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Experimental Investigation on Compaction Properties of Sandy Soils

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Abstract

In this research, an effort has been made to develop a correlation between standard and modified proctor compaction test parameters, i.e., maximum dry unit weight (γ_{dmax}) and optimum moisture content (OMC) of sandy soils. Standard and modified proctor along with classification tests were carried out on hundred and twenty sandy soil samples with different grain size distributions. Based on the test results, the soil samples were classified into various groups of medium to fine sand with non-plastic fines up to 45%. Regression analyses were performed on the experimental data and correlations were proposed to express modified Proctor parameters (γ_{dmod} and OMC_{mod}) in term of standard Proctor test parameters (γ_{dstd} and OMC_{std}). The validation of the proposed predictive correlations was done by using test results of another set of sandy soil samples not used in the development of the correlations. The results of the analyses showed that variation between experimental and predicted values of γ_{dmod} is within ± 4 % confidence interval and that of OMC_{mod} is within ± 2.0 %. Further, based on the test results, an effort has been made to investigate the effect of fines (finer than 75μm) on compaction characteristics. It was observed that γ_{dmax} both in case of standard and modified proctor increases with increase in fines content up to 35% and beyond that it decreases. However, the value of OMC in both the cases decreases with increase in fine content. The correlations proposed in this paper may be very useful during the project preliminary/ pre-feasibility stages in the field of Geotechnical Engineering.

Key Words: Compaction characteristics, compaction energy, maximum dry unit weight, optimum moisture content

1. Introduction

Field compaction is an integral part of every earthwork construction projects. Application of compaction energy (*CE*) along with addition of specified amount of water results in denser packing of the soil particles. It is an established fact that the dry unit weight of the soil mass increases with increase in water content uptill certain value i.e., optimum moisture content (*OMC*) and afterwards dry unit weight decreases provided *CE* remains constant. Generally, for field compaction control in earthwork construction projects, standard proctor compaction test (SPCT) parameters (γ_{dstd} ,OMC_{std}) are considered for lightly loaded structures e.g., walkways, footpaths, floor of residential building etc., where as modified proctor compaction test (MPCT) parameters (γ_{dmod} ,OMC_{mod}) are used for heavy loaded structures like embankment for pavements, railways, runways, bridge abutments etc. The amount of *CE* required in case of MPCT is approximately 4.5 times more as compared with SPCT. This research is focused to develop correlation between MPCT and SPCT parameters. Along with this, an effort has been made to correlate the fines present in the samples with maximum dry unit weight (γ_{dmax}) and *OMC*. Such correlations may be very useful during the project planning/pre-feasibility stages; however, the actual performance of the relevant test during design/execution stage can not be avoided. Various researchers including Rabaiotti et al. [1], Connelly et al. [2], Scott et al. [3], McCook [4] and Hamdani [5] have focused their research in this area.

Rabaiotti et al. [1] while carrying out revision of the Swiss standard "SN 670 330 b" for Swiss Federal Institute of Technology collected road materials belonging to various soils classification groups. Standard and modified AASHTO compaction tests were carried out on these materials. Based on the test results, an attempt was made to correlate the degree of compaction of road material. The correlations between specific weights resulting from compaction tests are presented in Eq. 1.

$$\eta = \frac{\text{Dry density according to AASHTO standard}}{\text{Dry density according to AASHTO modified}} \quad (1)$$

The value of η is 0.97 for poorly or well graded gravels (GP/GW), 0.95 for moraine with high plasticity (SC) and 0.93 for moraine with low plasticity (SC-SM).

Connelly et al. [2] carried out standard and modified compaction tests on representative groups of Nebraska soils for Nebraska Department of Roads (NDOR) to develop formulae to convert SPCT parameters to MPCT parameters and vice versa. Table 1 presents the formulae proposed by Connelly et al.

Table 1: Conversion Formulae proposed by Connelly et al. [2]

Soil Type	Standard To Modified (pcf)	Modified to Standard (pcf)
Gravel	γ_{dstd} + 0, OMC_{std}-2	γ_{dmod} - 0, OMC_{mod}+2
Fine Sand	γ_{dstd} + 1, OMC_{std} -1	γ_{dmod} - 1, OMC_{mod} +1
Sandy Silt	γ_{dstd} + 10, OMC_{std} -3	γ_{dmod} - 10, OMC_{mod} +3
Loess	γ_{dstd} + 10, OMC_{std} -4	γ_{dmod} - 10, OMC_{mod} +4
Loess-Till	γ_{dstd} + 12, OMC_{std} -6.5	γ_{dmod} - 12, OMC_{mod} +6.5
Till	γ_{dstd} + 15, OMC_{std} -6.5	γ_{dmod} - 15, OMC_{mod} +6.5
Shale	γ_{dstd} + 13, OMC_{std} -7	γ_{dmod} - 13, OMC_{mod} +7

Scott et al. [3] based on their research showed that modified compaction test is recommended to perform in the laboratory than standard compaction test where Rolling Dynamic compaction is used for field compaction control as energy imparted in MPCT is more representative as compared to standard compaction test [3].

McCook [4] developed the correlation between one point standard proctor test and relative density test for 29 filter sands. Key wall Retaining system [6] suggested that 90-92 % of γ_{dmod} is roughly equivalent to 95 % of the γ_{dstd} except for fine grained soils (i.e silt and clay) where the difference may be significantly larger.

Further, Hamdani [5] based on standard and modified compaction tests on large number of soils revealed that there exists an underlying correlation between compaction characteristics of standard and modified compaction tests. Based on the test results, he proposed correlations between maximum dry unit weight and optimum moisture content obtained by standard and modified compaction tests. These correlations are presented in Eq. 2 and Eq. 3.

$$\gamma_{dmod}(\text{pcf}) = 0.02 \times (\gamma_{dstd})^2 - 3.79 \times \gamma_{dstd} + 293.4 \quad (2)$$

$$OMC_{mod} = -0.036 \times (OMC_{std})^2 + 1.754 \times OMC_{std} - 5.564 \quad (3)$$

In Eq. 2 and Eq. 3, γ_{dmod} and OMC_{mod} are compaction parameters related to MPCT and γ_{dstd} and OMC_{std} are related to that of SPCT.

