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Compaction Behavior of China Clay-Sand Mixtures

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Abstract - *Various energy levels is an important process. The aim of this study is to develop correlations in order to estimate the compaction parameters dependent on the compaction energy for soil mixtures with various fine contents. Linear regression analysis are used in the derivation of the correlations for the prediction of maximum dry density(γd.max) and optimum moisture content(OMC) obtained from standard, reduced standard, modified and reduced modified proctor compaction tests with the index properties of mixtures. The proposed correlations are reasonable ways to estimate the compaction parameters for a soil, which is to be used for field applications. These correlations minimize field efforts to determine the properties of soil which can be attributed to both savings in time and cost in a construction project*

Key Words: OMC – Optimum Moisture Content, MDD - Maximum Dry Density, RSP – Reduced Standard Proctor Test, SP – Standard Proctor Test, RMP – Reduced Modified Proctor Test, MP – Modified Proctor Test.

1. INTRODUCTION

Nearly all soils are mixtures containing coarse and fine particles whose behaviour under mechanical, thermal and hydraulic loading is strongly influenced by the ratio of fine to coarse particles. Thorough understanding of physical changes in the behaviour of coarse fraction can be robustly predicted, whereas the changes in fine fraction of soil mixtures are purely physico-chemical phenomenon. Due to the presence of active and inert clay fractions in fine-grained soils, the prediction of behaviour of fine-grained soil gets complicated. It is also observed from the documented geotechnical engineering literature that most of the studies related to fine-grained soils are region specific.

Hence it is not possible to obtain a unique engineering solutions related to such soils. Further, it is observed from author's publications that, the role of clay minerals in fine-grained soils/fraction play dominant role in predicting the characteristics of fine-grained soils. The fine-grained soils can be classified into kaolinitic soils (k-soils), montmorillonitic soils (m-soils), kaolinitic -montmorillonitic soils (k-m soils), and illitic soils based on predominant clay minerals present in the soils. Generally in kaolinite soils are less expansive and flocculent in nature (A-force domination), whereas montmorillonitic soils are repulsive in nature (R-force domination). In case of kaolinitic-montmorillonitic soils (K-M soils) both A-force and R-forces present may get neutralized because of the combined effect. In order to understand the behaviour of kaolinitic soils where predominant clay mineral is kaolinite, the present experimental study is thought of which serves as a pivotal reference in study of kaolinitic soils.

Compaction of soil by mechanical means is a common soil modification method to improve the engineering properties of soils. The effectiveness of the compaction is usually measured by soil's moisture content and dry density in reference to maximum dry density (MDD) and optimum moisture content (OMC). Compaction being a soil modification technique is employed in highway projects, railway subgrades, airfield pavements, earth dams and landfill liners. During construction, to achieve the necessary degree of compaction (required MDD&OMC), soils are usually compacted using plate compactors, Pneumatic rollers, double drum rollers as well as sheep foot rollers based on the nature of soil being compacted. In laboratory, soil compaction is usually performed with the Proctor compaction apparatus. The Proctor compaction tests provide a standard method for a standard amount of compaction energy.

The most important parameters obtained from the compaction curve are the maximum dry unit weight (γd.max) and the optimum water content (OMC), representing the compaction behaviour. The behaviour of the compacted soils depends on the dry unit weight, the water content, the compaction energy level, the soil type and their gradation.

Indirect correlative approaches are necessary for estimating the engineering properties of soils, particularly for a project where there is a limited time frame, lack of test equipment or financial limitations. In case of inadequate data availability, the correlations serve as a guideline to determine the engineering properties of kaolinite-sand mixtures. However, available correlations in published literature lack the suitability for direct application to the field data and may lead to erroneous conclusions.

While proposing correlations relating to compaction characteristics with index properties of the soil, Uncertainties like type of soil, clay mineralogy, and geological formations has to be considered very effectively. Therefore, the correlation equations with compaction parameters should be used cautiously by taking these uncertainties into consideration.

2. Literature Review

Compaction characteristics of fine grained soils were studied by investigators and have proposed correlations for OMC and γd max, which are briefly discussed below

Sridharan & Nagaraj (2000) concluded that the shrinkage index (liquid limit-shrinkage limit) correlates better with the compaction characteristics than plasticity index and liquid limit of soils.

Gurtug and Shridharan (2004) have obtained the compaction behaviour and prediction of the characteristics of fine grained soils from simple index test with reference to variation in compaction energy levels. The optimum water content which decreases with the compacting energy has a good correlation with the plastic limit for all energy levels. The correlation for optimum moisture content is ”OMC = k1wp“.The k1 values obtained are 1.0, 0.92, 0.70 and 0.7 for RP, SP, RMP and MP energy levels respectively. The maximum dry unit weight, γd max = k2γd wp. The k2 values are 0.94, 0.98, 1.1 and 1.07 for RP, SP, RMP and MP respectively.

Sridharan & Nagaraj (2005) shown 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 of the soil. The correlation proposed “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.

Sivrikaya, et.al (2013), have studied on prediction of compaction parameters for coarse-grained soils with fines content of more than 5% W_{opt} has much better correlation with WL than WP, and γd max can be estimated more precisely from W_{opt} instead of properties of soils.

3. MATERIALS AND METHODOLOGY

Commercially available clay minerals (Pure china clay) is procured from Bangalore and stored in plastic bins. River sand obtained was wet washed to remove inorganic fraction and oven dried for 24 hours at 110oC to remove organic content. The oven dried sample was sieved through 425μm is sieve to have fine-sand fraction and stored in plastic bins. Laboratory air cooled samples were prepared by mixing natural sand with china clay in different proportions as specified below

- 100% china clay (100C)
- 10% sand + 90% china clay (10S + 90C)
- 20% sand + 80% china clay (20S + 80C)
- 30% sand + 70% china clay (30S + 70C)
- 40% sand + 60% china clay (40S + 60C)
- 50% sand + 50% china clay (50S + 50C)
- 60%sand + 40% china clay (60S + 40C)
- 70%sand + 30% china clay (70S + 30C)
- 80%sand + 20% china clay (80S + 20C)
- 90%sand + 10% china clay (90S + 10C)

The following laboratory tests were conducted on the prepared mix proportions:

1. Specific gravity (ASTM D 854 & IS: 2720, Part 3) – to determine the value of Specific gravity (G).

2. Grain size analysis (ASTM D 6913 & IS: 2720, Part 4) – to determine the percentage of various sizes of particles in a natural soil.

3. Atterberg limits - to find out the index properties like liquid limit, plastic limit and plasticity index (ASTM D 4318 & IS: 2720 Part 5) and shrinkage limit (ASTM D 4943 & IS: 2720 Part 6).

4. Compaction tests:Standard Proctor (ASTM D 698 & IS: 2720, Part 8), Modified Proctor (ASTM D 1557 & IS: 2720, Part 8) Reduced Standard Proctor (ASTM D 698 & IS: 2720, Part 8) and Reduced Modified Proctor (ASTM D 1557 & IS: 2720 Part 8) were conducted on all kaolinite-sand mixtures under study. For each of these tests, six samples, each of mass 2.5kg, were mixed with different moulding water contents thoroughly and were kept separately inside polythene covers for moisture equilibration for periods ranging from 5 to 7 days (maturation time). After this equilibration period, compaction tests were conducted on this soil samples. From the compaction curves, the values of optimum moisture content and maximum dry density for all the soils under study were determined.

Table 1: shows the Physical properties of kaolinite - sand mixtures.

