**New approach for evaluating soils optimum moisture content arithmetically and checking method statistically**

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**Abstract**. The computing of optimum moisture content for certain soils according to specification ASTM D698 depends on constructing fitting 3rd or 2nd degree curve relationship between moisture content versus soil dry unit weight on fitting curve, the computed optimum moisture content may differ for the same soil with respect to fitting curve Plate and its position.

The objective of this study is finding the optimum moisture content based on computing average moisture content that came from standard or modified proctor compaction test trails .

The research deals with (52) compaction test results with wide range for optimum moisture content and dry unit weight to construct the relationships between them.

The difference values between average moisture content for compaction trails and optimum moisture content calculated from fitting curve (according to the specification) can be neglected which can be regarded as good evidence to conduct the simulation for optimum moisture content computing with fast and reasonable calculation way.

the study also explore the maximum dry density values which versus standard optimum moisture content and average adopted moisture content.

Statistical part depends on evaluating many statistical function values for standard and research method.

The total average of difference between standard method and average value (this study depends) for moisture content was about (-0.20) and average of differences for dry unit weight was (0.261).

**keywords** :Optimum moisture content; maximum dry density; average moisture content,

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**1. Introduction**

In 1933, R. R. Proctor showed that the dry density of a soil obtained by a given compactive effort depends on the amount of moisture the soil contains during compaction. For a given soil and a given compactive effort, there is one moisture content called “optimum moisture content” that occurs in a maximum dry density of the soil. Those moisture contents both greater and smaller than the optimum value will result in dry density less than the maximum.

The laboratory compaction procedure is intended to simulate the compactive effort anticipated in the field. B. N. MacIver and G. P. Hale(1986).

For construction of highways, airports, and other structures, it is often necessary to compact soil to improve its strength. Proctor (1933) developed a laboratory compaction test procedure to determine the maximum dry unit weight of compaction of soils which can be used for specification of field compaction. This test is referred to as the' standard Proctor compaction test and is based on the compaction of the soil fraction passing No, 4 U.S. sieve, Braja M. Das(2002).

Ashis K. Bera and Sourav Chakraborty (2015) studied the compaction and unconfined compressive strength of sand modified by class F fly ash,  compaction tests have been performed with varying compaction energy (2700 kJ/m3- 300 kJ/m3), types of sand, and fly ash content (0% to 40%) respectively. From the experimental results, it has been found that the optimum value of unconfined compressive strength obtained for a sand-fly ash mixture comprised of 65% sand and 35% fly ash. Based on the data obtained in the present investigation, a linear mathematical model has been developed to predict the OMC of sand-fly ash mixture.

Elham Ghanbari and Amir Hamidi(2016) explored Numerical modeling of rapid impact compaction in loose sands by conducting A three dimensional finite element model to simulate rapid impact compaction (RIC) in loose granular soils using ABAQUS software for one impact point. The behavior of soil under impact loading was expressed using a cap-plasticity model. Numerical modeling was done for a site in Assalouyeh petrochemical complex in southern Iran to verify the results. In-situ settlements per blow were compared to those in the numerical model. Measurements of improvement by depth were obtained from the in-situ standard penetration, plate loading, and large density tests and were compared with the numerical model results. Contours of the equal relative density clearly showed the efficiency of RIC laterally and at depth. Plastic volumetric strains below the anvil and the effect of RIC set indicated that a set of 10 mm can be considered to be a threshold value for soil improvement using this method. The results showed that RIC strongly improved the soil up to 2 m in depth and commonly influenced the soil up to depths of 4 m.

NG K.S.(2015)with others try to investigate the relationship between maximum dry density and optimum moisture content and their correlation function with index properties, Additional variables are included in the multi linear regression (MLR) analyses such as grain size distribution and specific gravity other than the index properties. The recommended model requires only the plasticity index and specific gravity.

ASTM D698-12e2, recommended to Calculate the dry unit weight and water content of each compacted specimen. "Plot the values and draw the compaction curve as a smooth curve through the points. Plot dry unit weight to the nearest 0.1lbf/ft3 (0.2 kN/m3) and water content to the nearest 0.1 %. From the compaction curve, determine the optimum water content and maximum dry unit weight".

**2.Compaction tests result**

The main concept of soil compaction test is to compute the optimum moisture content and maximum dry unit weight of the tested soil.

The compaction test results depends (52) tests which represent compaction curves collected for many soil types with wide range of maximum dry unit weight and optimum moisture content.

some of tests conducted with three trials and others depends more to compute the maximum dry unit weight and optimum moisture content, tests was in different international units.