Bloomfield and Ware [7] carried out heavy compaction test on coastal dune sands with varying amount of plastic fines. It had been observed that at lower moisture content, the addition of 10 % fines significantly increases the maximum dry density of the soil. It was also observed that the optimum value of fines to sand ratio occurs at 0.2 to 0.3. Kim et al. [8] carried out compaction tests on decomposed granitic soils and it was observed that as fine aggregate content increases, the dry density decreases and *OMC* increases. Deb et al. [9] studied the effect of plastic and non-plastic fines on poorly graded sands. Their research revealed that by the addition of fine contents up to 30%, the maximum dry density increases and beyond 30%, it decreases. However, *OMC* decreases as the percent of fines added is increased up to the point where maximum value of density is achieved. Khan et al. [10] compared actual soil classification of alluvial soils with that from the test results of cone penetration test and dilatometer test. They concluded that dilatometer was unable to differentiate between fine sand and silt. Also, cone penetration test data interpretation may describe clays as silty sand to sandy silt.

2. Test Materials and Laboratory Testing

In the experimental program reported herein, 120 sandy soil samples were selected for the development of the proposed correlations and 50 similar soil samples were selected for the validation purposes. The following tests were conducted on the selected samples according to the standard procedures.

a) Grain size analysis (ASTM D-422)
b) Atterberg Limit Test (ASTM D-4318)
c) Specific gravity test (ASTM D-854)
d) Soil Classification (ASTM D-2487)
e) Standard Proctor compaction test (ASTM D-698)
f) Modified Proctor compaction test (ASTM D-1557)

3. Results and Discussions

Figure 1 shows the grain size distribution (GSD) curves for all the soil samples, which are confined within a band. All the selected samples fall in the range of medium to fine sand, with some silty sand samples. Median grain size (D_{50}) of the entire band is in the range of 0.8 mm to 0.075 mm and effective grain size (D_{10}) in the range of 0.19 mm to 0.014 mm.

The test data for 120 samples selected for development of predictive correlations are summarized in Table 2, whereas Table 3 presents the data of 50 samples used for the validation of the predictive equations. The samples used in the study contain sand (percent passing 4.75 mm, and percent retained on 75 μm) varying between 50 and 100 %. The gravel (percent retained on 4.75 mm) in the samples varies from 0 to 5% and the fines (percent finer than 75 μm) varies from 0 to 45%. The fines present in the samples are non-plastic in nature except fines in few samples which have liquid limit (LL) in the range of 18 to 22 and plasticity index (PI) ranging between 0 and 4. All values of PI fall below the hatched zone in the plasticity chart indicating that the fines are low to non-plastic silt. The specific gravity of the tested samples falls in the range of 2.55 ~ 2.72. The soil samples are classified in to various groups such as, well graded sand (SW), poorly graded sand (SP), poorly graded sand with silt (SP-SM), silty sand (SM) and well graded sand with silt (SW-SM) according to the Unified Soil Classification System (USCS) as described in ASTM D-2487.

The compaction curves of all the samples both for Modified Proctor and Standard Proctor are shown in Figure 2 and Figure 3, respectively. The compaction parameters corresponding to modified compaction tests, i.e., γ_{dmod} and OMC_{mod} are, generally, in the range of 15.7 ~ 20.5 kN/m^3 and 8.0 ~ 15.5%, respectively. As indicated in Figure 2, the above mentioned range of γ_{dmod} is further sub divided for individual soil classification group, i.e., SP, SP-SM, SM and SW/SW-SM. The value of γ_{dmod} for SP samples varies between 15.7 ~ 17.5 kN/m^3, for SP-SM, between 16.5 ~ 18.5 kN/m^3, for SM and SW/SW-SM samples, it falls in the range of 16.5 ~ 19.8 kN/m^3 and 18.5 ~ 20.5 kN/m^3, respectively. Also in Figure 2, compaction curves of sample number 15, 24, 26 and 28 have been marked to identify the variation in compaction characteristics due to change in soil group for Modified Proctor. The result of grain size analysis and classification symbol of these four samples is also given in Figure 2. Similarly, the standard proctor parameters (γ_{dstd} and OMC_{std}) are generally in the range of 14.8 ~ 19.5 kN/m^3 and 11.0 ~ 18.0%, respectively. Specifically in Figure 3, SP samples have γ_{dstd} between 14.8 ~ 16.7 kN/m^3 while for the soil groups SP-SM, SM and SW/SW-SM, the value of γ_{dstd} are 16.2 ~ 18.0 kN/m^3, 16.2 ~ 19.0 kN/m^3 and 17.5 ~ 19.5 kN/m^3, respectively. Like in Figure 2, four compaction curves of sample number 47, 56, 58 and 61 are identified in Figure 3 to observe the change in γ_{dstd} and OMC_{std} due to change in soil group. The variation in γ_{dmax} and OMC in both modified proctor and standard proctor tests is mainly due to the variation of gradation and fines content in the samples. In both the cases, the maximum compaction density is achieved in case of SW/SW-SM samples. Further, for both the cases as the fines content in the samples increases, the γ_{dmax} increases