Table 1

Sample	Sp.Gr	L.L (%)	P.L (%)	P.I	S.L (%)	S.I
100C	2.74	65	29	36	18	47
90C+10S	2.72	63	28	35	20.1	42.9
80c+20S	2.7	57	26.3	30.7	21	36
70C+30S	2.67	53	25	28	21.2	31.8
60C+40S	2.65	50.5	24.5	26	21.9	28.6
50C+50S	2.63	43	22.3	20.7	22	21
60C+40S	2.61	38.5	19.5	19	22.5	16
70C+30S	2.59	37	19	18	22.2	14.8
80C+20S	2.55	NP	-	NP	-	-
90C+10S	2.52	NP	-	NP	-	-

Table 2: Magnitude of compaction energy levels imparted to kaolinite-sand mixtures

Table 2

Sl no	Compaction Energy	
	Designation	Magnitude (Kj/m^3)
1	Reduced Standard Proctor - RSP	355.5
2	Standard Proctor - SP	592.5
3	Reduced Modified Proctor - RMP	1616
4	Modified Proctor - MP	2693.3

Table 3: Compaction characteristics of kaolinite-sand mixture for different energy levels

Table 3

Test	R.S.P		S.P		R.M.P		M.P	
Sample	O.M.C (%)	γd Max. (kN/m³)	O.M.C (%)	γd Max. (kN/m³)	O.M.C (%)	γd Max. (kN/m³)	O.M.C (%)	γd Max. (kN/m³)
100C	32.1	12.65	30.3	13.54	27.7	14.38	25	15.22
90C+10S	25.3	15.03	27.5	14.24	24	15.9	21.5	16.56
80c+20S	21.5	15.8	20.5	16.43	17.8	20.4	17.8	18.05
70C+30S	18.9	16.94	18.2	17.8	16	18.19	14	18.71
60C+40S	15.6	17.9	15.3	18.43	13.4	18.6	12.4	19.04
50C+50S	14.4	18.04	14	18.46	11.5	19.53	10.7	19.88
60C+40S	11.4	19.43	10	19.8	8.3	20.55	8.3	20.86
70C+30S	10.9	19.07	11.5	19.45	9	19.6	8.8	20.3
80C+20S	11.2	18.7	10.8	18.9	9.3	19.25	9.5	19.47
90C+10S	11.5	18.1	11.3	18.41	9.7	18.63	9.3	18.82

Figures 1a through 1c shows the variation of Liquid limit, Plastic Limit and Shrinkage limit of the soil with respect to the percentage of sand content in the soil sample being tested. The results show that, as the sand content in the soil mixture increases the liquid limit as well as the plastic limit of the mixture tends to decrease, however the shrinkage limit increases with the increase in sand content which can be inferred as the soils having higher sand content tend to have higher volumetric changes.

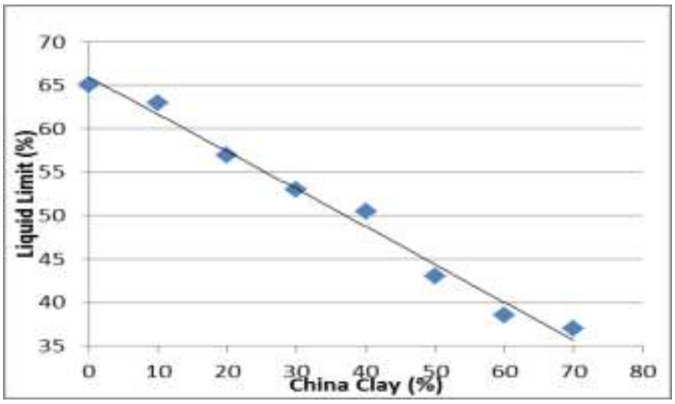

Fig.1 (a): Variation of Liquid Limit v/s China clay (%)

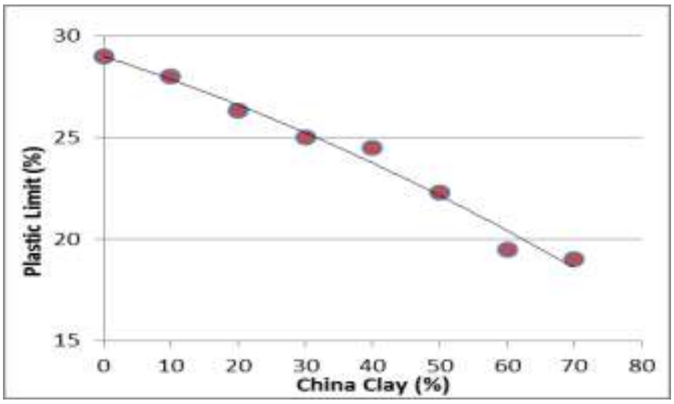

Fig.1 (b): Variation of Plastic Limit v/s China clay (%)

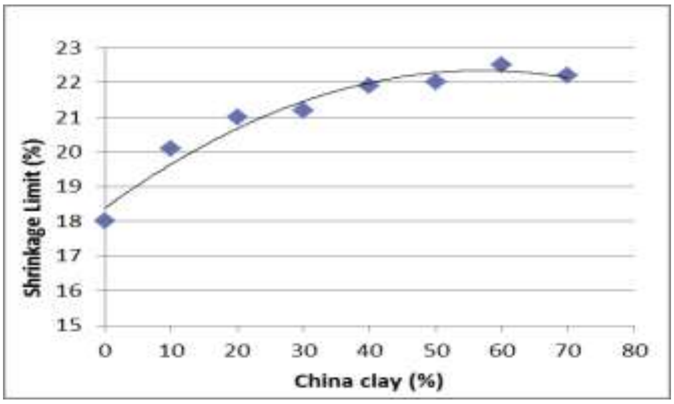

Fig.1 (c): Variation of Shrinkage Limit v/s China clay (%)

Table 4: Shows the corelation between china clay (%) and Atterberg limits.

Table 4

Sl no.	Relation	R
1	Liquid Limit = $-0.0001(\text{China Clay }\%)^2 - 0.4238(\text{China Clay }\%) + 65.917$	0.984
2	Plastic Limit = $-0.0006(\text{China Clay }\%)^2 - 0.108(\text{China Clay }\%) + 29$	0.981
3	Shrinkage Limit = $-0.0012(\text{China Clay }\%)^2 + 0.1391(\text{China Clay }\%) + 18.379$	0.958

The results show that as the sand content in the soil increases, the liquid limit as well as the plastic limit of the soil tends to decrease. However the shrinkage limit increases with the increase in sand content which can be inferred as the soils having higher sand content tend to have higher volumetric changes.

Figures 2a through 2d shows the variation of OMC with percentage china clay for different energy levels and combined energy levels respectively. There is a tendency of increase in OMC (by 2.79 times across the plots of Shrinkage limit v/s percent china clay) with increase in percentage of china clay which can be attributed to the fact that the percentage fines in the mixture enhances the water retention capacity hence the

OMC. This tendency is more prominent in RSP in relative comparison to MP energy level.

From Fig.2 (a) through 2(d), it is evident that the OMC increases hence it can be inferred that OMC is directly proportional to the percentage fines in the mix.

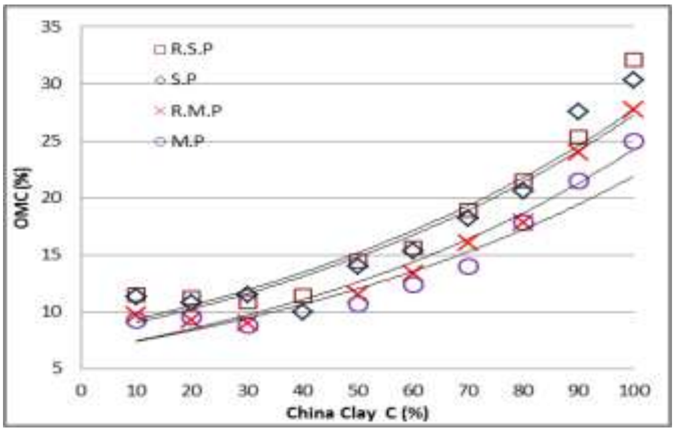

Fig.2(a): Variation of OMC v/s Fines with different mix proportions of China clay with Exponential Relationship.

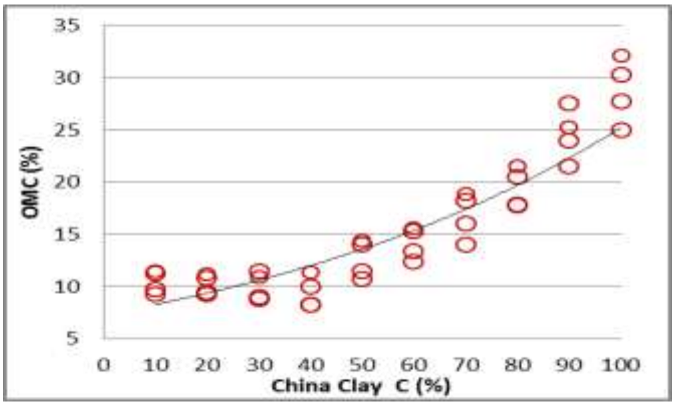

Fig.2(b): Variation of OMC v/s Fines with different mix proportions of China clay with Exponential Relationship.

