Correlation of Compaction Characteristics of Fine-Grained Soils using Atterberg Limits

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***Abstract*: Soil compaction is a vital part of the construction process. It is used for support of structural entities such as building foundations, roadways, walkways, and earth retaining structures. Compaction requires significant time and effort. Hence, there is a necessity to predict of compaction characteristics of soils with the help of its correlation with index properties of soils which can be determined easily.**

In the present experimental work, six field soils have been selected from various locations in Karnataka. Index property tests were carried out on the soil samples as per BIS specifications. The soils were subjected to various compaction energy levels like Standard Proctor (SP), Reduced Standard Proctor (RSP), Modified Proctor (MP), and Reduced Modified Proctor (RMP) and the respective maximum dry density (MDD) and optimum moisture content (OMC) were determined.

An attempt has been made to establish the correlation between compaction characteristics (OMC & MDD) of fine-grained soils for varying compaction energy levels with Liquid Limit, Plastic Limit and Shrinkage Limit using MLRA (Multiple Linear Regression Analysis) equations. It is observed that a good correlation exists between compaction characteristics of fine-grained soils with index properties of soils with a regression value ranging from 0.993 to 0.997. Hence it clearly says that compaction characteristics can be effectively predicted using Atterberg limits of soils, thus saving materials, time and money.

Key words: Compaction characteristics, Correlation, Index properties, Multiple Linear Regression Analysis (MLRA).

1. INTRODUCTION

Compaction of soil is a process of application of mechanical energy for its densification by removal of air voids and rearranging the particles. The reduction in the voids ratio makes it more difficult for the water to flow through the soil. This is important if the soil is being used for retaining water such as in case of an earth dam. It also helps in preventing the water pressures that causes soil to liquefy during earthquakes. So modification of soil is a vital process for improving its engineering properties and it is also essential in many applications such as highway, railway subgrades, air field pavements and in constructing earth and earth retaining structures. The soil mass is compacted to achieve the three basic criteria i.e. reduction in subsequent settlement of soil mass under working loads, reduction in permeability and increases the shear strength of the soil. The construction of structures on fine-grained soils is considered as one of the challenging task in geotechnical engineering. For structures to be safe and sound, they are to be built on good soils.

Field compaction of fine-grained soils usually involves different equipment with compaction energy varying significantly. Hence the compaction characteristics need to be obtained at different compaction energies. Knowledge of compaction behavior and its characteristics of fine-grained soils at different compaction energy levels assume great importance from the view point of practical significance.

Prior to the field compaction, the determination of compaction characteristics namely, optimum moisture content and maximum dry density is necessary. It requires relatively more time, effort and money for obtaining these engineering properties of soils. For preliminary assessment of the soil characteristics, predictive models can be useful, especially when index properties are already known. Several relationships to connect OMC and MDD found in the literature for the Standard Proctor compaction test based on some selected index properties such as liquid limit (LL), plastic limit (PL) and specific gravity (Gs). Therefore, there is a need of correlating the compaction characteristics with index properties and consistency limits as they are easy to determine.

Few correlations were developed to predict the compaction characteristics of fine-grained soils with the index properties and specific gravity. The present paper examines the compaction characteristics of fine-grained soils. Data were collected to integrate several fine-grained soils and new best-fit models were developed to predict the compaction properties (OMC and MDD) for the different compaction energies as a function of specific gravity and index properties.

2. LITERATURE REVIEW

- Investigators like Lambe (1916), Proctor (1933), Hogentolger (1936), Hilf (1956), Olson (1963), Barden & Sides (1970), and Nagaraj & Srinivas (1983) have attempted to explain the shape of the curve of OMC v/s MDD for fine-grained soils.
- Proctor (1933) believed that the moisture in a relatively dry soil, created capillary effects, which held particles together resulting in high frictional resistance.