Plates 1, 2, 3, 4, 5 and 6 viewed all test results that will be depends for evaluation of new optimum moisture content calculation steps in this study

**Plate (1) moisture content and dry unit weight relationship(tests 1, 3, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 18 and 22)**

**Plate 2 moisture content and dry unit weight relationship(tests 2, 6, 19, 20, 21, 29, 33 and 17)**

**Plate 3 moisture content and dry unit weight relationship(tests 4, 16, 23, 24, 25, 26, 27 and 28)**

**Plate 4 moisture content and dry unit weight relationship(tests 30, 31, 32, 34, 35, 36, 37 and 38)**

**Plate 5 moisture content and dry unit weight relationship(tests 39, 40, 42, 43, 44, 46, 47 and 48)**

**Plate 6 moisture content and dry unit weight relationship(tests 49, 50, 51, 52, 41and 45)**

Plates from (1) to (6) was constructed based on the unity of dry density units.

Table(1) surmise all test results that adopted for evaluation of the reality of using average moisture content as the optimum moisture content and the table also listing maximum dry densities versus standard optimum and average moisture content.

**Table (1) optimum moisture and dry density computing by the standard method (from top of smooth curve) and research method(moisture depends the average of compaction trails value and dry density versus).**

| Test no. | (ω%)Opt. from Standard method | ɣdry from Standard conventional method (pcf, kN/m3, gm/cm3) | Average (ω%)for compaction trails for each test (calculated arithmetically) | ɣdry versus average (ω%) (pcf, kN/m3, gm/cm3) |
| --- | --- | --- | --- | --- |
| 1 | 11 | 126.5(pcf) | 9.94 | 126.1407977 |
| 2 | 7 | 20.8(kN/m3) | 6.808571429 | 20.79916263 |
| 3 | 11 | 121(pcf) | 11 | 120.8273 |
| 4 | 13 | 1.95(gm/cm3) | 13.1 | 1.940867 |
| 5 | 6.7 | 139.5(pcf) | 5.394 | 135.5648219 |
| 6 | 12 | 19(kN/m3) | 12.05555556 | 19 |
| 7 | 15.2  | 114(pcf) | 15.05 | 113.6517663 |
| 8 | 15.5  | 108(pcf) | 15.58333333 | 107.4987813 |
| 9 | 17.1  | 103.8(pcf) | 18.08333333 | 106.8766707 |
| 10 | 15.1 | 115.5(pcf) | 14.15 | 114.1746168 |
| 11 | 16.7  | 113.9(pcf) | 16.75714286 | 112.6931211 |
| 12 | 19.5  | 110(pcf) | 18.18333333 | 107 |
| 13 | 13.9 | 107(pcf) | 15 | 105.645 |
| 14 | 12.2 | 127(pcf) | 12.66 | 126 |
| 15 | 14 | 119(pcf) | 14.45 | 118.8458233 |
| 16 | 12.5 | 1.887(gm/cm3) | 11.625 | 1.948862305 |
| 17 | 12 | 18.8(kN/m3) | 11.2 | 18.8209808 |
| 18 | 15 | 104(pcf) | 13.85 | 102.6791368 |
| 19 | 9 | 20.6(kN/m3) | 9.34 | 20.55599727 |
| 20 | 15 | 17.9(kN/m3) | 15.6 | 17.5189952 |
| 21 | 13 | 19(kN/m3) | 13.528 | 18.77797162 |
| 22 | 6.1 | 145(pcf) | 6.5 | 145.116525 |
| 23 | 12 | 1.867(gm/cm3) | 12.08333333 | 1.869377778 |
| 24 | 16.2 | 1.72(gm/cm3) | 15.78333333 | 1.7 |
| 25 | 13 | 1.86(gm/cm3) | 13.7 | 1.9367851 |
| 26 | 15.5 | 2.085(gm/cm3) | 14.60002154 | 2.066024277 |
| 27 | 13.7 | 2.18(gm/cm3) | 13.10423333 | 2.164064212 |
| 28 | 14.6 | 2.22(gm/cm3) | 16.39088026 | 1.728956516 |
| 29 | 11 | 18.8(kN/m3) | 11.30967332 | 18.85 |
| 30 | 13.5 | 2.16(gm/cm3) | 13 | 2.1583 |
| 31 | 15 | 2.138(gm/cm3) | 14.68333333 | 2.125105222 |
| 32 | 15.8 | 2.07(gm/cm3) | 14.60002154 | 2.066024277 |
| 33 | 15 | 18(kN/m3) | 18.64101901 | 17.53860734 |
| 34 | 17.2 | 2.17(gm/cm3) | 17.1724204 | 2.178778765 |
| 35 | 15 | 1.86(gm/cm3) | 16.41824081 | 1.809446969 |
| 36 | 15.2 | 1.88(gm/cm3) | 15.81811657 | 1.871650144 |
| 37 | 16.8 | 2.1(gm/cm3) | 16.98504293 | 2.104379583 |
| 38 | 13.1 | 1.94(gm/cm3) | 14.32063991 | 1.933161944 |
| 39 | 19.5 | 2.149(gm/cm3) | 17.56925459 | 2.103963215 |
| 40 | 16.5 | 2.1(gm/cm3) | 16.20043505 | 2.119558896 |
| 41 | 17.5 | 2.15(gm/cm3) | 16.87201949 | 2.158730165 |
| 42 | 15 | 2.19(gm/cm3) | 15.07560774 | 2.184616355 |
| 43 | 14.8 | 1.88(gm/cm3) | 18.97618979 | 1.850145439 |
| 44 | 13.8 | 1.89(gm/cm3) | 20.86727568 | 1.794550846 |
| 45 | 15 | 1.84(gm/cm3) | 17.00703062 | 1.801542346 |
| 46 | 14 | 1.83(gm/cm3) | 14.84671968 | 1.722069359 |
| 47 | 17 | 1.85(gm/cm3) | 20.06966074 | 1.656591526 |
| 48 | 13.5 | 2.175(gm/cm3) | 13.10423333 | 2.164064212 |
| 49 | 13 | 2.13(gm/cm3) | 11.6 | 2.120524 |
| 50 | 15.5 | 2.14(gm/cm3) | 14.68333333 | 2.125105222 |
| 51 | 12.5 | 2.16(gm/cm3) | 12 | 2.1482 |
| 52 | 19.5 | 2.04(gm/cm3) | 14.88400218 | 2.00854957 |