Table 5: Shows the corelation between OMC and Percentage fines for all energy levels with corelation coeffecients.

Table 5

Sl no.	Exponential Relation	R
1	$OMC_{RSP} = 8.2951e^{0.0121*C}$	0.955
2	$OMC_{SP} = 8.0285e^{0.0122*C}$	0.939
3	$OMC_{RMP} = 6.5531e^{0.0131*C}$	0.933
4	$OMC_{MP} = 6.5844e^{0.012*C}$	0.928
5	$OMC_{Combined} = 7.3216e^{0.0124*C}$	0.907

*C : % China Clay

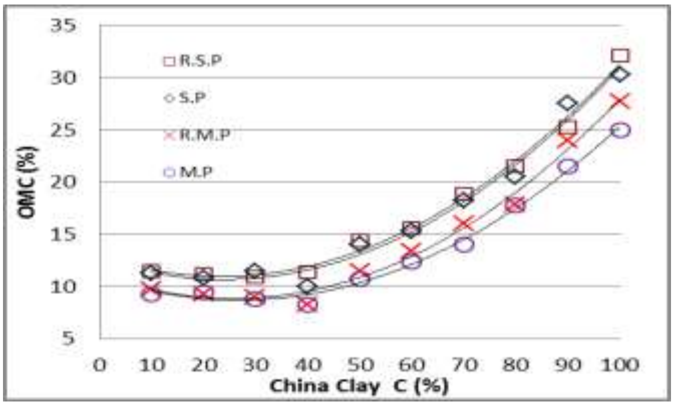

Fig.2(c): Variation of OMC v/s Fines with different mix proportions of China clay with Polynomial Relationship.

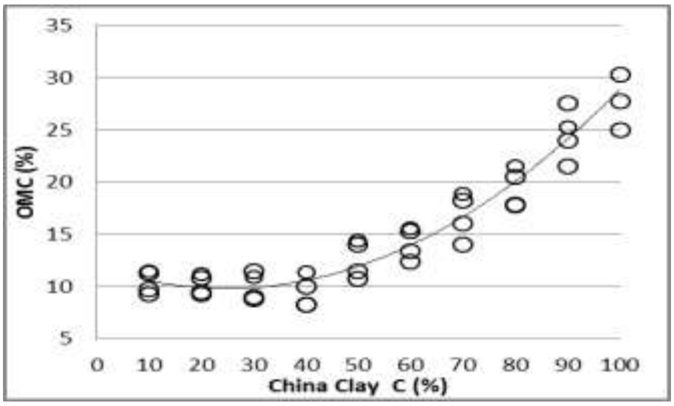

Fig.2 (d): Variation of OMC v/s Fines with different mix proportions of China clay – Combined Variation with Polynomial Relationship.

Table 6: Shows the corelation between OMC and percentage fines for all energy levels with corelation coeffecients.

Table 6

Sl no.	Polynomial Relation	R
1	$OMC_{RSP} = 0.0035 C^2 - 0.1618 C + 12.862$	0.992
2	$OMC_{SP} = 0.0035 C^2 - 0.1672 C + 12.673$	0.983
3	$OMC_{RMP} = 0.0035 C^2 - 0.1795 C + 11.177$	0.988
4	$OMC_{MP} = 0.0031 C^2 - 0.166 C + 10.918$	0.993
5	$OMC_{Combined} = 0.0034 C^2 - 0.1686 C + 11.907$	0.965

*C : % China Clay

Figures 3a and 3b present the variation of MDD with percentage china clay for different energy levels and combined energy levels respectively. From the above figures it can be observed that there is a tendency of increase in MDD values up to 40% china clay beyond which there is a tendency of decrease in the values of MDD which agrees well with the results reported in the literature (Sridharan et.al).

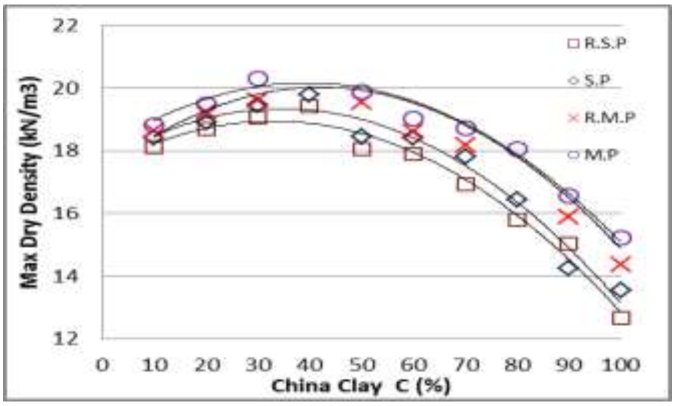

Fig.3 (a): Variation of MDD v/s Fines with different mix proportions of China clay with Polynomial Relationship.

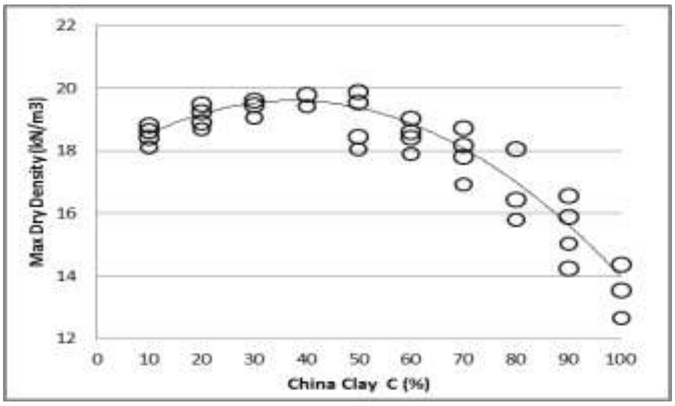

Fig.3 (b): Variation of MDD v/s Fines with different mix proportions of China clay – combined Variation with Polynomial Relationship.

Table 7: Shows the correlation between MDD and percentage fines for all energy levels

Table 7

Sl no.	Polynomial Relation	R
1	$MDD_{RSP} = -0.0014\ C^2 + 0.0893\ C + 17.474$	0.977
2	$MDD_{RMP} = -0.0014\ C^2 + 0.1003\ C + 17.61$	0.970
3	$MDD_{SP} = -0.0015\ C^2 + 0.1284\ C + 17.328$	0.737
4	$MDD_{MP} = -0.0014\ C^2 + 0.1086\ C + 18.031$	0.963
5	$MDD_{Combined} = -0.0014\ C^2 + 0.1066\ C + 17.611$	0.895

*C : % China Clay

From the above relations it can also be observed that the MDD decreases with the increase in percentage fines in the mix. MDD is inversely proportional to the percentage fines in the mix.

Figures 4a through 4d it can be observed that, the OMC of the sand – kaolinite mixture show an increasing tendency with the liquid limit irrespective of the energy levels. (Fig.4b). The equations in Table 8 and Table 9 along with their respective correlation coefficient gives an idea about the relation between liquid limit and OMC of the soil.