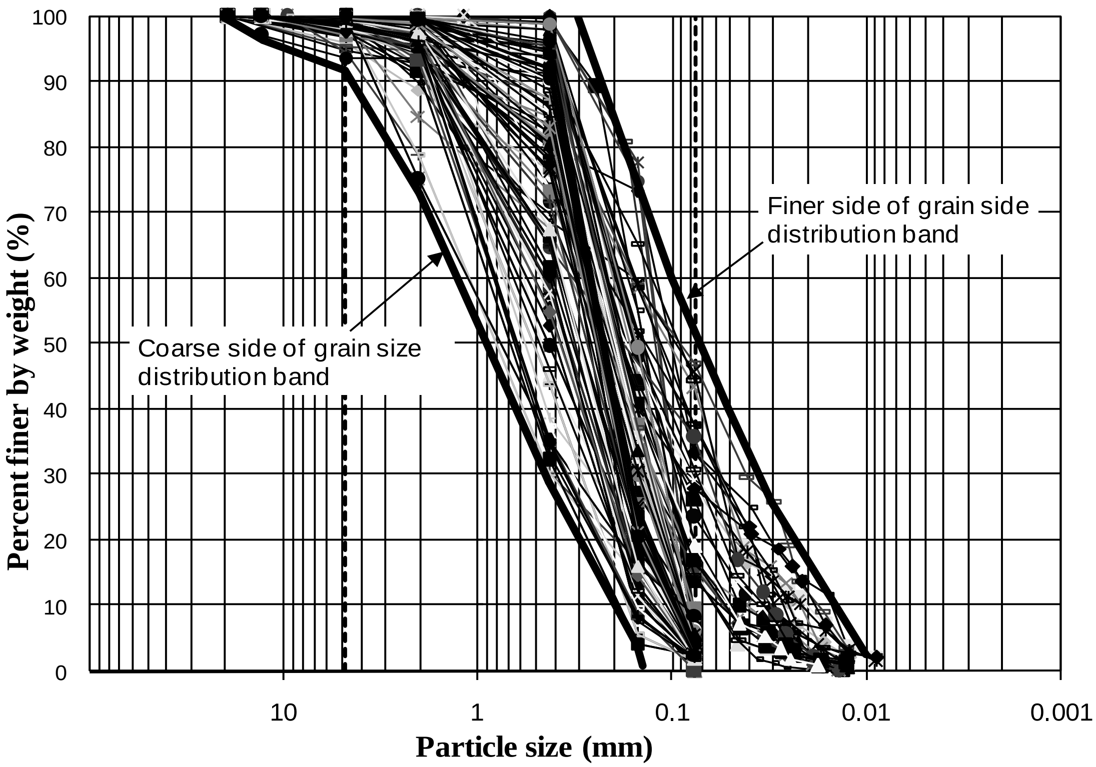
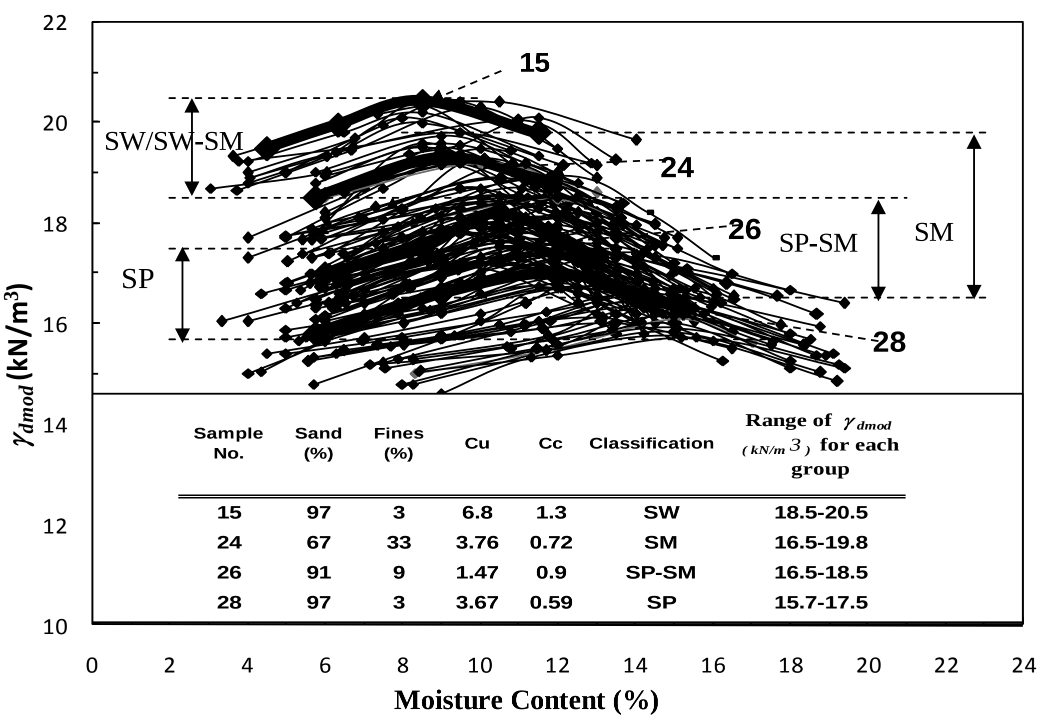


Fig. 1 Grain size distribution curves of 170 sand samples



Sample No.	Sand (%)	Fines (%)	Cu	Cc	Classification	Range of γ_{dmod} (kN/m^3) for each group
15	97	3	6.8	1.3	SW	18.5-20.5
24	67	33	3.76	0.72	SM	16.5-19.8
26	91	9	1.47	0.9	SP-SM	16.5-18.5
28	97	3	3.67	0.59	SP	15.7-17.5

Fig. 2 Modified proctor compaction curves of sandy samples used in the study

Table 2: Summary of Grain Size Analysis and Compaction Tests on 120 samples (Used for Development of Correlations)

No of Samples	USCS Classi-fication	Gravel (%)	Sand (%)	Fines (%)	Liquid Limit (%)	Plasticity Index (%)	Specific Gravity, G_s	C_u	C_c	Modified Proctor (ASTM D-1557)		Standard Proctor (ASTM D-698)	
										γ_{dmod} (kN/ m³)	OMC_{mod} (%)	γ_{dstd} (kN/m³)	OMC_{std} (%)
40	SM	0-5	50-97	13-45	0-22	NP-4	2.62-2.72	2.86-11.58	0.43-2.14	16.5-20.4	8-13	15.6-19.5	11.0-16
35	SP-SM	0-3	88-95	5-10	-	NP	2.55-2.66	1.38-8.24	0.63-1.29	15.7 - 19.8	9.5-15.5	15.2-18.8	11.5-18.0
35	SP	0-6	92-100	0-4	-	NP	2.57-2.67	1.93-5.0	0.56-1.07	16.2-19.0	9-15.5	15.2-18.1	11-18.0
5	SW-SM	0-2	90-91	8-9	-	NP	2.60-2.70	7.32-11.76	1-1.1	18.5-20.5	9.0-9.5	17.6-19.5	11.5-12.5
5	SW	0-2	95-100	0-4	-	NP	2.64-2.69	4.74-9.10	1.0-1.64	18.6-20.0	8.5-11.0	17.4-19.0	11.0-14.0