- Hogentolger (1936) considered that the shape of the compaction curve reflects four stages of the swelling soils hydration, lubrication, swelling and saturation.
- Hilf (1956) used the theory of pore water pressure in unsaturated soils to explain the process of compaction and importance of it in construction of embankment.
- McRae (1958) studied the effect of the compaction effort on Maximum dry density. He developed compaction index, which can be used to correlate the compaction requirements in different soils.
- Gilbert Justice(1968), Lang Felder(1970) and Chan(1990) reported that for montmorillonite soils at about OMC, the air void in compacted cohesive soils are no longer inter connected and air permeability is zero.
- Benson & Trast (1995) reported the estimation of water content. Gens (1996) gave a conclusion that the compaction procedure such as compaction water content and the compactive effort are known to have a significant influence on the subsequent mechanical behavior of compacted cohesive soils.
- Prashanth et al (1998) studied the compaction on volume basis. Beson & Manoj (1997), Lisa R Blotz et al (1998), T.S.Najaraj & N.S.Pandian (2000) highlighted about re-examination of OMC & MDD of fine-grained soils.
- Sridharan & H B Nagaraj (2005) gave the relationship and modifications of standard proctor and modified proctor.
- Shivakumar & Wheeler (2000) reported that change in OMC produces radical effect on soil behavior. Gurtug & Sridharan (2004) studied the compaction behavior & characteristics of fine-grained soils with reference to compaction energy. They reported that index properties namely Plastic limit, liquid limit & shrinkage limit can be related to the compaction characteristics of the fine-grained soils. The various studies done are as listed below.
- Sridharan & H.B.Nagaraj (2000) concluded that the shrinkage index (liquid limit-shrinkage limit) correlates better with the compaction characteristics than plasticity index or the liquid limit of soils.
- Gurtug&Sridharan (2004) gave correlations for the plastic limit and the different methods of Proctor tests namely, Standard Proctor (SP), Reduced Standard Proctor (RSP), Modified Proctor (MP) and Reduced Modified Proctor (RMP). The equations proposed where of the form OMC=k1Wpwhere k1values are 1, 0.92, 0.7 and 0.7 for RSP, SP, RMP, MP respectively.
- The study of Sridharan & H.B.Nagaraj (2005) shows that liquid limit or plasticity index don't correlate well with the compaction characteristics. However, the plastic limit correlates well with the OMC and MDD. The correlation proposed is OMC= 0.92Wp, MDD=0.23(93.3-Wp). However, the relationship between index properties of fine-grained soils with compaction characteristics for soils having different clay mineralogy and energy levels are very scanty.

3. MATERIALS

For the present experimental study, six field soils were selected from Mysore District based on their index properties. An index property tests were conducted to these six soils and compaction tests for varying energy level is conducted for soils passing 425µm sieves.

4. METHODOLOGY

In order to understand the soil characteristics, the following physical tests were conducted on the soil samples as per Bureau of Indian Standards (BSI) specifications.

1. Specific gravity test [IS: 2720 (Part-3 sec-1)-1980]
2. Sedimentation analysis [IS: 3104-1965]
3. Atterberg limits [IS: 2720 (Part-5)-1985]
4. Compaction tests
   a. Reduced Standard Proctor test (RSP)
   b. Standard Proctor test (SP) [IS:2720 (Part-7)-1974]
   c. Reduced Modified Proctor test (RMP)
   d. Modified Proctor test (MP) [IS:2720(Part-8)-1980/1987]

5. RESULTS AND DISCUSSIONS

Six soil samples are collected from different locations in Karnataka for the study. These soils were wet sieved through 425 µm IS Sieve to remove the coarser fraction. They were then oven dried and powdered to have soil fractions finer than 425 µm size. The resulting soils were stored in separate plastic bins.

Laboratory investigations are carried out on the samples to determine Index properties, and Compaction characteristics. Compaction characteristics of the soils passing 425µm are determined from different energy levels.

The index properties and compaction characteristics of the soils established from the laboratory tests are presented in Table-1 and Table-2.