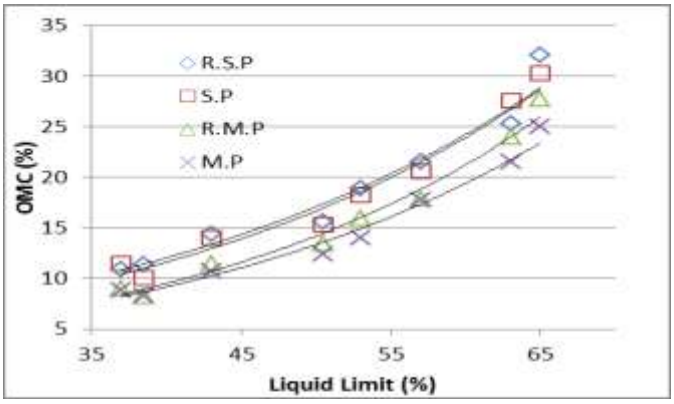

Fig.4 (a) Correlation of Liquid limit v/s OMC of the soil at varying energy levels with Exponential Relationship

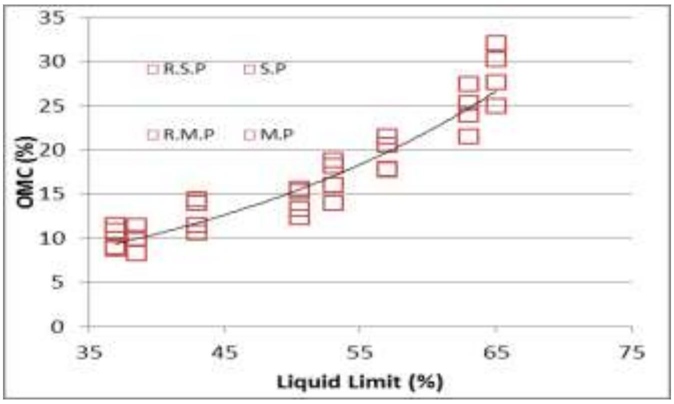

Fig.4 (b) Correlation of Liquid limit v/s OMC of the soil at varying energy levels- Combined variation with Exponential Relationship.

Table 8: Shows the correlation between OMC and Liquid Limit for all energy levels

Table 8

Sl no.	Exponential Relation	R
1	$OMC_{RSP} = 2.9587e^{0.0351*WL}$	0.984
2	$OMC_{SP} = 2.7224e^{0.0362*WL}$	0.980
3	$OMC_{RMP} = 1.8909e^{0.0403*WL}$	0.989
4	$OMC_{MP} = 2.0351e^{0.0376*WL}$	0.988
5	$OMC_{Combined} = 2.3596e^{0.0373*WL}$	0.902

Figures 4(c.) and 4(d) show the relation between OMC and Liquid limit of the soils with varying energy levels and combined energy levels.

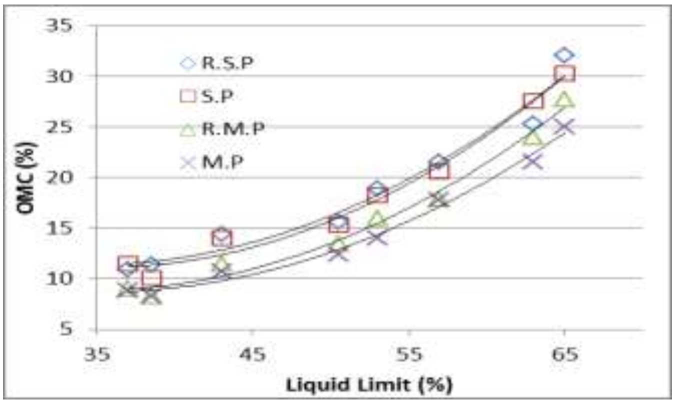

Fig.4 (c) Correlation of Liquid limit v/s OMC of the soil at varying energy levels with Polynomial Relationship.

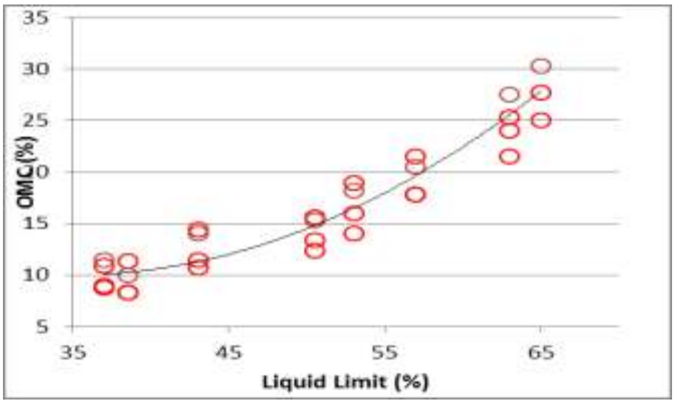

Fig.4 (d) Correlation of Liquid limit v/s OMC of the soil at varying energy levels. – Combined Variation with Polynomial Relationship.

Table 9: Shows the relation between OMC and Liquid Limit for all energy levels.

Table 9

Sl no.	Polynomial Relation	R
1	$OMC_{RSP} = 0.0199 *(WL)^2 – 1.3678* W_L + 34.81$	0.981
2	$OMC_{SP} = 0.0215 *(WL)^2 – 1.5237 *WL + 38.06$	0.992
3	$OMC_{RMP} = 0.0195 *(WL)^2 – 1.3515* WL + 32.22$	0.993
4	$OMC_{MP} = 0.0174 *(WL)^2 – 1.213* WL + 29.8$	0.994
5	$OMC_{Combined} = 0.0196*(WL)^2 – 1.364 *WL + 33.72$	0.915

From the above variations, (Fig.4 (a) through 4(d)), it is evident that the liquid limit and OMC of the soil are directly related. As the OMC of the soil increase the corresponding value of liquid limit increases linearly. If the liquid limit of the kaolinite – sand mixture (K-S Mixture) is known, OMC of the K-S Mixture can be reasonably estimated with a fair degree of accuracy.

Figures 5(a) through 5(d) shows the variation of MDD with Liquid limit of the K- S Mixtures. It can be noted that MDD of K-S Mixture increases up to a value of WL = 25% and then has a tendency to decrease irrespective of energy levels. This tendency is more prominent in MP energy level in relative comparison to other energy levels which is given by the relations in Table 10 and Table 11 with their respective regression coefficients.

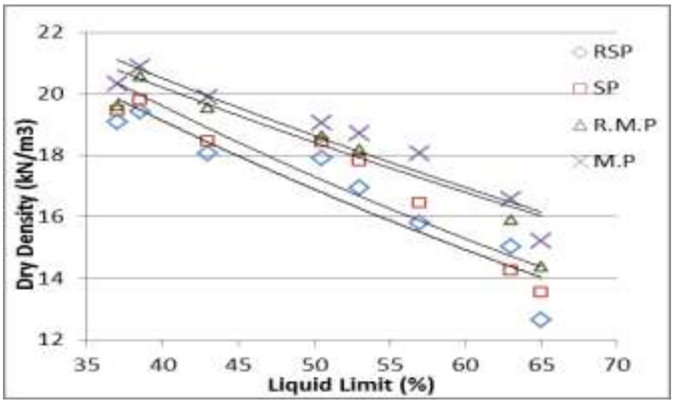

Fig.5 (a) Correlation of Liquid limit v/s MDD of the soil at varying energy levels. (Exponential Relationship)

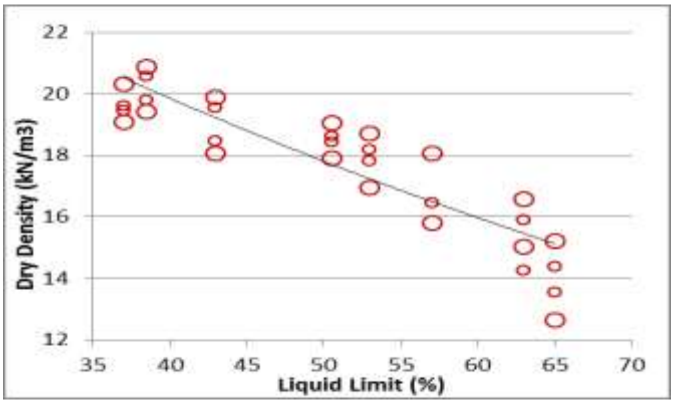

Fig.5 (b) Correlation of Liquid limit v/s MDD of the soil at varying energy levels – combined variation with Exponential Relationship.

Table 10: Shows the correlation between MDD and Liquid Limit for all energy levels.