C_u –Uniformity Coefficient = $\frac{D_{60}}{D_{10}}$, C_c = Curvature Coefficient = $\frac{D_{30}^{2}}{D_{10} \times D_{60}}$, Fines = % passing 75 µm sieve, Gravels = % retained 4.75 mm sieve

Table 3: Summary of Grain Size Analysis and Compaction Tests on 50 samples (Used for Validation of Correlations)

No of Samples	USCS Classi-fication	Gravel (%)	Sand (%)	Fines (%)	Liquid Limit (%)	Plasticity Index (%)	Specific Gravity, G_s	C_u	C_c	Modified Proctor (ASTM D-1557)		Standard Proctor (ASTM D-698)	
										γ_{dmod} (kN/ m³)	OMC_{mod} (%)	γ_{dstd} (kN/m³)	OMC_{std} (%)
10	SP-SM	0-2	93-95	5-6	-	NP	2.55-2.66	2.38-3.50	0.66-1.07	16.7-18.7	9-14.5	15.6-17.0	12-16
28	SP	0-2	94-100	0-4	-	NP	2.57-2.67	2.0-4.69	0.57-1.30	15.8-18.9	9.5-15.5	14.8-17.4	12.5-18.0
4	SW	0-1	97-100	0-2	-	NP	2.64-2.69	6.15-6.42	1.02-1.65	18.6-19.5	8.5-13.5	17.5-18.3	11.5-17
1	SW-SM	0	91	9	-	NP	2.60-2.70	11.11	1.0	20.5	9	19.5	12.5
7	SM	0	55-85	15-45	-	NP	2.63-2.70	3-12	0.7-3.2	17.7-18.7	10.0-13.0	16.50-17.90	13.0-17.0

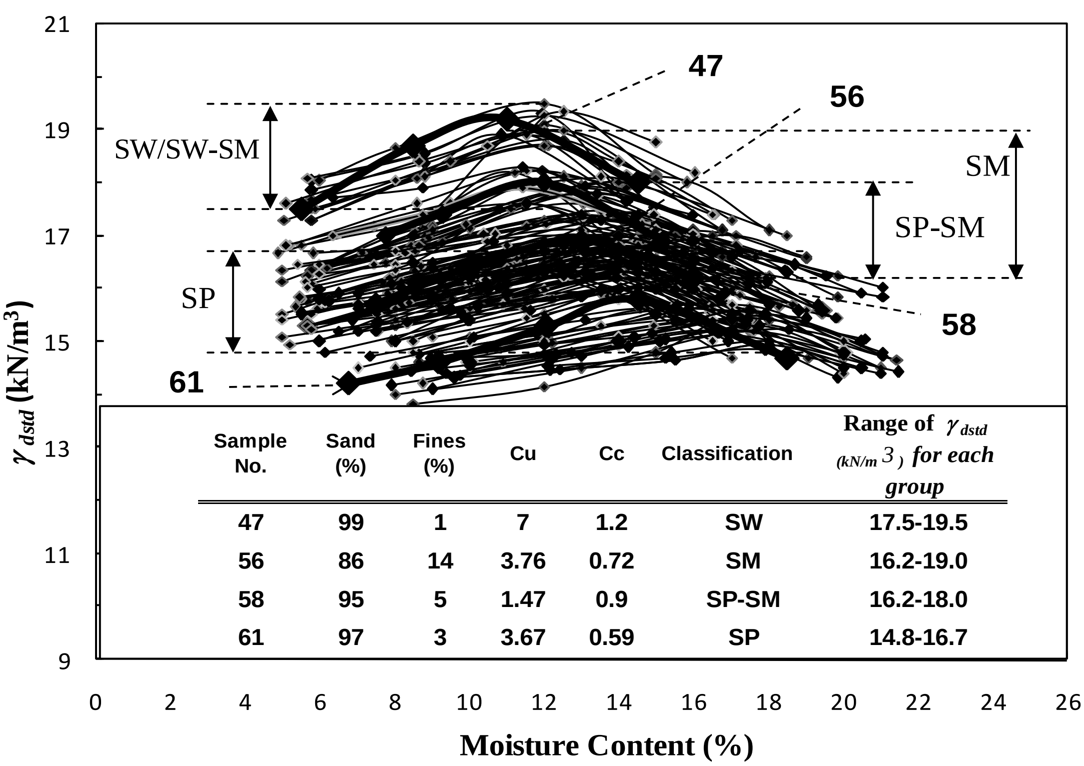


Fig. 3 Standard proctor compaction curves of sandy samples used in the study

and the *OMC* decreases as evident from Figure 2 and Figure 3. However, the effect of fines on γ_{dmax} and *OMC* is not visible in Figure 2 and Figure 3 and has been separately discussed in Article 6 of this paper. This finding implies that maximum compaction in case of sandy soils can be achieved either by using well graded soil or by mixing fines in the range of 30~35% as discussed in later part of the paper.

4. Development of Correlations

A correlation represents the degree of association between observations of two or more variables. In this research, bivariate correlations have been proposed between SPCT and MPCT parameters. Parameters obtained through SPCT are treated as independent variables while parameters of MPCT are dependent variables. Linear regression analysis was carried out on experimental data of each group of sandy soils presented in Table 2. Calibration of the correlation is carried out using regression analysis and the values of coefficients for input and output parameters are calculated. The final best fit correlations expressed in general form are given in Eq. 4 & 5 and details of the regression analyses are reported in Table 5.

$$\gamma_{dmod} = \alpha \times \gamma_{dstd} \quad (4)$$

$$OMC_{mod} = \beta \times OMC_{std} \quad (5)$$

The values of factor α and β in Eq. 4 & 5 depend on type of soil and based on the results of the regression analyses, Table 4 summarizes the regression coefficients of α and β. The factors α and β are being recommended for soil groups like SP, SP-SM, SM and SW/SW-SM.