Table 1: Index Properties of Fine-Grained Soils

Soils	Specific Gravity	Free Swell Ratio (FSR)	Free Swell Index (FSI) (%)	Degree Of Expansion	Atterberg's Limit			Grain Size Distribution		
					Liquid Limit (%)	Plastic Limit (%)	Shrinkage Limit (%)	Fine Sand (%)	Silt (%)	Clay (%)
1	2.64	1.2	20.0	Low	30.3	14.3	12.6	73.5	16.5	10
2	2.75	1.19	19.0	Low	29.7	14.6	12.1	66.8	15.4	17.8
3	2.77	1.08	8.3	Low	26.3	13.4	12.5	75	16	9
4	2.67	1.13	13.0	Low	24.7	12.2	11.9	76.2	15.9	7.9
5	2.68	1.27	27.3	Low	33.1	19	15.4	78	13.5	8.5
6	2.7	1.14	14.3	Low	29.7	13.5	9.8	76	14	10

Table 2: Proctor Compaction Results

Soils	RSP		SP		RMP		MP	
	OMC (%)	MDD (kN/m^3)	OMC (%)	MDD (kN/m^3)	OMC (%)	MDD (kN/m^3)	OMC (%)	MDD (kN/m^3)
1	14.5	16	13	17.25	11.5	18.5	11	19.15
2	17.5	15.15	16	16.4	14.5	17.5	13.5	18.6
3	13.2	17.55	11.5	18.4	11	19.2	10.2	20.32
4	12.5	17.2	11.6	18.3	11	19.3	9.5	19.6
5	16.8	16.7	16	17.4	14.7	18	13.9	19.1
6	14.5	17.23	13.3	17.5	13.8	17.9	12.9	18.97

Table 3 shows the magnitude of compaction energy for levels, carried for the experimental work.

Table 3 Magnitude of Compaction Energy Levels

Sl. No.	Compaction Energy	
	Designation	Magnitude (kJ/m3)
1	Reduced Standard Proctor	355.5
2	Standard Proctor	592.5
3	Reduced Modified Proctor	1616
4	Modified Proctor	2693.3

From Figure 1 to 6 shows the compaction curve for varying energy levels with zero air void line for all soils.

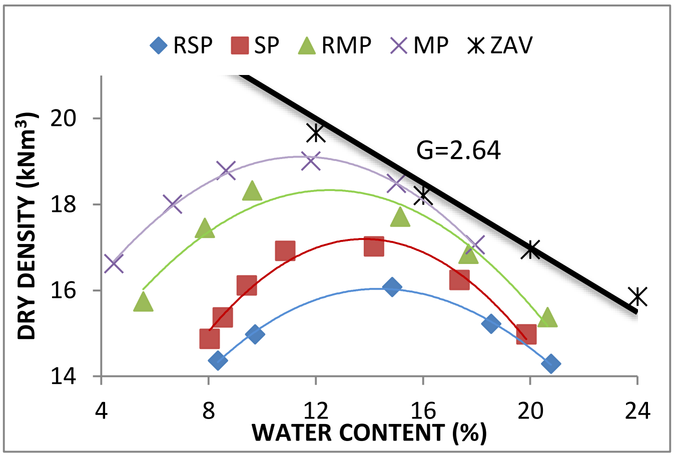

Fig 1 Compaction Curves for Soil-1

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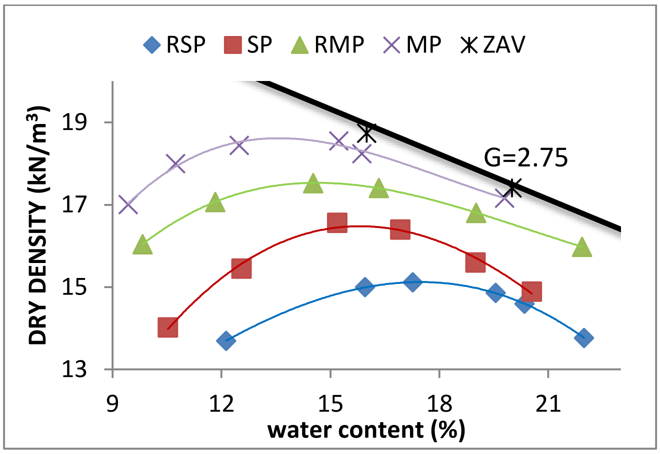

