Effect of Relative Compaction on the Bearing Capacity of Cohesive Soils

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Abstract:

The study examined the effect of bearing capacity of soil on the relative compaction by taking samples from different sites and carrying out strength experiments and comparing bearing capacity with the relative compaction to investigate the possibility of reducing the percentage of the approved measurements in the specifications of the percentages allowed for buildings with fixed load. A number of parameters have been prepared to calculate the amount of the degree of measurement to be adopted and the light tolerance required in any engineering work and for various factor of safety and non-compliance with specifications, which require in most cases to be the degree of compaction more than 95%. Linear regression equation between bearing capacity and relative compaction was proposed that can be applied without complying with required specification.

Keywords: relative compaction, bearing capacity, cohesive

1-Introduction

Compaction, in general, is the densification of soil by removal of air, which requires mechanical energy. The degree of compaction of a soil is measured in terms of its dry unit weight. When water is added to the soil during compaction, it acts as a softening agent on the soil particles. The soil particles slip over each other and move into a densely packed position. The dry unit weight after compaction first increases as the moisture content increases (Das, 2007). The need for compaction is a high requirement and vital procedures by geotechnical engineers in order to reduce compressibility, permeability and increase shear strength (Whitlow, 2001). Major engineering projects such as road and highways constructions and earth-fill embankment dams are mainly a compaction projects. The compaction in such projects is performed according to standard procedures. According to engineering requirements, the soil in roads, highways and embankment earth fill dams should be
compacted to at least 90% - 95% and sometimes to 98% relative compaction at optimum water content.

Theories presented by Lambe (1958) and by Seed and Chan (1959) suggest that clays compacted at moisture contents less than optimum would have a flocculated structure, while samples compacted at moisture levels greater than optimum would tend to have a more dispersed microstructure, with a primary particle orientation normal to the axis of compaction as shown in Figure (1). However, investigations by Sloane and Kell (1966), using the electron microscope, showed no evidence for edge to face structure for their kaolinite samples compacted dry of optimum. Rather, they found an essentially random arrangement of particle domains. For compaction wet of optimum moisture, their results do indicate some orientation of the domains normal to the compaction axis.

Many factors affecting compaction First, Soil type that is, grain-size distribution, shape of the soil grains, specific gravity of soil solids, and amount and type of clay minerals present has a great influence on the maximum dry unit weight and optimum moisture content. Das (2010) reported that Lee and Suedkamp (1972) observed that four types of compaction curves can be found. These curves are shown in Figure (2). The following Table (1) is a summary of the type of compaction curves encountered in various soils.
Table (1) summary of the type of compaction curves encountered in various soils from Lee and Suedkamp -1972 as reported by Das-2010

| Type of compaction curve (Figure 2) | Description of curve | Liquid limit     |
|-------------------------------------|----------------------|------------------|
| A                                   | Bell shaped          | Between 30-70    |
| B                                   | 1-1/2peak            | Less than 30     |
| C                                   | Double peak          | Less than 30 and those greater than 70 |
| D                                   | Odd shaped           | Greater than 70  |

Second, is the effect of compaction effort. If the compaction effort per unit volume of soil is changed, the moisture–unit weight curve also changes. As the compaction effort is increased, the maximum dry unit weight of compaction is also increased. As the compaction effort is increased, the optimum moisture content is decreased to some extent. Soils become compacted by the simple application of pressure from foot traffic, Vehicles and even rain drops. The greater this pressure, the greater the soil compaction. The purpose of compaction is to improve the qualities of the soil used either as a sub-grade materials for roads or in the fills of any project. There are five Principal reasons to compact soil a) Increases load-bearing capacity, Prevents soil settlement and frost damage, Provides stability, Reduces water seepage, swelling, contraction and reduces settling of soil Das(2010).

1-1 Relative compaction

Relative compaction is the percentage ratio of the field dry density of soil to the maximum dry density as determined by standard compaction method. Once the maximum dry unit weight has been established for the soil being used in the compacted fill, we can express the degree of compaction achieved in the field by using the relative compaction, Cr.

