calculated. Compaction ratio values indicate that the soil was compacted at the site to satisfactory ranges suitable for engineering construction work.

1. Introduction
Soil compaction is a process by which soil particles are packed together by means of mechanical energy. In engineering earthworks, this process enhances soil bearing capacity; reduces its permeability and subsequent settlements [1]. Compaction properties namely the maximum dry density (MDD) and optimum moisture content (OMC) are usually evaluated using standard laboratory tests such as Standard and Modified Proctor tests [2], [3]. In these tests, a compaction curve that relates soil dry density and moisture content is drawn, from which MDD and OMC is determined, and used as criteria to control the specification of field compaction process. Based on the specification required, maximum strength can be achieved dry of the optimum and minimum hydraulic conductivity can be achieved wet of the optimum [4].

In construction sites, evaluation of compaction properties of soil is significant to assess their engineering suitability to avoid future settlement and maintenance costs [5]. Dry density measured at the site and the maximum dry density obtained from standard proctor test can be used to calculate the
percent compaction or compaction ratio. Compaction ratio is commonly adopted by geotechnical engineers to evaluate the compaction efficiency [6].

The current study aims to evaluate soil compaction characteristics based on standard laboratory and field tests of soil samples collected from a construction site located in AL-Khalis city, northeast of Iraq. Compaction ratio of soil is used to evaluate compaction specifications at the site.

2. Material and Method
Ten soil samples (BH1-BH10) were collected from a construction site figure (1) located in Al-Khalis city, northeast of Iraq. Based on USCS classifications, the soil can be considered as fine-grained soil type CL (CL is inorganic clay soil of low to medium plasticity). The soil was compacted using compaction machines and undergoing construction work has been taken place at the site figure (2). Five samples (BH1-BH5) were augured at 1.5m depth to perform laboratory Standard Procter compaction tests according to ASTM standard [2]. In this method, soil sample is sieved over a 4.75 mm sieve and compacted in a 101.6 mm diameter mold figure (3). Moisture (water) content of soil sample is then obtained using drying oven method [7]. The obtained moisture content and dry density are used to produce the compaction curve from which MDD and OMC are determined. As compaction of a particular soil is a function of compaction effort, different compaction efforts (i.e. 25, 40, 55 blows) are utilized to evaluate the effect of increasing of compaction energy on compaction curves.

In addition, a core displacement method [8] is implemented on additional five samples (BH6-BH10) to compute the field dry density. In this method, a core cutter figure (4) is pushed into the soil. The cutter is then dug out and used to calculate the soil wet and dry density.

Dry density $\rho_d$, determined in the field using core cutter method, and maximum dry density $\rho_{d-max}$ from standard proctor test, is used to calculate the percent compaction (or compaction ratio R), that is:

$$R = \frac{\rho_d (\text{field})}{\rho_{d-max} (\text{Lab})}$$ (1)

Compaction ratio is used to evaluate compaction efficiency at the site. A compaction ratio $R \geq 95\%$ of Standard Proctor maximum dry density is desired [6].

![Figure 1. Distribution of the soil samples](image)
Figure 2. Construction works in the study area

Figure 3. Standard Procter compaction mold used for laboratory compaction tests

Figure 4. Core cutter cylinder used for field density determination

3. Results and Discussion
Soil compaction characteristics (MDD and OMC) of BH1- BH5 samples using Standard Proctor method are determined using compaction curves shown in figures (5-9). The curve corresponding to the degree of saturation S = 100% or zero air voids ZAV line is drawn. Table (1) lists MDD and OMC values derived from compaction curves. OMC values were ranged from 15.4 to 22.5% while MDD values were ranged from 1.64 to 1.84 g/cm$^3$. 

Table 1: Soil Compaction Characteristics

| Sample | MDD (g/cm$^3$) | OMC (%) |
|--------|---------------|---------|
| BH1    | 1.64          | 15.4    |
| BH2    | 1.65          | 15.8    |
| BH3    | 1.67          | 16.2    |
| BH4    | 1.68          | 16.5    |
| BH5    | 1.84          | 22.5    |
Figure 5. Compaction curve of BH1 sample

Figure 6. Compaction curve of BH2 sample

Figure 7. Compaction curve of BH3 sample

Figure 8. Compaction curve of BH4 sample

Figure 9. Compaction curve of BH5 sample
Table 1. MDD and OMC values derived from compaction curves

| Sample Number | MDD (g/cm$^3$) | OMC (%) |
|---------------|----------------|---------|
| BH1           | 1.63           | 22.1    |
| BH2           | 1.68           | 20.4    |
| BH3           | 1.83           | 16.4    |
| BH4           | 1.79           | 16.2    |
| BH5           | 1.78           | 18.2    |

Figure (10) presents the dry density-moisture content relationship of BH5 sample using different compaction efforts (i.e. 25, 40, 55 blows). Table (2) lists the MDD and OMC values derived from figure (10). Increasing the compaction effort increases MDD and reduces OMC of the soil [9], [10].

In the literature, several authors have attempted correlate MDD with OMC of the soils. Figure (12) displays the relationship between MDD and OMC derived from compaction curves compared to the corresponding relationships from previous studies [11], [12]. The MDD correlates well with OMC with a correlation coefficient of $R^2=0.937$. 

Table 2. MDD and OMC values of BH5 sample using different compaction efforts

| Sample Number   | MDD (g/cm$^3$) | OMC (%) |
|-----------------|----------------|---------|
| BH5-25 Blows    | 1.78           | 18.0    |
| BH5-40 Blows    | 1.68           | 20.5    |
| BH5-55 Blows    | 1.84           | 15.4    |
Dry density, determined in the field using the core cutter method, and maximum dry density obtained from laboratory Standard Proctor test, is used to calculate compaction ratio of soil displayed in table (3). Specifications for earthwork structures (buildings, embankments, earth dams, etc.) usually call for a minimum of 95%. In the current work, R values indicate that the soil at the site was compacted to satisfactory ranges suitable for engineering construction works [6].

Table 3. Compaction ratio of soil samples

| Sample Number | Field Dry Density-Core cutter (g/cm³) | Sample Number | Maximum Dry Density-ASTM (g/cm³) | Compaction Ratio (R) |
|---------------|--------------------------------------|---------------|---------------------------------|----------------------|
| BH1           | 1.66                                 | BH6           | 1.63                            | 1.02                 |
| BH2           | 1.65                                 | BH7           | 1.68                            | 0.98                 |
| BH3           | 1.81                                 | BH8           | 1.83                            | 0.99                 |
| BH4           | 1.83                                 | BH9           | 1.79                            | 1.02                 |
| BH5           | 1.86                                 | BH10          | 1.78                            | 1.05                 |

4. Conclusion

Soil compaction characteristics namely OMC and MDD were evaluated at a construction site to assess field compaction specifications. Laboratory compaction tests performed on collected samples showed that OMC values were ranged from 15.4 to 22.5% while MDD values were ranged from 1.63 to 1.83 g/cm³. Increasing compaction effort increases MDD and decreases OMC of the soil. Compaction ratio calculated based on field and laboratory dry density indicates that the soil was compacted at the site to accepted ranges suitable for construction specifications.
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