Fig 2 Compaction Curves for Soil-2

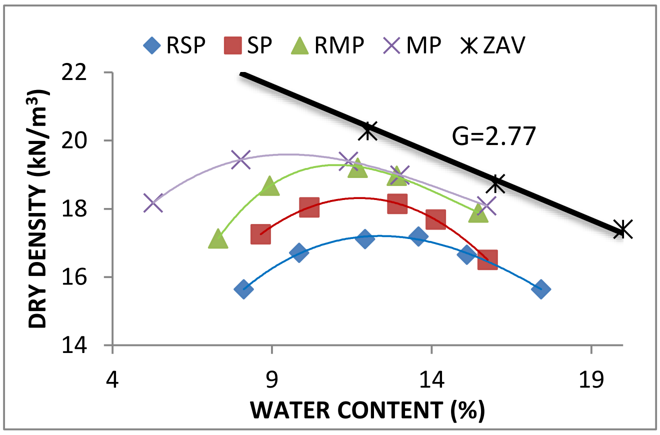

Fig 3 Compaction Curves for Soil-3

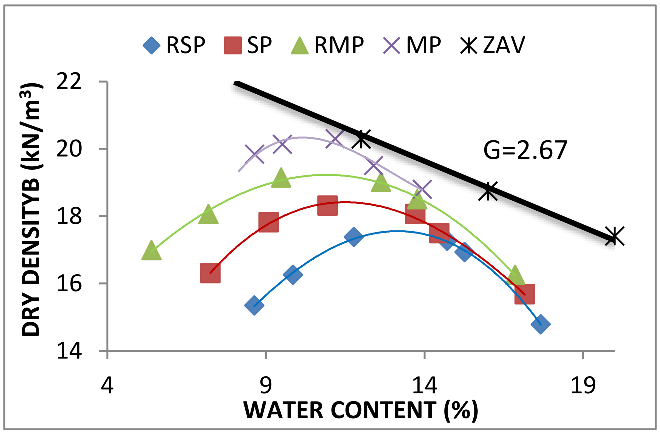

Fig 4 Compaction Curves for Soil-4

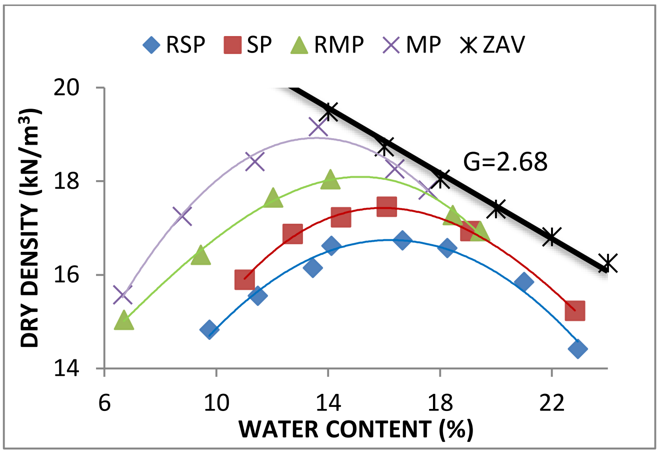

Fig 5 Compaction Curves for Soil-5

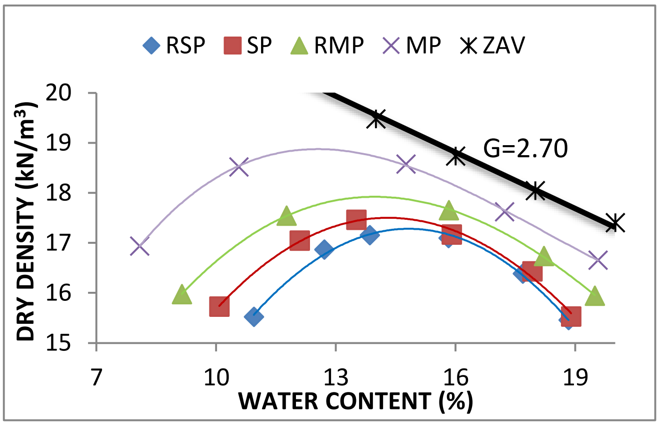

Fig 6 Compaction Curves for Soil-6

From Table-1 it can be observed that, for soil 1 and 2 even though the FSR of the soil is same, shrinkage limit of the soils are different and the same trend is observed for soil 4 and 6. For soil 3 and 6, which is having FSR 1.08 to 1.27, shrinkage limit of the soils varies from 12.5 to 15.4. Even though the percentage of fines in the range of 22% to 25%.

Figure 7 shows the variation of liquid limit (LL), plastic limit (PL) and shrinkage limit (SL) with percentage fines

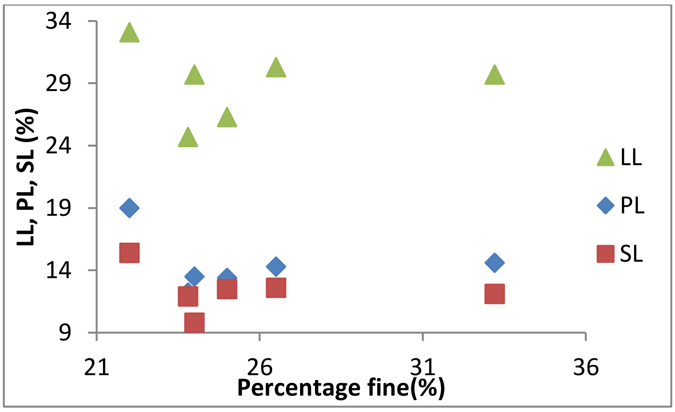

Fig 7 Variations of Attereberg limits with Percentage Fines

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From the Figure 7 it can be observed that, variation of liquid limit with percentage fines shows higher degree of scatter in relative comparison to plastic limit and shrinkage limit of the soil.

The shrinkage limit of a natural soil has been shown to be primarily a result of packing phenomena, which in turn governed by the grain-size distribution of the soil rather than the plasticity characteristics. Even though clay-size plays an important role in the shrinkage phenomena, there is a optimum clay content at which shrinkage limit of a soil can become minimum.

