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CORRELATIONS BETWEEN RELATIVE DENSITY AND COMPACTION TEST PARAMETERS

Youssef Gomaa [1] and Gihan Abdelrahman [2]

[1] *Assistant Lecturer, Civil Engineering Dept.,Fayoum University, Fayoum,Egypt*
youssefg_nile@yahoo.com
[2] *Associate Prof., Civil Engineering Dept.,Fayoum University, Fayoum,Egypt.*
gwakeb2006@yahoo.com

ABSTRACT

Correlations between physical and mechanical properties of sandy soil from different places in Fayoum governorate were predicted. Physical tests such as, sieve analysis presented as coefficient of uniformity, specific gravity, maximum and minimum void ratio, which are relative coefficient parameters, and mechanical tests such as modified and standard proctor tests were carried out. The main purpose of this research is to investigate possible correlations between relative density, D_r, coefficient of uniformity, C_u, , maximum dry density, $\gamma_{d\text{-max}}$, and degree of compaction, RC,. Also to compare maximum dry density, $\gamma_{d\text{-max}}$, which measured in laboratory, and that calculated using relative density D_r. Relative compaction, RC, which is defined as the ratio of the desired field dry unit weight, $\gamma_{d\text{-field}}$ to the maximum dry density $\gamma_{d\text{-max}}$, measured in the laboratory percent, was correlated to relative density based on a statistical evaluation of different sandy soil compacted by using Modified Proctor compaction test.

Keywords: Relative density, Coefficient of uniformity, Maximum dry density, Relative compaction, Optimum Moisture Content.

INTRODUCTION

Throughout the relatively short period of soil mechanics as an engineering science, researchers have tried to find relationships between different physical and mechanicals soil properties. However, these relationships are usually affected by the mineralogy of the soil under consideration, its geological history, and the state of its structure, Lamb [1]. This may be an explanation for the differences noticed in the previous work regarding the parameters of equations suggested as relationships between some of the properties. Soil classification tests, such as sieve analysis for sand soil, are relatively quick and easy to perform and are considered to be not expensive. However, the tests required for the determination of compaction parameters are relatively expensive and need some testing time. The availability of correlations between the tests results would reduce the effort and cost by guessing with confidence any compaction properties. In this research, different tests were carried out such that sieve analysis, specific gravity, Standard, and Modified Proctor compaction tests. Also minimum and maximum void ratio, were tested using Egyptian code [2]. The test results are used to evaluate the different soil properties required for investigation of possible correlations between them. The relationships between tested maximum and minimum void ratio, tested minimum void ratio and coefficient of uniformity, and tested and calculated minimum void ratio were studied. Then, correlation between degree of compaction, RC, and relative density. Then, relationship between coefficient of uniformity and maximum dry density tested by using standard proctor tests and calculated using relative density.

TESTING PROGRAM

All the tests were carried out in order to investigate the possible correlations of compaction parameters. Twenty different sample of pure sand tested in this research were collected from different cities from Fayoum governorate as shown in table 1. From sieve analysis results, coefficient of uniformity C_u and coefficient of curvature C_c were calculated. All tested samples were classified as poorly graded sand according to ASTM [3] and having less than 12 percent fines. Also minimum, e_{min} ,and maximum void ratio, e_{max}, were tested to calculate relative density, $D_{r,.}$ Other tests were carried out for all the samples such as, specific gravity, Standard , and Modified Proctor compaction tests.

Table 1 Different test results of sand

Sample	Tested		Grain Size Distribution			Tested	Standard Proctor		Modified Proctor	
No.	e_{max}	e_{min}	C_u	C_c	% Fines	G_s	γ_{dmax}	O.M.C %	γ_{dmax}	O.M.C %
1	0.73	0.43	3.61	0.53	0.77	2.71	1.82	7.50	1.89	7.5
2	0.68	0.42	3.33	0.58	1.05	2.71	1.85	11.00	1.89	11
3	0.62	0.37	3.10	1.42	0.78	2.66	1.84	14.00	1.88	13.2
4	0.69	0.39	3.53	1.59	0.89	2.63	1.79	13.45	1.82	10.5
5	0.77	0.47	2.61	0.63	0.36	2.69	1.79	10.30	1.87	9.8
6	0.65	0.41	2.74	1.15	0.13	2.71	1.84	8.00	1.89	13.9
7	0.57	0.38	5.00	1.01	0.79	2.73	1.91	11.90	1.97	9.6
8	0.62	0.37	5.19	1.02	0.43	2.62	1.96	12.50	1.96	12.8
9	0.68	0.44	3.17	0.61	0.94	2.63	1.74	14.51	1.86	10
10	0.71	0.42	2.75	1.11	0.90	2.62	1.75	12.92	1.79	11
11	0.60	0.35	4.55	1.05	0.78	2.60	1.93	9.48	1.93	8.2
12	0.64	0.40	2.67	1.26	1.15	2.59	1.79	13.50	1.83	12.5
13	0.73	0.43	2.89	0.96	1.81	2.61	1.76	10.00	1.89	7.8
14	0.68	0.42	3.68	1.20	0.69	2.62	1.92	14.18	1.93	10.8
15	0.67	0.39	3.16	1.07	0.93	2.65	1.87	13.76	1.95	10.46
16	0.73	0.49	1.78	1.32	0.32	2.61	1.75	14.00	1.86	12
17	0.70	0.43	1.78	1.07	0.65	2.62	1.76	9.40	1.8	9.1
18	0.68	0.44	3.00	1.02	0.71	2.62	1.79	19.50	1.94	9.67
19	0.72	0.50	2.76	1.31	0.28	2.61	1.79	7.30	1.82	12.7
20	0.72	0.43	2.84	1.13	0.93	2.65	1.77	12.55	1.86	11.4