Table 4: Factors α and β to be used in Eq. 4 & 5, respectively.

Soil Type	α	R^2	β	R^2
Poorly graded sand (SP)	1.067	0.88	0.800	0.76
Poorly graded sand with silt (SP-SM)	1.072	0.92	0.804	0.78
Silty sand (SM)	1.062	0.92	0.785	0.71
Well graded sand/ well graded sand with silt (SW/SW-SM)	1.054	0.81	0.787	0.70

A good and reliable correlation must have high value of correlation coefficient (R^2), low value of standard error of estimate (SEE) and passes *F* and *t*-tests statistics with pre-selected confidence interval of about 95%. The correlation coefficient (R^2) is an index of goodness of fit between predictive correlation and sample data used to develop that correlation. It provides a quantitative index of association between measured and predicted values and is used as a measure of accuracy for future predictions. The R^2 values of 0.90 ~ 0.96 for Eq. 4 and 0.81 ~ 0.88 for Eq. 5 are rated as good correlation coefficients in geotechnical engineering. SEE measure the variance between experimental and predicted values of output parameter. SEE is divided by mean value of output variable to provide a standardized measure of fit and is termed as relative standard error of estimate (RSEE).

SEE values are in the range of 0.278 ~ 0.325 and 0.610 ~0.822 for Eq. 4 and 5 are quite low which indicates good prediction capability of the model. Figures 4 and 5 represent the variation between experimental data and predicted values using Eq. 4 &

Table 5: Regression output for Eq. 4 and 5

Soil Type	Correlation Coefficient, R	Standard Error of Estimate, SEE	*F* Statistics	*t*-Statistics	Lower 95%	Upper 95%
SM (Eq.4)	0.96	0.305	118639.2	344.44	1.056	1.068
SM (Eq.5)	0.84	0.822	4987.94	70.62	0.763	0.808
SP-SM (Eq.4)	0.96	0.325	108838.6	329.9	1.064	1.077
SP-SM (Eq.5)	0.88	0.812	7227.9	85.0	0.785	0.823
SP (Eq.4)	0.94	0.278	173002	415.93	1.059	1.069
SP (Eq.5)	0.87	0.693	10917.2	104.50	0.785	0.816
SW/SW-SM (Eq.4)	0.90	0.288	46135.4	214.8	1.043	1.065
SW/SW-SM (Eq.5)	0.81	0.610	2771.6	52.65	0.753	0.821

Eq. 5, respectively. These plots show that the prediction accuracy is within ± 4% for γ_{dmod} and ± 2% for OMC_{mod} (%).

Analysis of variance (ANOVA) is carried out to determine *F*- statistic for output parameters and *t*- statistics for input parameters. As indicated in Table 4, the model *F* value for both γ_{dmod} and OMC_{mod} (%) is greater than critical *F* indicating that Eq. 4 and 5 are significant. Similarly, absolute *t*- statistics for input parameters is greater than *t*- significance of the model.

5. Validation of Correlations

The last step in the development of any predictive correlation is the validation of the correlation by some independent data that was not seen by the model. In this study, subsequent to the formulation of the correlation, a new set of fifty soil samples which were not used in model development, were tested in the laboratory for the validation of the predictive correlations. Experimental values of γ_{dmod} and OMC_{mod} of these samples were plotted against the predicted values of the same parameters by Eq. 4 & 5 and are shown in Figure 6 and 7. The predicted values of both γ_{dmod} and OMC_{mod} fall within ± 4% and ± 2% of experimentally measured values, respectively. The empirical relationships developed by Connelly et al. [2] and Hamdani [5] have also been employed to predict γ_{dmod} and OMC_{mod} by using experimental results of standard proctor tests of these fifty samples.

For γ_{dmod}, 36 out of 50 predictions are exceeding the limits of ± 4% by using Hamdani equation (Eq. 2) whereas by using relation given in Table 1, 34 out of 50 predictions fall outside ± 4% band. It indicates that neither Connelly et al. [2] nor Hamdani [5] approach can be used to convert γ_{dstd} in to γ_{dmod} for local sands of Pakistan. Similarly, for the prediction of OMC_{mod} (%), it is observed that by using Hamdani relation (Eq. 3), the predicted values of OMC_{mod} fall well inside ± 2% band. It appears that Hamdani approach for predicting OMC_{mod} may be used for sandy soil with non-plastic fines. However, in predicting OMC_{mod} by using Connelly et al. relation given in Table 1, 14 out of 50 predictions falls outside ± 2% band. Hence, the relation presented in Table 1 cannot predict OMC_{mod} by using the results of standard proctor parameters.