Soils having almost same liquid limit i.e. group 1 (soil 1, 2 and 6) and group 2 (soil 3, 4) have different shrinkage limit. Hence it can be observed that, shrinkage limit need not be considered as plasticity characteristics of a soil. (Sridharan and Prakash 1998). Hence, while correlating the compaction characteristics with index properties of soil, shrinkage limit of soil has not been considered.

The equations were developed for MDD and OMC for soils passing 425µm IS sieve, using Liquid Limit and Plastic Limit with the help of Multiple Linear Regression Analysis. Table 4 shows the MLRA equations for varying energy levels

Table-4 Equations for OMC and MDD of soils passing 425mm IS sieve for varying energy levels

	COPACTION ENERGY LEVELS	EQUATIONS	R^2	R
OMC	RSP	OMC = 0.464×(LL)+0.096×(PL)	0.994	0.997
	SP	OMC = 0.335×(LL)+0.267×(PL)	0.994	0.997
	RMP	OMC = 0.418×(LL)+0.044×(PL)	0.994	0.997
	MP	OMC = 0.371×(LL)+0.076×(PL)	0.994	0.997
MDD	RSP	MDD = 0.800×(LL)-0.461×(PL)	0.986	0.993
	SP	MDD = 0.848×(LL)-0.496×(PL)	0.986	0.993
	RMP	MDD = 0.916×(LL)-0.573×(PL)	0.986	0.993
	MP	MDD = 0.928×(LL)-0.536×(PL)	0.988	0.994

From Table-4, it is clearly observed that, MLRA equations were well correlated with liquid limit and plastic limit with regression coefficient ranging from 0.993 to 0.997.