RELATIVE DENSITY CORRELATIONS

Relative density, D_r, is used to indicate the degree of packing of sand, it is applicable strictly to granular soils having less than 12 percent fines according to ASTM [3]. For sandy soil the relative density, $D_{r,}$ expresses the degree of compactness with respect to both the loosest and densest states achieved by slandered laboratory procedures. Most commonly, the relative density is expressed in terms of void ratio:

$$D_r = \frac{e_{max} - e_0}{e_{max} - e_{min}} \quad (1)$$

Where e_{max}= void ratio at the loosest state and e_{min}= void ratio at the densest state, e_0 = is the in-situ void ratio. Relative density, D_r, is a useful parameter for describing the relative behavior of cohesionless soils. Increasing relative density, D_r, generally means increasing strength and decreasing compressibility. If it is negative, a collapsible soil structure may be present, such as can occur with honeycombed soils and very loose cemented or calcareous sands with e_0 is bigger than e_{max}, Kulhawy, and Mayne [4]. Since it is very difficult to obtain truly undisturbed samples of clean soils, the direct measurement of D_r also is difficult. However, the three separate parameters, (e_{max}, e_{min}, and e_0) were be evaluated according to the specifications. Moreover, it is difficult to directly determine the in-place void ratio of clean sands and granular soils with depth because undisturbed sampling is generally not possible.

Correlation with Maximum and Minimum Void Ratio

The relationship between, the minimum and maximum void states has been proposed as a straight line, its inclination being equal to the value 0.571 by Poulos [5], with a compiled database indicates (n=304, R^2=0.851; S.E.=0.044). In recent study, following relation was obtained from tests results, and it is close to that obtained by Poulos [5] as shown in Fig.1.

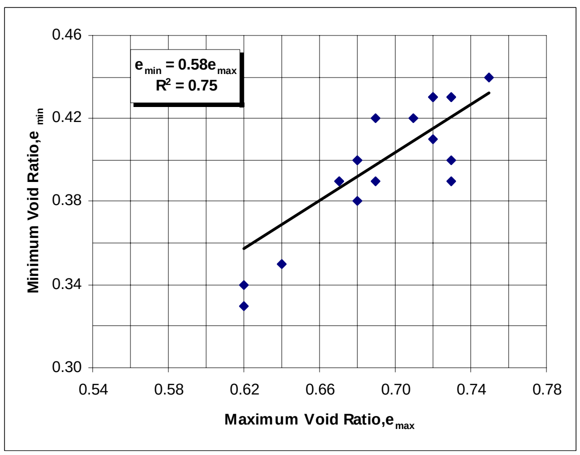


Figure 1 Relationship between minimum and maximum tested void ratio.

From tests results following equation were predicted, as maximum void ratio increase, the minimum void ratio increase for the same sample.

$$e_{min} = 0.58\, e_{max} \pm 0.02 \quad (2)$$

Correlation of Relative Density and Maximum Dry Density

Maximum dry density was calculated using measured minimum void ratio, e_{min}, and measured specific gravity, G_s, from the relationship: $\gamma_{d\text{-}max}$ (D_r)= $G_s/1+e_{min}$., and compared to modified and standard Proctor compaction tests results .