6. Effect of Fines on γ_{dmax} and OMC

The test data was analyzed to investigate the effect of increasing fines (finer than 75 µm) on γ_{dmax} and *OMC* for both standard proctor and modified proctor tests. The soil samples have been divided into various groups based on the fines content as per USCS classification system. Average value of γ_{dmax} and *OMC* of all the samples belonging to a specific group have been worked out and being plotted in Figure 8 and 9, respectively. Figure 8 shows the variation of average values of γ_{dmod} and γ_{dstd} with fines content present in the samples. The peak values of both γ_{dmod} and γ_{dstd} are being attained at about 35 % of fines content. However, in case of well graded samples (SW/SW-SM) even with low fines content (less than 12%), both γ_{dmod} *and* γ_{dstd} are about 8~ 9% more than their equivalent SP/SP-SM samples and have almost same unit weight values as compared with their respective SM samples with 35% fines content. By careful scrutiny of Figure 8, it can be observed that there is about 9.5% increase in both γ_{dmod} and γ_{dstd} when the fines content increases from 0 to 35%. Whereas, with fines content exceeding 35%, there is reduction in maximum dry unit weight for both standard and modified proctor cases. In this investigation, this decreasing trend of γ_{dmax} has been observed from 35% to 45 % fines content. This finding is very useful while dealing the compaction of sandy soil as backfill material; means that sandy soils can be best compacted either by using well graded material or by adding about 30~35% non plastic fines. Figure 9 plots the variation of *OMC* for both MPCT and SPCT with percentage of fines present in the samples. It can be clearly observed from Figure 9 that there is continuous decreasing trend of *OMC* for both MPCT and SPCT as fines content increases. It is worth mentioning here that *OMC* values for well graded (SW/SW-SM) and poorly graded (SP/SP-SM) samples do not show a significant difference as it has been observed in case of $\gamma_{max.}$ Therefore, in Figure 9, the values of *OMC* for SW/SW-SM and SP/SP-SM have been collectively averaged out. It can be seen from Figure 9 that OMC_{mod} decreases from 11.7% to 10% and OMC_{std} decreases from 14.6 % to 11.4 % as the fines content varies from 0 to 45%. Further, it can be observed from the same figure that in both cases, the decreasing trend of *OMC* is more pronounced when the fines are increased from 0 to 25% where as the

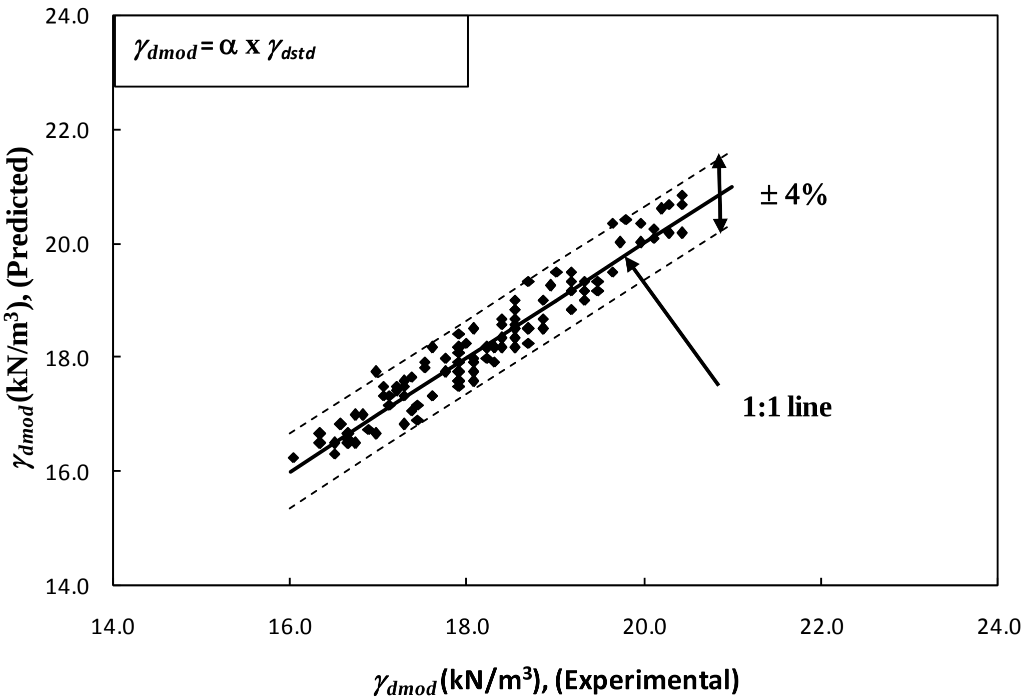


Fig. 4: Experimental vs predicted values of γ_{dmod} by proposed correlation (Eq. 4)

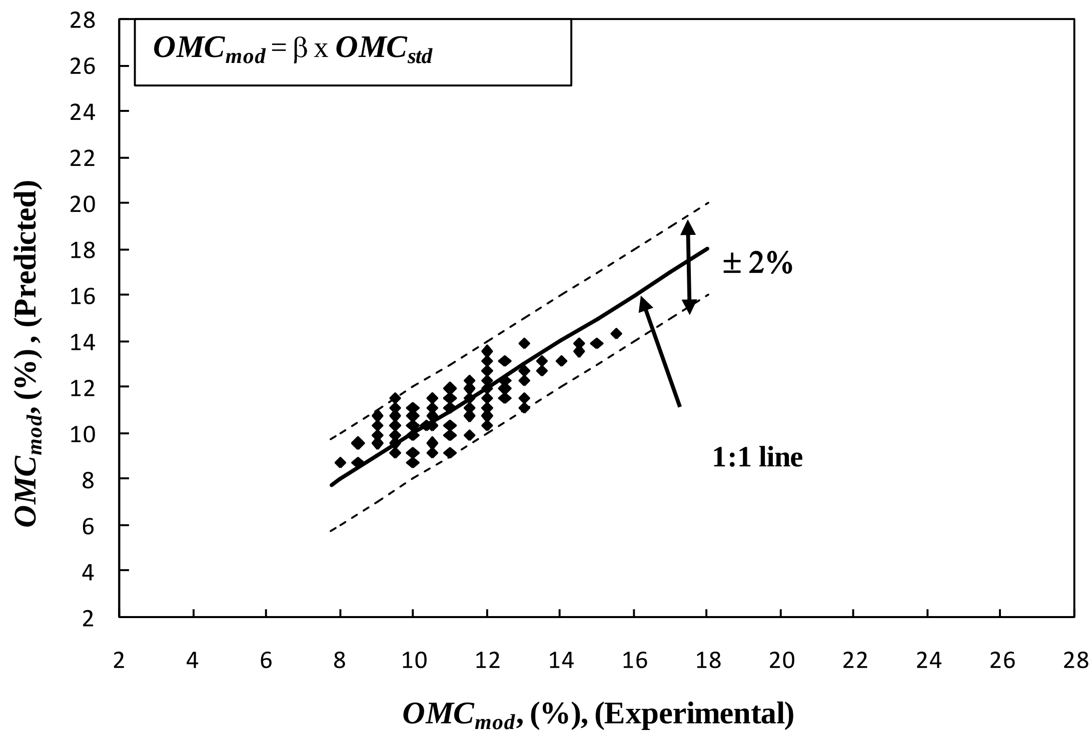


Fig. 5: Experimental vs predicted OMC_{mod} by proposed correlation (Eq. 5)