Table 5 and 6 shows the predicted values of OMC and MDD respectively for varying energy levels using equations presented in Table-4

Table-5 Predicted OMC (%) for varying energy levels

Soils	**RSP**	**SP**	**RMP**	**MP**
1	15.43	13.97	13.29	12.33
2	15.18	13.85	13.06	12.13
3	13.49	12.39	11.58	10.78
4	12.63	11.53	10.86	10.09
5	17.18	16.16	14.67	13.72
6	15.08	13.55	13.01	12.04

Table-6 Predicted values of MDD (kN/m^3) for varying energy levels

Soils	RSP	SP	RMP	MP
1	17.65	18.60	19.56	20.45
2	17.03	17.94	18.84	19.74
3	14.86	15.66	16.41	17.22
4	14.14	14.89	15.63	16.38
5	17.72	18.64	19.43	20.53
6	17.54	18.49	19.47	20.33

Figure 8 to 11 shows the variations of OMC of predicted values with laboratory values.

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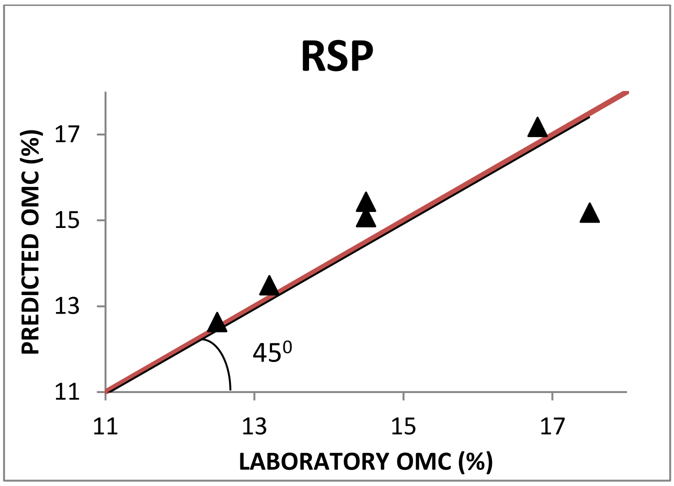

Fig. 8 Variations of Predicted and Laboratory values of OMC (RSP)

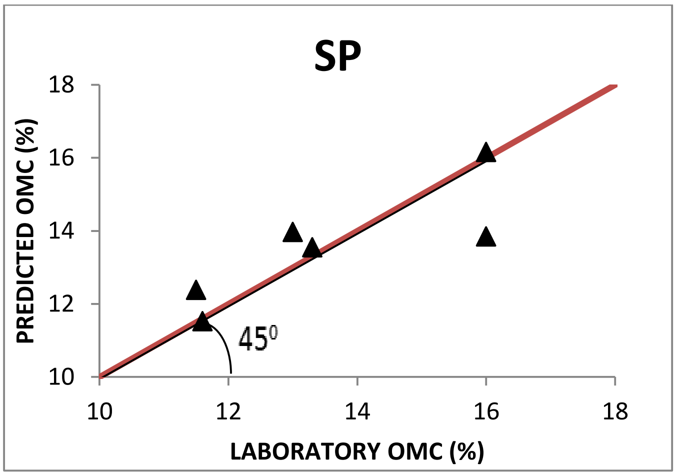

Fig. 9 Variations of Predicted and Laboratory values of OMC (SP)

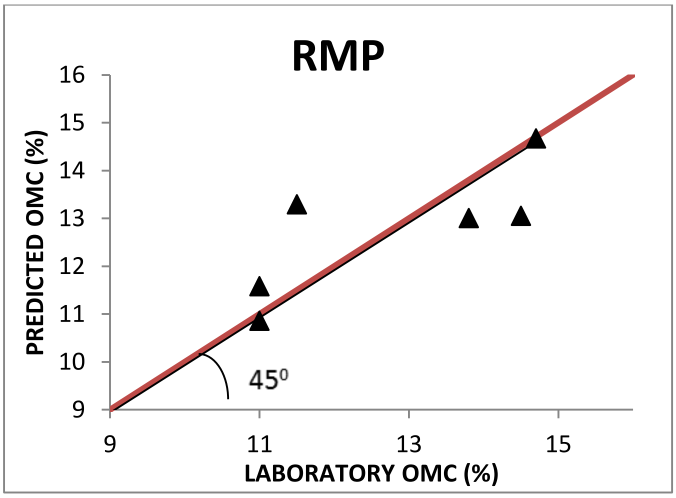

Fig. 10 Variations of Predicted and Laboratory values of OMC (RMP)