for example table (3) and Plate 7 viewed the detail of test number 39 result which surmised in table 2

**Plate 7 moisture content and dry unit weight relationship test Number (39)**

**Table (2) result detail for test No.39**

|  |  |
| --- | --- |
| ɣdry(gm/cm3) | ω% |
| 1.365535957 | 9.735839162 |
| 2.113432836 | 17.4760424 |
| 1.971234735 | 25.49588221 |
| ɣdry maximum from curve plot (gm/cm3) | ω% versus ɣdry maximum from curve |
| 2.149 | 19.5 |
| ɣdry versus average (ω%), gm/cm3 | Average (ω%) for the three compaction trails |
| 2.103 | 17.57 |

After computing the average moisture content and for made the sensible comparison between the calculated optimum moisture content by the standard method and the calculated average moisture for the same test the difference value (D.V.) is calculated as equations(1) and (2).

$$D.V.\left(ω\right)=ω\_{from standard method}-ω\_{ average moistutre content} (1)$$

$D.V.\left(γ\_{dry}\right)=γ\_{dry from standard method}-γ\_{dry versus average moistutre content} (2)$

Table(3) list the difference values for moisture content and maximum dry density that calculated by the two methods.

**Table(3) The difference values for dry density and moisture content**

| Test no. | $$D.V.(γ\_{dry })$$ | $$D.V.\left(ω\right)$$ |
| --- | --- | --- |
| 1 | 0.35920232 | 1.06 |
| 2 | 0.000837368 | 0.1914286 |
| 3 | 0.1727 | 0 |
| 4 | 0.009133 | -0.1 |
| 5 | 3.93517806 | 1.306 |
| 6 | 0 | -0.0555556 |
| 7 | 0.34823375 | 0.15 |
| 8 | 0.50121875 | -0.083333 |
| 9 | -3.076670698 | -0.9833333 |
| 10 | 1.32538325 | 0.95 |
| 11 | 1.206878878 | -0.05714286 |
| 12 | 3 | 1.3166667 |
| 13 | 1.355 | -1.1 |
| 14 | 1 | -0.46 |
| 15 | 0.1541767 | -0.45 |
| 16 | -0.0618623 | 0.875 |
| 17 | -0.0209808 | 0.8 |
| 18 | 1.32086322 | 1.15 |
| 19 | 0.04400272 | -0.34 |
| 20 | 0.3810048 | -0.6 |
| 21 | 0.22202838 | -0.528 |
| 22 | -0.116525 | -0.4 |
| 23 | -0.00237778 | -0.083333 |
| 24 | 0.02 | 0.41666667 |
| 25 | -0.0767851 | -0.7 |
| 26 | 0.018975723 | 0.8999780 |
| 27 | 0.015935788 | 0.595766667 |
| 28 | 0.491043484 | -1.7908803 |
| 29 | -0.05 | -0.3096733 |
| 30 | 0.0017 | 0.5 |
| 31 | 0.012894778 | 0.3166667 |
| 32 | 0.003975723 | 1.199978 |
| 33 | 0.461392658 | -3.6410190 |
| 34 | -0.00877877 | 0.027579 |
| 35 | 0.050553031 | -1.4182408 |
| 36 | 0.008349856 | -0.6181165 |
| 37 | -0.0043796 | -0.185043 |
| 38 | 0.006838056 | -1.2206399 |
| 39 | 0.045036785 | 1.9307454 |
| 40 | -0.0195589 | 0.29956495 |
| 41 | -0.0087302 | 0.627980505 |
| 42 | 0.005383645 | -0.0756077 |
| 43 | 0.029854561 | -4.1761899 |
| 44 | 0.095449154 | -7.0672757 |
| 45 | 0.038457654 | -2.00703062 |
| 46 | 0.107930641 | -0.84671968 |
| 47 | 0.193408474 | -3.0696607 |
| 48 | 0.010935788 | 0.3957666 |
| 49 | 0.009476 | 1.4 |
| 50 | 0.014894778 | 0.8166666 |
| 51 | 0.0118 | 0.5 |
| 52 | 0.03145043 | 4.6159978 |
| Average | 0.26105633 | -0.192776 |