Table 10

Sl no.	Exponential Relation	R
1	$MDD_{RSP} = 31.375e^{-0.012*WL}$	0.925
2	$MDD_{SP} = 32.244e^{-0.012*WL}$	0.936
3	$MDD_{RMP} = 29.242e^{-0.009*WL}$	0.778
4	$MDD_{MP} = 29.999e^{-0.01*WL}$	0.949
5	$MDD_{Combined}=30.693e^{-0.011*WL}$	0.842

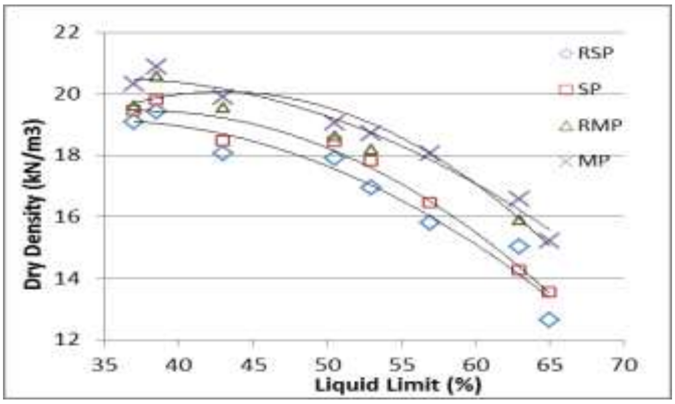

Fig.5 (c) Correlation ofLiquid limit v/s MDD of the soil at varying energy levels.(Polynomiall Relationship.

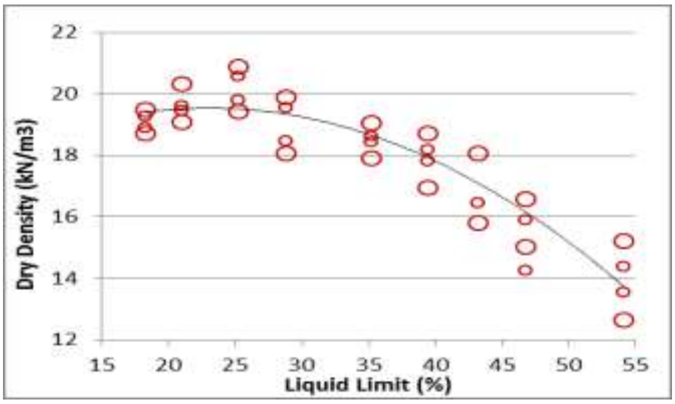

Fig.5 (d) Corelation of Liquid limit v/s MDD of the soil at varying energy levels – combined variation with Polynomial Relationship.

Table 11: Shows the corelation between MDD and Liquid Limit for all energy levels.

Table 11

Sl no.	Polynomial Relation	R
1	$MDD_{RSP} = -0.0062*(WL)^2 + 0.4289*WL + 11.722$	0.970
2	$MDD_{SP} = -0.008*(WL)^2 + 0.6009*WL + 8.0951$	0.989
3	$MDD_{RMP} = -0.0103*(WL)^2 + 0.8881*WL + 0.9743$	0.869
4	$MDD_{MP} = -0.0054*(WL)^2 + 0.3801*WL + 13.878$	0.988
5	$MDD_{Combined} = -0.0075*(WL)^2 + 0.5745*WL + 8.6672$	0.796

Figures 6(a) through 6(d) presents the variation of OMC with Plastic limit of soils for varying energy and combined energy levels with exponential and polynomial variations respectively. From these figures it can be concluded that plastic limit of K-S mixtures OMC can be reasonably predicted by with fair degree of accuracy which is given in Table 12 and Table 13 with their regression coefficients respectively.

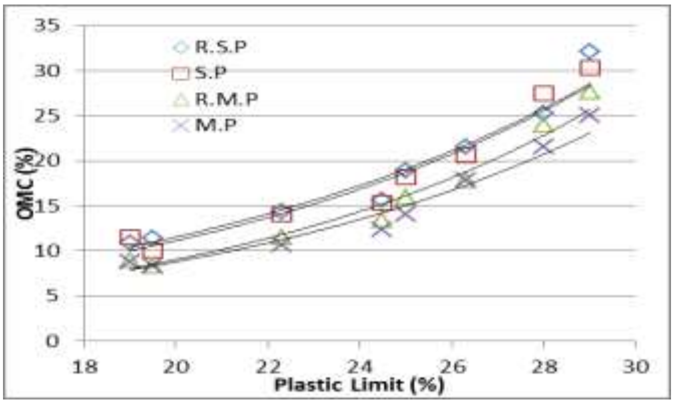

Fig.6 (a) Correlation of Plastic limit v/s OMC of the soil at varying energy levels (Exponential Relationship).

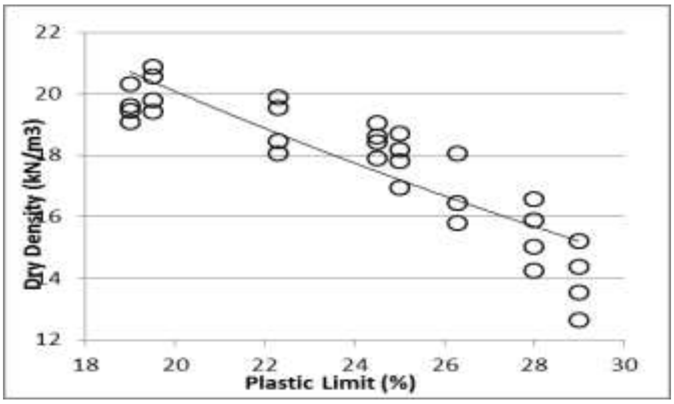

Fig.6 (b) Correlation of Plastic limit v/s OMC of the soil at varying energy levels – combined variation with Exponential Relationship.

Table 12: Shows the correlation between OMC and Plastic Limit for all energy levels

Table 12

Sl no.	Exponential Relation	R
1	$OMC_{RSP} = 1.5326e^{0.1009*PL}$	0.980
2	$OMC_{SP} = 1.3884e^{0.104**PL}$	0.974
3	$OMC_{RMP} = 0.8895e^{0.1159**PL}$	0.984
4	$OMC_{MP} = 1.0186e^{0.1076**PL}$	0.979
5	$OMC_{Combined} = 1.1783e^{0.1071**PL}$	0.8902

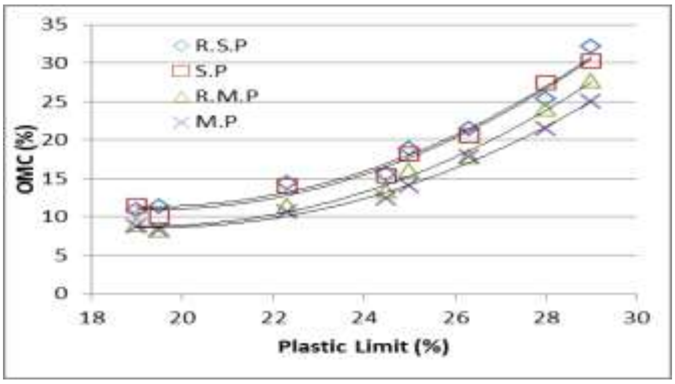

Fig.6 (c) Correlation of Plastic limit v/s OMC of the soil at varying energy levels (Polynomial Relationship)

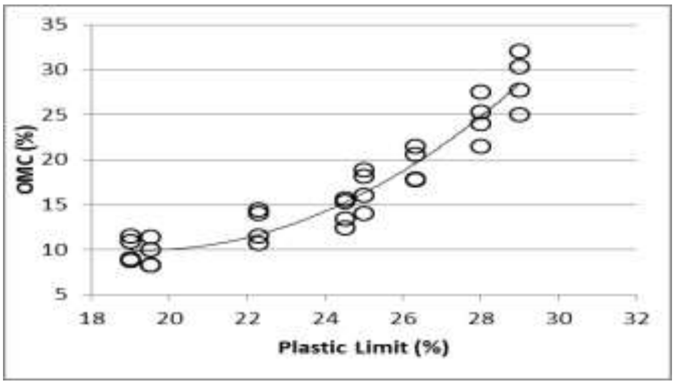

Fig.6 (d) Correlation of Plastic limit v/s OMC of the soil at varying energy levels – combined variation with Polynomial Relationship.