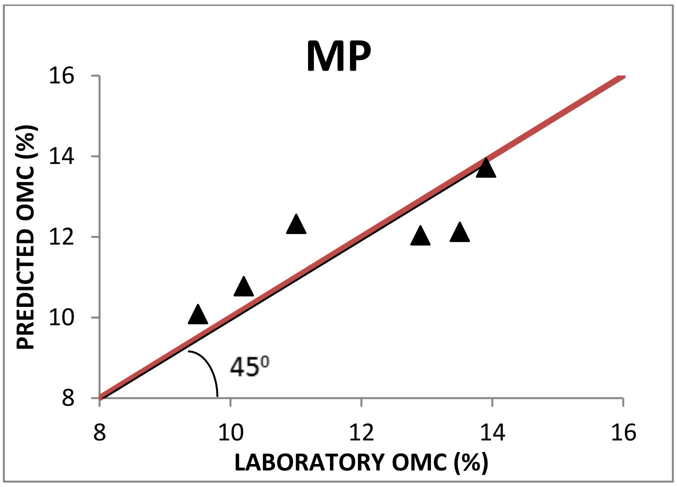

Fig. 11 Variations of Predicted and Laboratory values of OMC (MP)

Figure 12 to 15 shows the variations of MDD of predicted values with laboratory values.

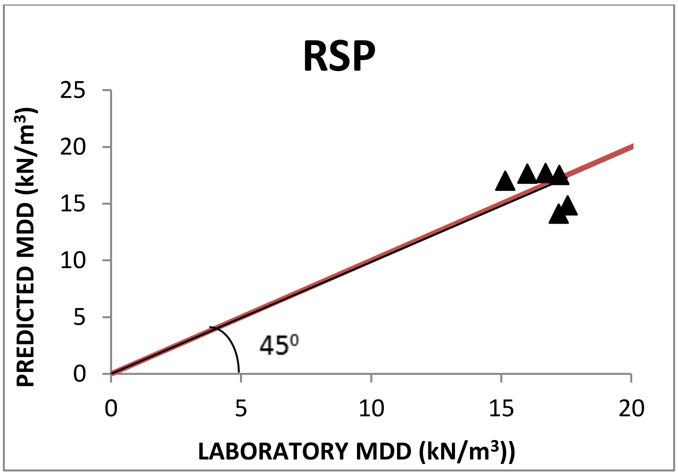

Fig. 12 Variations of Predicted and Laboratory values of MDD (RSP)

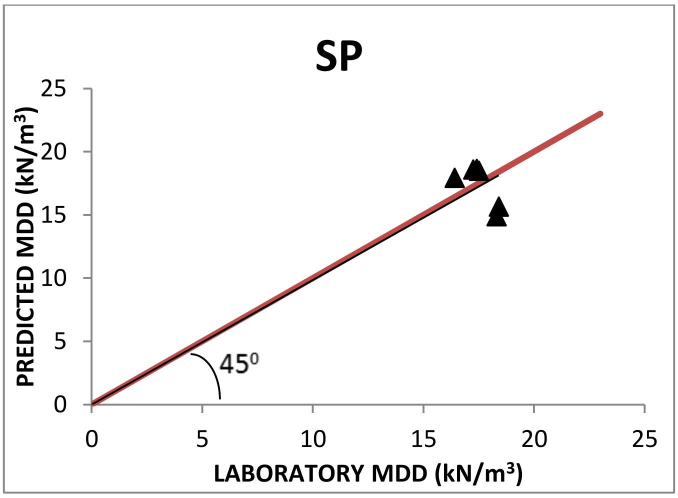

Fig. 13 Variations of Predicted and Laboratory values of MDD (SP)