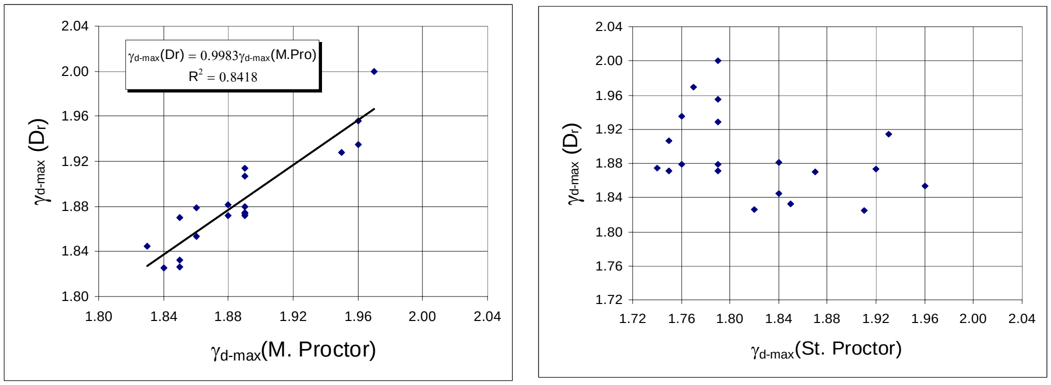


Figure 2 Correlation between maximum dry densities calculated using relative density and a) Modified Proctor and b) Standard Proctor compaction test.

As shown in Fig. 2-(a) maximum dry density calculated using relative density is almost directly proportional to that tested using modified Proctor test, following equation was calculated from Fig.2-(a):

$$\gamma_{d\text{-max}}\ (D_r) = 0.998\ \gamma_{d\text{-max}}\ (\text{M. Pro.}) \pm 0.02 \qquad (3)$$

While as shown in Fig. 2-(b), no relation can be estimated with that tested using standard Proctor compaction test. That is because that minimum void ratio calculated using Modified Proctor test is close to that tested.

Correlation with Relative Compaction

The compaction of soil in the fill is the most important part of the construction of an embankment particularly a high embankment as for an earth dam. It is desirable to obtain a high density of the soil placed in a fill to reduce future settlements, percolation through the fill and to increase its shear resistance. To examine the compaction properties, standard and modified proctor compaction tests were used to measure maximum dry density, $\gamma_{d\text{-max}}$, and optimum moisture content, OMC, to the sand. Due to the obvious disconnect between the types of energy in the laboratory and the field, some method is needed to express the laboratory–measured compaction parameters, i.e., maximum dry unit weight $\gamma_{d\text{-max}}$, and optimum moisture content, OMC, in terms of field compaction. Most commonly, this relationship is achieved by so-called performance based or end-product specifications wherein a certain relative compaction, RC, also known as percent compaction, is specified. The RC is simply the ratio of the desired field dry unit weight $\gamma_{d\text{-field}}$ to the maximum dry density measured in the laboratory $\gamma_{d\text{-max}}$ expressed in percent as follows:

$$RC = \frac{\gamma_{d-field}}{\gamma_{d-\max}} \times 100\% \qquad (4)$$

Where $\gamma_{d\text{-field}}$ is the dry density in the field, and $\gamma_{d\text{-max}}$ is the maximum dry density in the laboratory. The relative compaction, RC, is not the same as relative density, D_r, that was defined in equation (1) . Relative density D_r applies only to granular soils with fines less than 12% while relative compaction is used across a wide variety of soils. Wright et al. [5] published the following relationship between RC and D_r based on a statistical evaluation of 47 different granular soils compacted by using modified Proctor energy.

Dr= 0% for RC=80% (5)

Dr= 100% for RC=100%   (6)

Holtz, [6] suggested that the relative compaction, RC, and relative density, D_r, are related by the following empirical equation:

RC = 80 % + 0.2 D_r (D_r > 40%)   (D_r and RC %)   (7)

Holtz's equation (7) may be rewitten as follows:

D_r = 5 RC - 4   (D_r > 0.4)   (D_r and RC fraction)   (7`)

In this recearch, minimum, e_{min} ,and maximum, e_{max} ,void ratio were tested to calculate relative density, D_r. Actual void ratio e_0 is calculated at relative compaction, RC, percentage and maximum dry density was tested using modified Proctor according to following equation:

$$(e_0)_{RC} = \frac{G_s}{RC \times \gamma_{d-\max}} - 1 \qquad (8)$$

Where G_s is the tested specific gravity. By using relative compaction, RC, percentage, equation (1) became as follows:

$$(D_r)_{RC} = \frac{e_{\max} - (e_0)_{RC}}{e_{\max} - e_{\min}} \qquad (9)$$

Different relative compaction ratios were used compared to maximum dry density, γ_{d-max}, tested using Modified Proctor test, as RC equal to: 85%, 87.5%, 90%, 92.5%, 95%, 97.5%, and 100% of the maximum dry density. Statistical study on the twenty different pure sand samples was used to estimate a relationship between relative density D_r and Relative Compaction, RC, it has been proposed as a straight line as shown in Fig. 3.