Table 13: Shows the correlation between OMC and Plastic Limit for all energy levels.

Table 13

Sl no	Polynomial Equations	R
1	$OMC_{RSP} = 0.2067*PL^{2} - 7.9777*PL + 88.305$	0.988
2	$OMC_{SP} = 0.2109*PL^{2} - 8.1618*PL + 89.936$	0.993
3	$OMC_{RMP} = 0.1932*PL^{2} - 7.6009*PL + 82.015$	0.996
4	$OMC_{MP} = 0.1778*PL^{2} - 6.9001*PL + 75.577$	0.997
5	$OMC_{Combined} = 0.198*PL^{2} - 7.6601*PL + 83.958$	0.921

Figures 7(a) through 7(d) presents the variation of MDD with Plastic limit of soils for varying energy and combined energy levels with exponential and polynomial variations respectively. It can be noted that MDD of K-S Mixture increases up to a value of WL = 20%and then decreases. From these figures it can be concluded that plastic limit and MDD of K-S mixtures correlates well with plastic limit of soils. Table 14 and Table 15 give their relation with regression coefficients respectively.

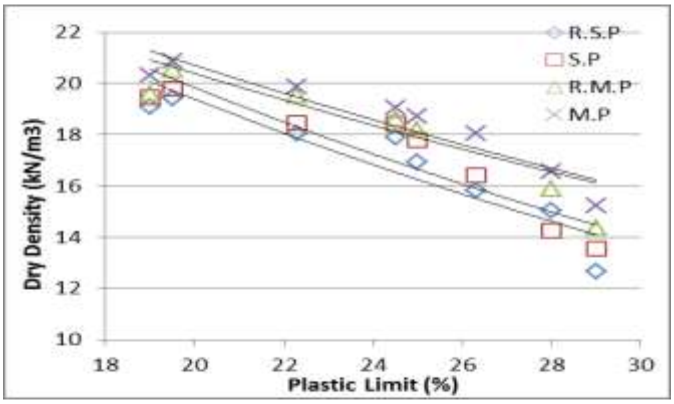

Fig.7 (a) Correlation of Plastic limit v/s MDD of the soil at varying energy levels. with Exponential Relationship.

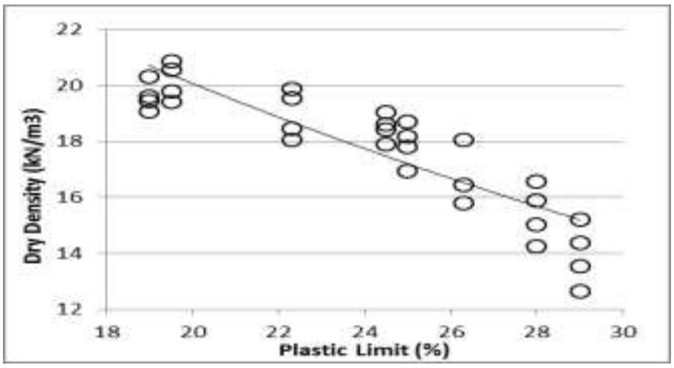

Fig.7 (b) Correlation of Plastic limit v/s MDD of the soil at varying energy levels – Combined Variation with Exponential Relationship.

Table 14: Shows the correlation between MDD and Plastic Limit for all energy levels.

Table 14

Sl no.	Exponential Relation	R
1	$MDD_{RSP} = 39.269e^{-0.035*PL}$	0.912
2	$MDD_{SP} = 20.958e^{-0.009*PL}$	0.571
3	$MDD_{RMP} = 20.847e^{-0.006*PL}$	0.430
4	$MDD_{MP} = 21.151e^{-0.006*PL}$	0.518
5	$MDD_{Combined} = 37.228e^{-0.031*PL}$	0.6814

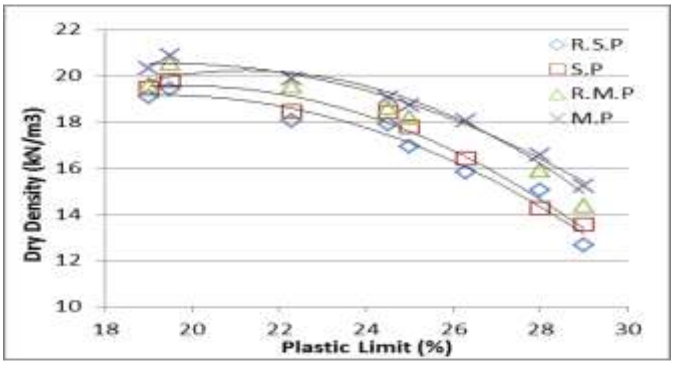

Fig.7(c) Correlation of Plastic limit v/s MDD of the soil at varying energy levels with Polynomial Relationship.

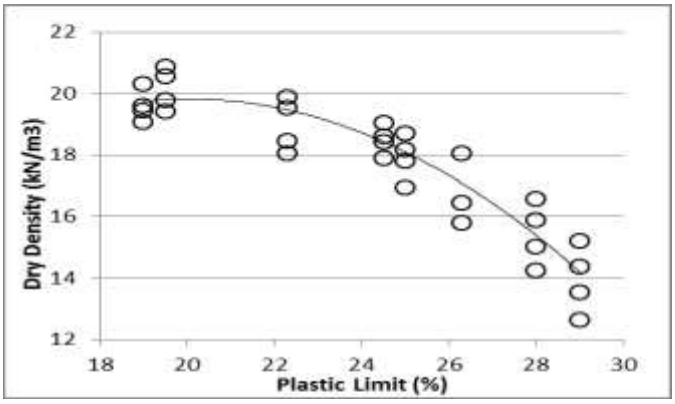

Fig.7 (d) Correlation of Plastic limit v/s MDD of the soil at varying energy levels – Combined variation with Polynomial Relationship.

Table 15: Shows the correlation between MDD and Plastic Limit for all energy levels

Table 15

Sl no.	Polynomial Relation	R
1	$MDD_{RSP} = -0.0138*PL^2 + 0.425*PL + 15.655$	0.977
2	$MDD_{SP} = -0.0166*PL^2 + 0.5637*PL + 14.502$	0.988
3	$MDD_{RMP} = -0.0193*PL^2 + 0.7743*PL + 12.202$	0.841
4	$MDD_{MP} = -0.0145*PL^2 + 0.5176*PL + 15.517$	0.973
5	$MDD_{Combined} = -0.0161*PL^2 + 0.5701*PL + 14.469$	0.887

Figures 8(a) and 8(b) presents the variation of OMC and MDD with Plasticity index. From these figures it can be observed that the OMC increases with increase in the plasticity index values and MDD value of soil mixtures has a tendency to decrease. The correlation equations with correlation coefficients are given in the Table 16.

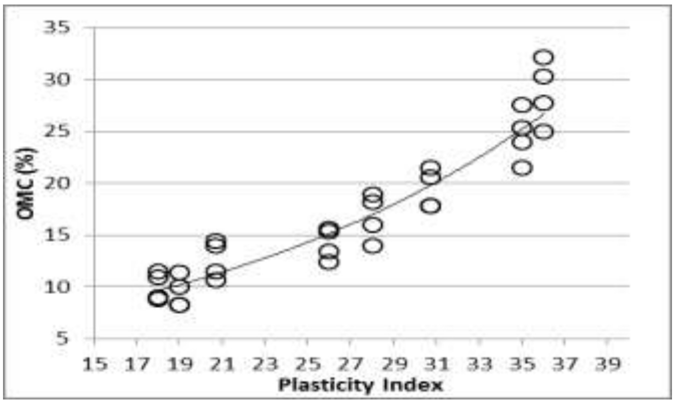

Fig.8 (a) Correlation of Plasticity Index v/s OMC of the soil at varying energy levels – Combined Variation with Exponential Relationship.