For all test trails the average values for D.V. was (0.261) and (-0.192) for ɣdry and optimum (ω%) respectively.

**3.Statistical Function analysis results**

The research compare the study results with standard method results by using Kolmogoorov-Smirnov normality test for evaluating the normal distribution of the data to be tested with suitable statistical function the results as seen in the table(4), all statistical analysis done by using SPSS software program.

**Table(4) The normality test values**

|  |  |
| --- | --- |
| Data type tested | Kolmogorov-Smirnova |
| Statistic | df | Sig. |
| ω average(this study depends) | 0.083 | 52 | 0.200 |
| ɣdry versus ω average(this study depends) | 0.126 | 52 | 0.038 |
| ωoptimum  | 0.106 | 52 | 0.200 |
| ɣdry (max) by standard ASTM | 0.123 | 52 | 0.049 |

Results listed in table (4) gave that the data distribution for maximum dry density values for both standard and research method was not normal with significance difference less than (0.05) therefore the 2 independent sample Mann-Whitney non parametric test will adopt as table (5) shows

**Table (5) The Mann-Whitney test values for Densities data**

|  |
| --- |
| **Test Statistics** |
|  | Density |
| Mann-Whitney U | 1220.500 |
| Wilcoxon W | 2598.500 |
| Z | -0.855 |
| Asymp. Sig. (2-tailed) | 0.393 |
| a. Grouping Variable: G |

|  |
| --- |
| **Ranks** |
|  | G | N | Mean Rank | Sum of Ranks |
| Density | 1.0000 | 52 | 55.03 | 2861.50 |
| 2.0000 | 52 | 49.97 | 2598.50 |
| Total | 104 |  |  |

For the optimum moisture content values the independent Samples T test for comparing two data series because it has normal distribution with no significant difference (Sig>0.05) as table (4) refers, table(6) shows the two independent samples T test (this type of test suppose that H0:μ1=μ2, in another words this test type depends no difference between the compared means against the alternative hypotheses Ha: μ1≠μ2) the computations done after units convert to metric units system.

**Table (6) 2-independent T test results for optimum moisture content data series**

|  |
| --- |
| **Group Statistics** |
|  | G | N | Mean | Std. Deviation | Std. Error Mean |
| ω | 1.0000 | 52 | 14.080769 | 2.8755247 | 0.3987635 |
| 2.0000 | 52 | 14.273545 | 3.2072153 | 0.4447607 |

|  |
| --- |
| **Independent Samples Test** |
|  | Levene's Test for Equality of Variances | t-test for Equality of Means |
| F | Sig. | t | df | Sig. (2-tailed) | Mean Difference | Std. Error Difference | 95% Confidence Interval of the Difference |
| Lower | Upper |
| ω | Equal variances assumed | 0.538 | 0.465 | -0.323 | 102 | 0.748 | -0.1927758 | 0.5973479 | -1.3776125 | 0.9920609 |

Noting that group(1) refers to the standard values and group(2) refers to research method values (based on obtaining average moisture content and maximum dry density versus it).

From the presented data its clearly there are not restorable differences between all statistical function values or could say not significance differences between research and standard method number.

**4.Collected data evaluation**

According to tables (2), (3) , (4),(5) and (6) data can be noted that difference for moisture content and ɣdry maximum not has wide range values and the most differences value was less than one unit.

**5.Conclusion**

1. The method of research for calculating the average moisture content of the compaction test trials can be used to provide quick way of optimum moisture content expectation.
2. The average difference values between the average moisture content (research method) and the standard method was (-0.192).
3. The average difference values between the ɣdry maximum versus average moisture content (research method) and the calculated ɣdry by the standard method was (0.261).
4. All statistical functions results gave good acceptance indication between research and standard method values with not significance differences.
5. All calculation results indicates that adopting research method values can be acceptable with reasonable difference values from standard, that's more clearly for the differences of moisture content than the differences depends maximum dry densities.

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