Where: Cr= \( \frac{\gamma_d}{\gamma_{d\text{ max}}} \times 100 \)

Where: \( \gamma_d \) = dry unit weight achieved in the field

\( \gamma_{d\text{(max)}} \) = maximum dry unit weight (from proctor compaction test)

Most earthwork specifications are written in terms of the relative compaction, and require the contractor to achieve at least a certain value of Cr. The minimum acceptable value of Cr listed in a project specification is a compromise between cost and quality. If a low value is specified, then the contractor can easily achieve the required compaction and presumably, will perform the work for a low price. Unfortunately, the quality will be low. Conversely, a high specified value is more difficult to achieve and will cost more, but will produce a high-quality fill. Table (2) presents typical requirements.
Table (2) typical compaction requirements (after Rahman et. al., 2011)

| Type of Project                              | Minimum Required Relative Compaction |
|---------------------------------------------|-------------------------------------|
| Fills to support building or roadways       | 90%                                 |
| Upper 150 mm of sub grade below roadway     | 95%                                 |
| Aggregate base material below roadways      | 95%                                 |
| Earth dams                                  | 100%                                |

2- Effect of relative compaction on the soil properties

Nabil and Behbehani (2014) studied the influence of relative compaction on the strength of sandy soils in Kuwait was examined herein by a comprehensive laboratory testing program on surface samples. The program includes basic properties, compaction and, direct shear tests. Various soil parameters were determined including the compaction characteristics, the cohesion c, and angle of friction $\phi$. The results indicated that as the relative compaction increases towards 100%, the strength increases and the soil compressibility decreases. A comparison was made between the soil parameters for the samples compacted on the dry side, and on the wet side of optimum moisture content at several relative compaction ratios. The difference in the values obtained for the two cases are explained.

Hosseini and Jesmani (2014) expressed the secant friction angle of sands as a function of normal stress and relative compaction. Direct shear tests were performed on air-dried and saturated sand samples at different normal stresses to evaluate the variation of secant friction angle with these factors. Secant friction angle increases with increasing relative compaction. For instance, at normal stress of 1kg/cm$^2$, secant friction angles of Babolsar sand, dry filter, and saturated filter increased $5^\circ$ (from $38^\circ$ to $43^\circ$), $3^\circ$ (from $50^\circ$ to $53^\circ$), and $3^\circ$ (from $49^\circ$ to $52^\circ$), respectively, as the relative compaction increased from 93% to 100%.

Yusoff et al., (2016) studied the effect of different compaction energy on certain geotechnical properties of soil by a laboratory study conducted to evaluate the relationship between soil type, soil moisture content with different compaction energy and strength characteristic. Specimens were compacted with impact energy at levels of 596 kg/m$^3$ (Standard Proctor) and 2682 kJ/m$^3$ (Modified Proctor) over a wide range of moisture contents to determine dry unit weight, and Unconfined Compression Strength Test (UCS). Result show that compaction energy is an important factor in determining soil strength that should be considered during the planning phase of any earthwork construction operation.

3-Materials and Methods

Two types of soils were used in this study collected from Al-Nahrawan and Al-Ammiria sites. Soils were collected (disturbed sample) at a depth 0.5m after removing the top soil of about 0.3m below the ground surface. The initial physical properties and the optimum moisture content and maximum dry density were determined in accordance with American Standard for Testing and Materials (ASTM) standard procedure which includes also fundamental geotechnical tests: Atterberg’s limits, specific gravity, hydrometer and compaction. Atterberg’s limits test was carried out in accordance with British Standards 1377 Part 1 to determine the index properties of the natural soil of three sites. The basic properties
of the studied soils are presented in Table (3). According to unified soil classification tests (USC) low plastic silt (ML-soil) for Al-Ammiria soil and low plastic clay soil (CL-soil) for Al-Nahrawan soil. Five sets of soil specimens from each site were prepared.

Table (3) Physical properties of soils

| Soil type     | L.L | P.L | P.I | G.S | CLAY% | SILT% | SAND % | According to USC |
|---------------|-----|-----|-----|-----|-------|-------|--------|-----------------|
| Al-Nahrawan   | 66  | 24.5| 12.1| %   | %     | %     | %      | CL              |
| Al-Ammiria    | 33  | 26  | 9.49| %   | 40    | 56    | 4      | ML              |

3-1 Compaction

Compaction tests were carried out in accordance with ASTM D1557 for Modified Proctor Compaction tests on the samples determine the compaction characteristics of each soil. The soils were placed in five layers into a mold, with each layer compacted by 56blows of 4.5kg rammer dropped from a distance of 457mm. Soil samples were mixed with different moisture content according to the optimum moisture content. Five sets of soil specimens from each soil were prepared. The first set of soil specimens was prepared at optimum moisture content and maximum dry densities. Second and third sets of soils specimens were prepared at the dry side of the optimum with different initial water content. The fourth and fifth sets of soil specimens were prepared at the wet side of optimum.