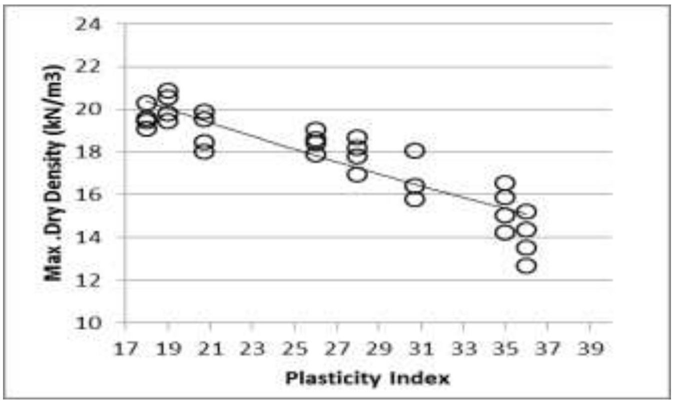

Fig.8 (b) Correlation of Plasticity Index v/s MDD of the soil at varying energy levels – Combined Variation with Exponential Relationship.

Table 16: Shows the correlation between Plasticity Index with OMC and MDD for combined energy levels.

Table 16

Sl no.	Exponential Relation	R
1	$OMC_{Combined} = 3.4801e^{0.0566*IP}$	0.947
2	$MDD_{Combined} = 27.481e^{-0.017*IP}$	0.845

The correlation of max dry unit weight (γd max) with dry unit weight at plastic limit (γd.wp.) is obtained from Fig 9(a) and 9(b).

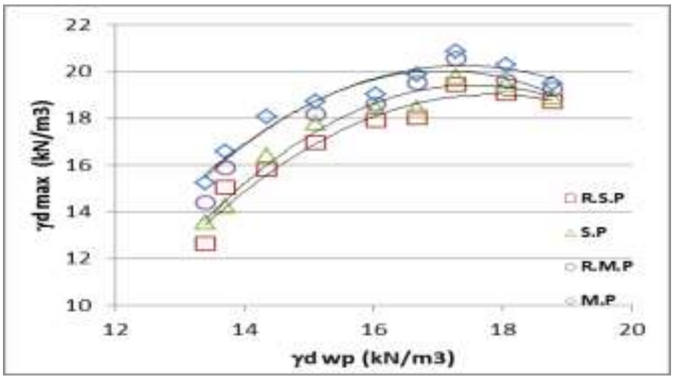

Fig.9 (a) Correlation between MDD v/s MDD at Plastic Limit of the soil at varying energy levels. (Exponential Relationship)

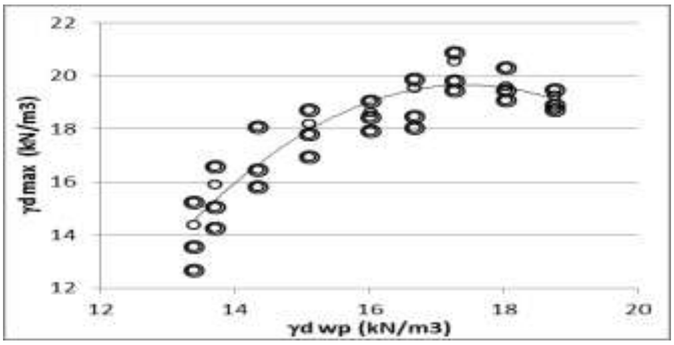

Fig.9 (b) Correlation between MDD v/s MDD at Plastic Limit of the soil at varying energy levels. – Combined Variation with Exponential Relationship.

Table 17: Shows the correlation of max dry unit weight - γd max with dry unit weight at plastic limit.

Table 17

Sl no.	Exponential Relation	R
1	$\gamma d\ max_{RSP} = 6.107e^{0.064*\gamma d\ wp}$	0.885
2	$\gamma d\ max_{SP} = 6.3739e^{0.0627*\gamma d\ wp}$	0.881
3	$\gamma d\ max_{RMP} = 9.3372e^{0.0425*\gamma d\ wp}$	0.681
4	$\gamma d\ max_{MP} = 9.0537e^{0.0452*\gamma d\ wp}$	0.854
5	$\gamma d\ max_{Combined} = 7.5739e^{0.0536*\gamma d\ wp}$	0.780

The variations of Maximum dry density v/s OMC for varying energy levels (figures 10(a) and 10(b)) show that the OMC follows a decreasing trend with increase in density.

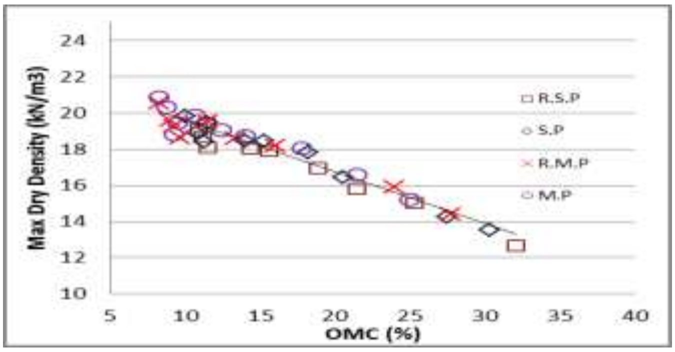

Fig.10 (a) Correlation of MDD v/s OMC for varying energy levels. - (Linear Relationship)

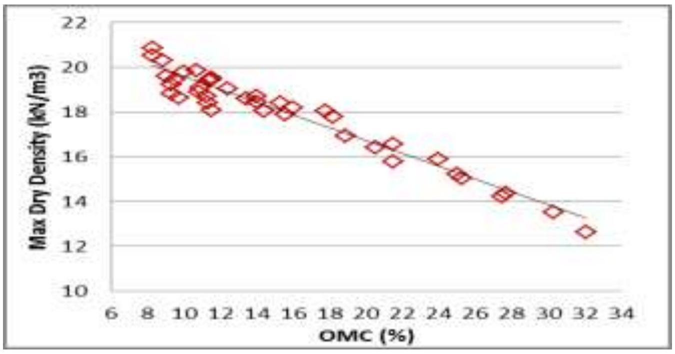

Fig.10 (b) Correlation of MDD v/s OMC for varying energy levels - Combined Variation with Linear Relationship.

Table 18: Shows the correlation of max dry unit weight with OMC of the soil

Table 18

Sl no.	Linear Relation	R
1	$\gamma d\ max_{RSP} = -0.2908*OMC + 22.192$	0.986
2	$\gamma d\ max_{SP} = -0.2924\ OMC + 22.501$	0.981
3	$\gamma d\ max_{RMP} = -0.2453\ OMC + 22.102$	0.842
4	$\gamma d\ max_{MP} = -0.2805\ OMC + 22.543$	0.955
5	$\gamma d\ max_{Combined} = -0.2854\ OMC + 22.445$	0.942

4. RESULTS AND DISCUSSION

PERCENTAGE FINES

From the variations of Percentage fines to the OMC and MDD , it can be noted that as the percentage of fines increases the OMC values tend to increase (follows a polynomial trend) gradually and reaches a maximum value between 30-40. The MDD on the other hand shows a decreasing trend with the increase in fines. As the fines increase more water will be required for compaction of the soil.

OPTIMUM MOISTURE CONTENT

In order to know how the OMC of sand and clay mixtures of different proportions at different compaction energy levels varies, attempt has been made to correlate results with plasticity characteristics. From.4(a) through 4(d), 6(a)through 6(d) and 8(a) through 8(d), it can be observed that the OMC increases as liquid limit, plastic limit, plasticity index, increases respectively for different energy levels. So OMC is lower initially and is linearly proportional to these limits.

MAXIMUM DRY DENSITY

The maximum dry densities for sand - kaolinite mixtures for different compaction energy are compared with index properties of soil to know its variation. From figures, From.5 (a) through 5(d), 7(a) through 7(d) and 9(a) through 9(d), for different energy level it can be inferred that the maximum dry density decreases as liquid limit, plastic limit, plasticity index increases respectively. It is observed that maximum dry density can be achieved initially when the Atterberg limits are lower.

CORRELATION BETWEEN MAXIMUM DRY UNIT WEIGHT AND OMC

The variation of maximum dry density with OMC is shown in fig for RSP, SP, RMP and MP. Very good correlations exist between γd max and OMC for different energy level are shown in equations in the Table 13. Though the trend seems linear in the beginning there exists a polynomial relationship between the values. No identical increment is observed in the values in the variation against γd max and OMC for all energy levels of compaction.