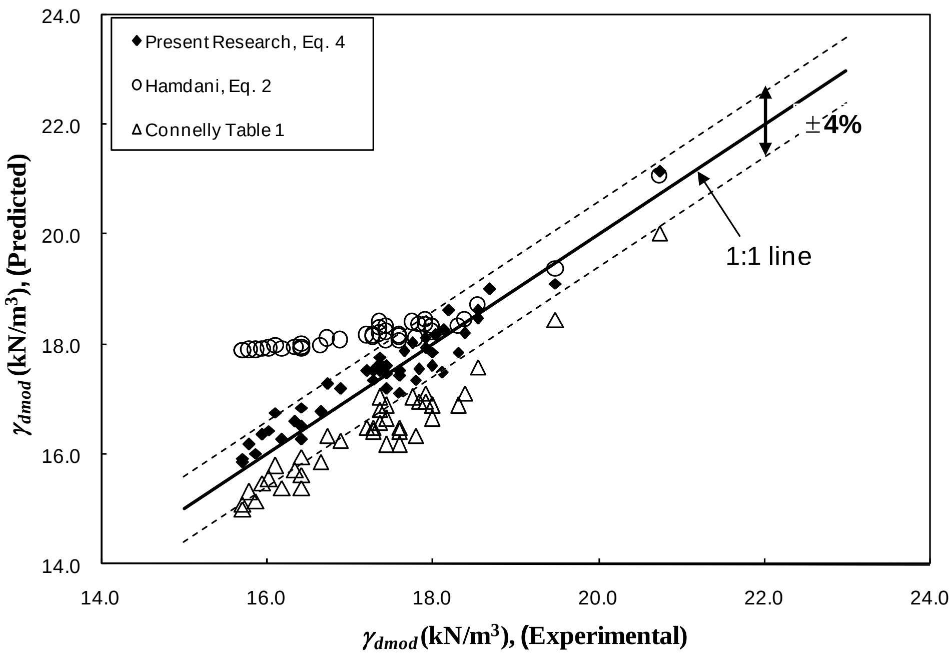


Fig. 6: Comparison of experimental vs predicted values of γ_{dmod} by Eq. 4 with Eq. 2 and Table 1

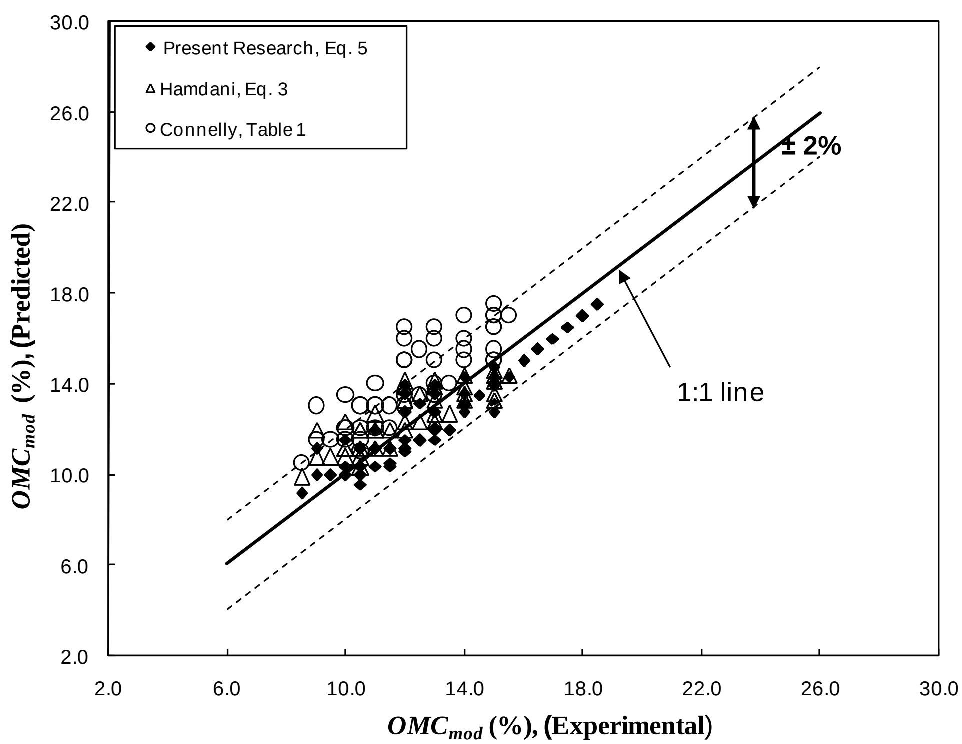


Fig. 7: Comparison of experimental vs predicted values of OMC_{mod} by Eq. 5, with Eq. 3 and Table 1