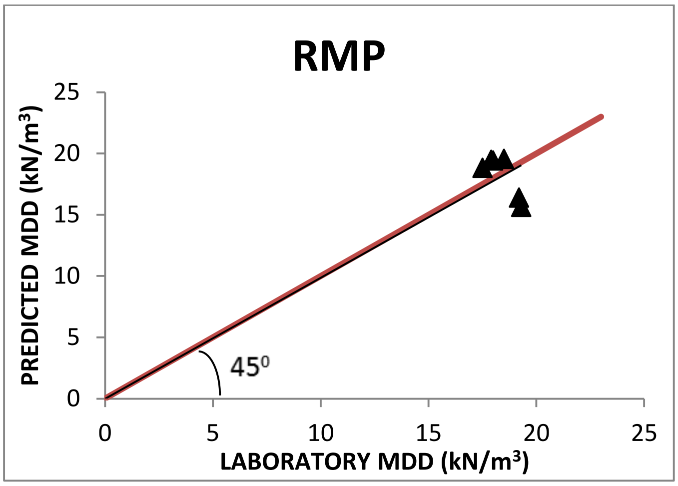

Fig. 14 Variations of Predicted and Laboratory values of MDD (RMP)

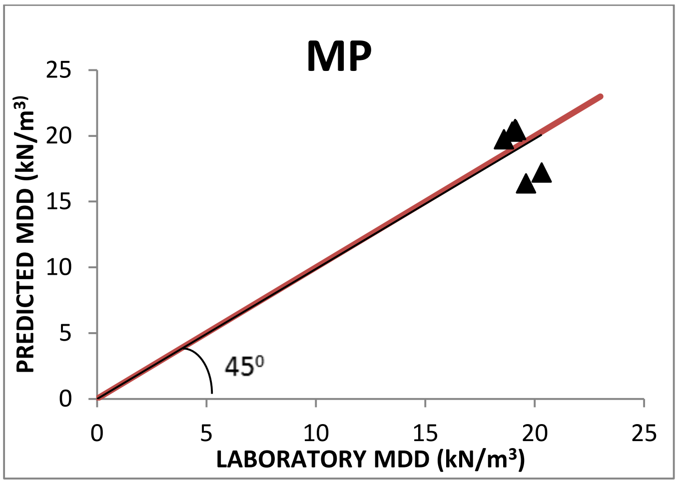

Fig. 15 Variations of Predicted and Laboratory values of MDD (MP)

From Figure 8 to 15, it is clearly observed that predicted compaction characteristics correlates well with the laboratory values. It can be concluded that, the equations proposed by the authors can be adopted for the determination OMC and MDD for all energy levels for a soil having percentage fine ranging from 22% to 33.2% and liquid limit ranging from 24.7% to 33.1%

6. CONCLUSIONS

Based on the analysis of data obtained from laboratory soil testing and correlation between compaction characteristics for varying energy levels with index properties for fine-grained soils, following conclusions were made:

- Soils used for the present study are having low degree of expansion.
- Even though soils are having almost same liquid limit, shrinkage limits will be different.
- The compaction characteristics can be correlated by liquid limit and plastic limit for fine-grained soils.
- The study highlights that there is a need for careful determination of Atterberg Limits of soils which can be effectively correlated with compaction characteristics for various energy levels.
- From multiple linear regression analysis, it can be observed that good regression coefficient values are obtained when compaction characteristics are correlated with index properties of fine-grained soils.
- The correlation equations in terms of index properties, values developed from regression analysis yielded coefficients of R value varies from 0.993 to 0.997 and hence implies that they are significant factors predicting OMC and MDD of fine-grained soils for different compaction energy levels.
- Compaction characteristics can be effectively predicted using Atterberg limits of soils, thus saving materials, time and money.

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