D_r = 5.5 RC – 4.47   (0.85 <RC>1)   (10)

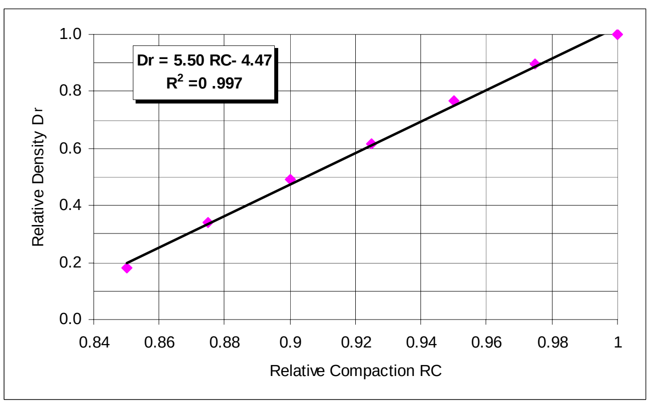


Figure 3. Relationship between Relative Compaction and Relative Density.

Eequation (10) shows good agreement compareing with Holtz's equation (7`).

CORRELATIONS WITH COEFFICIENT OF UNIFORMITY C_U

Correlation with Void Ratio

Coefficient of uniformity C_u is a function of grain size distribution of sandy soil, it is a percentage of, sixty percent size, D_{60}, divided by ten percent size, D_{10},. It describes the general slope and shape of the distribution curve. The bigger the value of the coefficient of uniformity, the larger the range of particle sizes in the soil. A well graded soil has a coefficient of uniformity bigger than 6, Craig [7]. In this study the sample's Coefficient of uniformity C_u, ranged between 1.5 to 5.25 which less than 6 i.e. it is classified as poorly graded sand. Minimum and maximum void ratio $e_{min,}$ e_{max} were inversely proportional to coefficient of uniformity C_u, as shown in Fig. 4, void ratio decreases with the increase of coefficient of uniformity $C_{u.}$

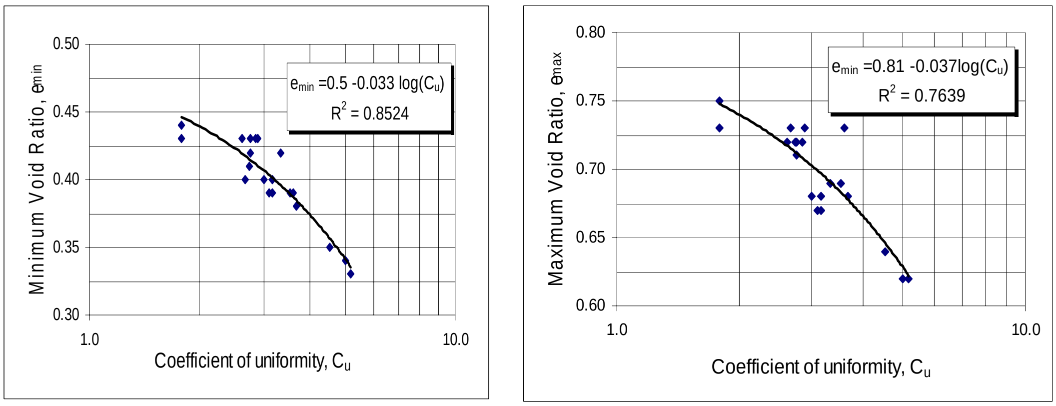


Figure 4 Correlation between minimum and maximum void ratio and coefficient of uniformity.

From Fig. 4, following logarithmic equations were developed, both are valid for clean sands with poorly graded distribution and C_u less than 6.

$$e_{min} = 0.5 - 0.033 \log (C_u) \quad (11)$$

$$e_{max} = 0.81 - 0.037 \log (C_u) \quad (12)$$

For a variety of natural and reconstituted samples of sands, Youd [8] found that, e_{max} and e_{min} depended primarily on the particle roundness R besides the uniformity coefficient, C_u,. The partials roundness, R, is defined as the ratio of the minimum radius of the particle edges to the inscribed radius of the entire particle. Youd [8] obtained minimum void ratios from simple shear tests , curves are only valid for clean sands with normal to moderately skewed grain-sized distributions. Fig. 4 re-plotted as measured points taking in consideration the particle roundness R, as shown in Fig 5. Most of the tested samples plotted around the sub-angular curve.