3-2 Unconfined compressive strength (UCS)

The test was performed on the soil samples after compacted in 1000cm³ mold’s at their respective moisture content. The samples were extruded from the mold’s and trimmed into cylindrical specimens of 38mm diameter and 75mm length Plate (1). Four cylindrical specimens from each mold were then placed in the lower platen of a compression testing machine and a compressive force was applied to the specimen with a strain control at 0.10 mm. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred. The UCS in kN/m² was calculated from the Eq. (1).

Compressive Strength= Failure Load /Corrected Area of Specimen------ (1)

\[ Q_u = \frac{P}{A_c} \text{ where } A_c = \frac{A_o}{(1-\varepsilon_o)} \]

Plate (1a & b) method for obtaining samples from mold
(a) Al-Ammiria

(b) Al-Nahrawan

Figure (3) Grain size distribution of both soils

Figure (4) Dry unit weight versus moisture content for both sites
4-Results and discussion

Figures (5) and (6) depict the effect of molding water content on the stress-strain curves obtained from the unconfined compressive strength for both soils. The measurement of both soil was taken at different molding water contents. In other words, obtaining different degrees of compaction through different initial dry density. The first two groups were at the dry sides of the optimum, other at the optimum moisture content and finally the rest two groups at the wet side of optimum. It was observed from the trends of the curve that the value of the peak of stress-strain curves decreased with increasing initial water content. This result is due to the structure of the soil whereas the soil at the dry side of the optimum at the flocculated state than at the dispersion state in the wet side Lambe (1958). This means samples stiffer and less compressible as compared to samples compacted on the wet side of optimum. The increase in water content of soil also reflected in its stress-strain behavior. The failure strain increases with the increase in water content. The stress-strain curve show that the sample behaves like very stiff clay (brittle behavior) with a pronounced peak at lower water contents and gradually show ductile behavior at higher water contents.

Figures (7&8) show the effect of dry density in terms of initial water content on cohesion. It is obviously from these figures and for both types of soil that increasing in the water content will lead to reduce in cohesion. This could be attributed that increasing the moisture content will cause the water to fill the voids and the soil will be more in dispersed state. The same observation was found by Nabil and Behbehani (2014). In another words an increase in shear strength in turn it will increase in bearing capacity of soil.

The relationship between relative compaction and bearing capacity for different factor of safety (for spread footing) for both sites were presented in figure (8a&b). It is observed a linear regression relationship so, the engineer can describe the bearing capacity needed for any project and according to the curve can decide the percentage of relative compaction in order to enable the engineer not to comply with the specification.

![Figure(5) Effect of relative compaction on stress-strain curves of Al-Nahrawan](image-url)
Figure (5) cont. Effect of relative compaction on stress-strain curves of Al-Nahrawan

Figure (6) Effect of relative compaction on stress-strain curves of Al-Ammiria soil
Figure (7) Water content versus cohesion for (a) Ammiria site (b) Al-Nahrawan site

Figure (8) Relationship between allowable bearing capacity and relative compaction for different factor of safety for (a) Al-Ammiria (ML-soil) (b) Al-Nahrawan (Cl-soil)

5-Conclusions

1- There is an inverse relationship between the relative compaction and the shape of the stress-strain curve that’s means compacted on the wet side of optimum appear the stress-strain curve was smaller peak than for the samples compacted on the dry side of the optimum which indicating a stiffer and less compressible as compared to samples compacted on the wet side of optimum

2-There is a linear relationship between relative compaction and cohesion for cohesive soil.

3- Direct relationships between relative compaction and bearing capacity.

4- Linear regressions equation between bearing capacity and relative compaction

\[ y = Ax + 87 \]  (1) for cohesive soil

Where \( x \) = allowable bearing capacity (kN/m²)
y = relative compaction (%)  
A = factor depends on factor of safety

5- The degree of compacting depends on the required bearing capacity. Therefore in sites that do not require high bearing capacity such as walkways and garage it is possible not to comply with the specifications, which require that the degree of compaction not less than 95%. This means can reduce the degree of compaction to less than 95%, which affects the cost and speed of completion of work.

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