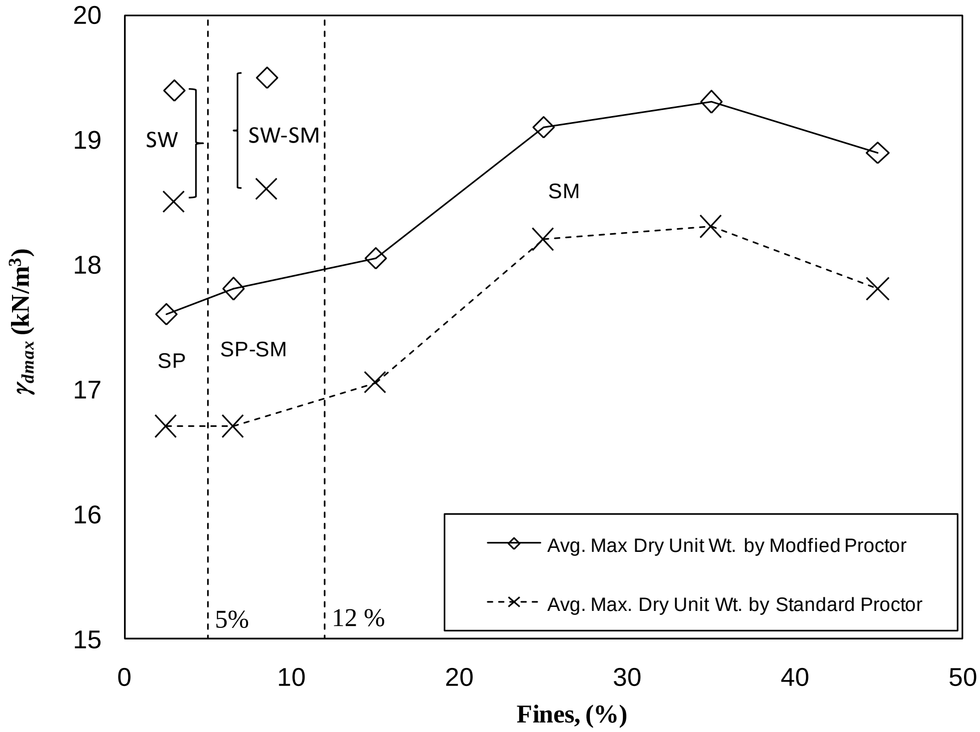


Fig. 8: Fines vs average γ_{dmax} for sand samples used in the study

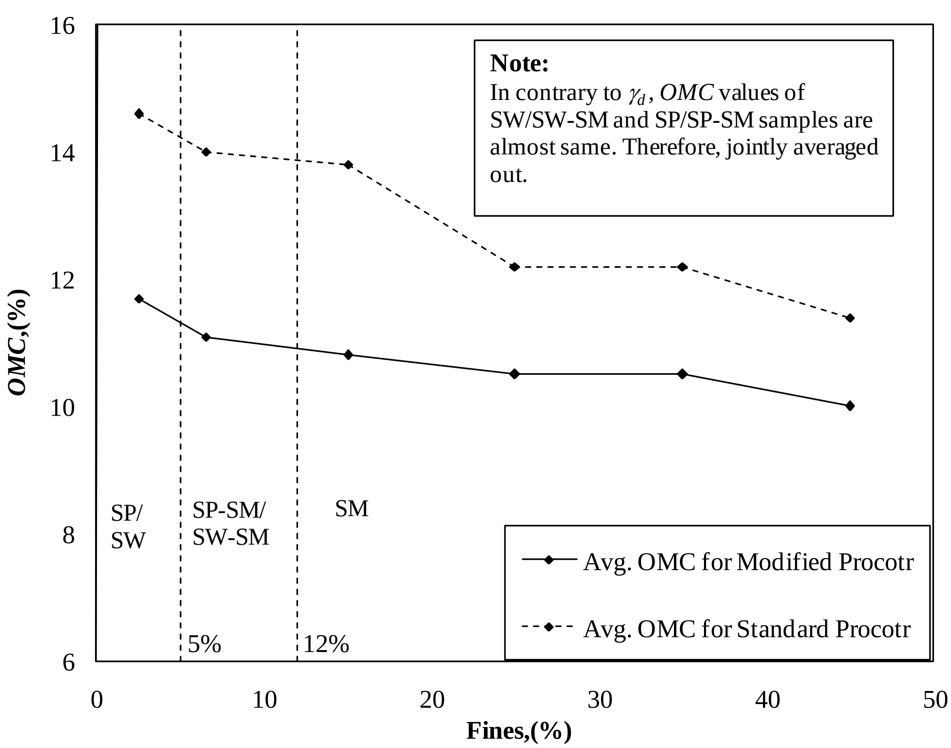


Fig. 9: Fines vs average *OMC* (%) for sand samples used in the study

rate of decrease in *OMC* is very negligible beyond 25% addition of fines. The probable reason for this decreasing trend in *OMC* with the addition of fines may be attributed to denser packing that is accomplished with the addition of fines filling the void spaces, hence resulting in maximum unit weight at lower values of *OMC*. However, it is difficult to separate the relative contributions of fines and moisture content in denser packing as both contribute up to a certain limit.

7. Conclusions

On the basis of the above research, the following conclusions are made:

- The γ_{dmod} can be predicted based on experimental value of γ_{dstd} for sandy soils containing non plastic fines by using the correlation: $\gamma_{dmod} = \alpha \times \gamma_{dstd}$ The value of α varies from 1.062 to 1.072 (Table 4) depending on soil type. The experimental versus predicted values of γ_{dmod} fall within ± 4 % indicating good prediction accuracy of the model.
- Like γ_{dmod}, the OMC_{mod} for sandy soils can also be predicted based on laboratory value of OMC_{std} by using the relation: $OMC_{mod} = \beta \times OMC_{std}$. The value of β based on soil type varies from 0.785 to 0.804 (Table 4). The experimental versus predicted values of OMC_{mod} fall within ± 2% indicating good prediction accuracy of the relation.
- Based on the results of the compaction tests, it can be inferred that maximum dry unit weight determined through modified proctor (γ_{dmod}) is 6 ~ 7% more than that of achieved by standard proctor (γ_{dstd}). However, the optimum moisture content in case of modified proctor test (OMC_{mod}) is 2 ~ 2.5% less as compared with determined through standard proctor (OMC_{std}) for the same samples.
- The maximum dry unit weight (γ_{dmax}) obtained through either standard or modified proctor increases with the increase in non plastic fines up to 35% and afterwards it decreases with further addition of fines, whereas the optimum moisture content shows a continuous decreasing trend with the addition of non-plastic fines.
- The maximum value of γ_{dmax} in both standard proctor and modified proctor is achieved in case of well graded (SW/SW-SM) samples and silty sand (SM) samples with 30~40% silt contents. Based on this observation, it can be concluded that sandy soils can be best compacted for a given effort either by using well graded sand (which is rare in nature) or by adding about 30~35% non plastic fines in poorly graded sands.

8. References

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