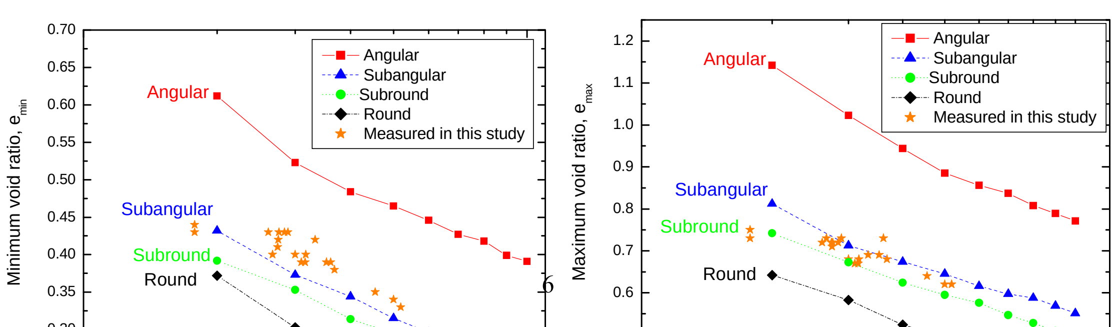


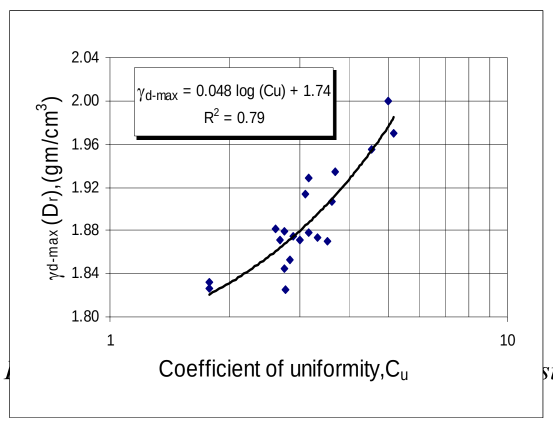
Figure 5 Generalized curves for estimating e_{min} and e_{max} from gradational and particles shape characteristics, (Kulhawy and Mayne, [4]).

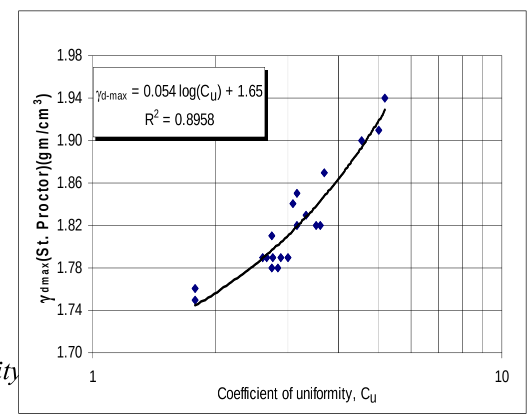
Correlation with Maximum Dry Density

Fig. 6-a and b, illustrates the proposed relationships and between coefficient of uniformity C_u and a) $\gamma_{d\text{-}max}$ which calculated using relative density and b) the experimental results of $\gamma_{d\text{-}max}$ measured from standard proctor test. The following proportional relationships were obtained by using logarithmic relationship:

$$\gamma_{d\text{-}max}(D_r) = 0.048 \log (C_u) + 1.74 \quad (13)$$

$$\gamma_{d\text{-}max} (\text{St. Proctor}) = 0.054 \log (C_u) +1.65 \quad (14)$$





CONCLUSIONS AND RECOMMENDATIONS

Correlations were developed between relative density, coefficient of uniformity, and maximum dry density tested in standard and modified Proctor test. Twenty different samples of Fayoum sandy soil were tested and studied. They are valid for clean sands with sub-angular particle size distribution and C_u less than 6. From previous study and tests results following conclusions were predicted

1. Propotional relationship between maximum and minimum void ratio for the same sample, minimum void ratio value is 58% of maximum void ratio.

2. Maximum dry density calculated using relative density is almost directly proportional to that tested using modified Proctor test and nearly both have same values, while the tests results showed poor agreement with that calculated using standered Proctor test.
3. Good correlation was obtained to allow prediction of maximum dry density from relative density values and from the field compaction test. Different relative compaction ratios, RC, were used, (0.85 to 1) of the maximum dry density.
4. Inversely logarithmic equations were suggested to estimate minimum and maximum void ratio from coefficient of uniformity.
5. Proportional logarithmic relationship were obtained between maximum dry density, calculated using relative density and coefficient of uniformity and maximum dry density tested using standard Proctor, and coefficient of uniformity.

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