The experimental results and the plots, show that there is non-linear relationship between the ordinate and abscissa. The relationship can be better established with polynomial regression fits when compared to exponential regression fits.

COMPARISION OF ACTUAL DATA WITH EXPERIMENTALLY OBTAINED RESULTS

In order to have a comparison between the laboratory obtained test results and values obtained from regression equations for naturally available fine grained soils authors data have been extensively utilized. The physical properties and compaction characters for various energy levels have been provided in the tables.

Compaction characteristics obtained from plastic limit as water content bears good correlation in relative comparison to those obtained from liquid limit as the criteria. The comparison of values of OMC and MDD of natural soils with estimated values from liquid limit and plastic limit shows that there is good relation with these values and it follows a linear relationship.

Reduced Standard Proctor Test Values of Soil Samples

Table 19

Source	G	Sand (%)	Silt & clay (%)	W_L (%)	W_p (%)	Actual data		Estimated data from liquid limit		Estimated data from plastic limit	
						$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)
T Narasipura	2.64	36	64	41	24.68	15.5	23	15.84	21.78	16.87	18.29
Nanjanagudu	2.64	26	74	39	20.1	14.7	16.82	16.19	20.58	18.12	14.07
chikkahalli	2.8	10	90	41.76	22	14.3	18	15.7	22.24	17.6	15.82
Bommanahalli	2.79	45	55	54.6	29	15.5	29	13.42	29.95	15.69	22.27
CFTRI	2.6	32	68	32	19	14.6	18.9	17.44	16.37	18.42	13.05
Adithya Circle	2.63	30	70	28	19	16.4	17.1	18.15	13.97	18.42	13.05
Sriramapura	2.6	18	72	32	17	16.15	13	17.44	16.37	18.96	11.21
Nanjanagudu	2.63	40	60	55	20	15.7	19	13.35	30.19	18.14	13.98
Chamarajanagar	2.61	35	65	61	28	14	28	12.29	33.8	15.96	21.35
J.P.Nagar	2.72	33	67	40	20	16.67	19.2	16.02	21.18	18.14	13.98
H.D.Kote	2.89	19.5	81	39	31	14	30	16.19	20.58	15.15	24.11
T Narasipura	2.71	23	77	31	19	16.8	19	17.61	15.77	18.42	13.05
Chamarajanagar	2.86	8	92	54	33	13.6	31	13.53	29.59	14.6	25.95

Standard Proctor Test Values of Soil Samples

Table 20

Source	G	Sand (%)	Silt (%)	W_L	W_p	Actual data		Estimated data from liquid limit		Estimated data from plastic limit	
						$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)
Red Soil(Mysore)	2.66	26	74	43	23	17.5	18	16.19	21.35	17.85	15.33
Chamarajanagar	2.6	448	52	33	22	17.2	18.5	17.79	15.95	18.09	14.61
Mandya	2.67	19	81.4	30	20	17.5	17	18.27	14.33	18.58	13.19
Adithy Circle	2.66	45	55	35	23	15.91	19	17.47	17.03	17.85	15.33
T Narasipura	2.64	36	64	41	24.68	16.5	20.8	16.51	20.27	17.44	16.52
Sharadadevinagar	2.59	20	80	38.09	14	15.9	12.8	16.98	18.7	20.05	8.91
Begur	2.66	30	70	37.97	14	15.7	12.8	17	18.64	20.05	8.91
chikkahalli	2.8	10	90	41.76	22	14.5	20.1	16.39	20.68	18.09	14.61
Bommanahalli	2.79	45	55	54.6	29	15.9	26.6	14.34	27.62	16.38	19.6
CFTRI	2.6	32	68	32	19	15.11	17.3	17.95	15.41	18.83	12.48
Adithya Circle	2.63	30	70	28	19	16.7	17.1	18.58	13.25	18.83	12.48
Somanathapura	2.67	25	75	36	14	18.5	13.5	17.31	17.57	20.05	8.91
Sriramapura	2.6	18	72	32	17	16.42	16	17.95	15.41	19.32	11.05
Nanjanagudu	2.63	40	60	55	20	16.3	18.2	14.28	27.83	18.58	13.19
J.P.Nagar	2.72	33	67	40	20	17.07	17.7	16.67	19.73	18.58	13.19
H.D.Kote	2.89	19.5	81	39	31	14.8	28.2	16.83	19.19	15.89	21.03
T Narasipura	2.71	23	77	31	19	17.8	17	18.11	14.87	18.83	12.48
Chamarajanagar	2.86	8	92	54	33	14.8	27.5	14.44	27.29	15.4	22.45

Reduced Modified Proctor Test Values of Soil Samples

Table 21

Source	G	Sand	Silt (%)	W_L	W_p	Actual data		Estimated data from Liquid Limit		Estimated data from Plastic Limit	
						$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)
T Narasipura	2.64	36	64	41	24.68	17.3	18.8	17.26	18.27	18.1	15.26
Nanjanagudu	2.64	26	74	39	20.1	16.42	11.22	17.55	17.23	19.09	11.63
H.D.Kote	2.62	15	85	30	30.68	14.2	23.59	18.84	12.58	16.8	20.01
Sharadadevinagar	2.59	20	80	38.09	14	17.4	12.5	17.68	16.76	20.41	6.8
Begur	2.66	30	70	37.97	14	16	10	17.7	16.7	20.41	6.8
Shindanapura	2.54	47	53	54	23	18.8	20.6	15.41	25	18.46	13.93
Bommanahalli	2.79	45	55	54.6	29	16.5	26	15.32	25.31	17.16	18.68
CFTRI	2.6	32	68	32	19	16.5	16.3	18.55	13.61	19.32	10.76
Somanathapura	2.67	25	75	36	14	18.2	11.2	17.98	15.68	20.41	6.8
Nanjanagudu	2.63	40	60	55	20	15.7	19	15.26	25.51	19.11	11.56
Chamarajanagar	2.61	35	65	61	28	14	28	14.41	28.62	17.38	17.89
J.P.Nagar	2.72	33	67	40	20	16.67	19.2	17.41	17.75	19.11	11.56
H.D.Kote	2.89	19.5	81	39	31	15.1	23	17.55	17.23	16.73	20.27
H.D.Kote	2.89	28	72	16	14	17.8	11.4	20.84	5.33	20.41	6.8
T Narasipura	2.71	23	77	31	19	18.1	14	18.69	13.09	19.32	10.76
Chamarajanagar	2.86	8	92	54	33	15.8	24	15.41	25	16.29	21.85

Modified Proctor Test Values of Soil Samples

Table 22

Source	G	Sand (%)	Silt & (%)	W_L	W_P	Actual data		Estimated data from Liquid Limit		Estimated data from Plastic Limit	
						$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)	$\gamma_{d\,max}$ (kN/m³)	OMC (%)
Chamarajanagar	2.6	44.8	52	33	22	18.66	14	18.83	12.95	19.07	12.05
Mandya	2.67	19	81.4	30	20	18.27	12.48	19.22	11.54	19.47	10.62
Sharadadevinagar	2.64	32	68	38	25	19.22	17.2	18.17	15.28	18.48	14.2
Adithya Circle	2.66	45	55	35	23	18.3	15.5	18.56	13.88	18.88	12.77
T Narasipura	2.64	36	64	41	24.68	18.3	16.2	17.78	16.69	18.54	13.97
chikkahalli	2.8	10	90	41.76	22	17.1	15.9	17.68	17.04	19.07	12.05
Shindanapura	2.54	47	53	54	23	19.2	16.1	16.08	22.77	18.88	12.77
Bommanahalli	2.79	45	55	54.6	29	18.9	20.3	16	23.05	17.68	17.06
H.D.Kote	2.89	19.5	81	39	31	16.1	21.5	18.04	15.75	17.28	18.49
H.D.Kote	2.89	28	72	16	14	19.2	11.2	21.05	5	20.67	6.32
T Narasipura	2.71	23	77	31	19	18.4	14	19.09	12.01	19.67	9.9
Chamarajanagar	2.86	8	92	54	33	15.9	22	16.08	22.77	16.89	19.93

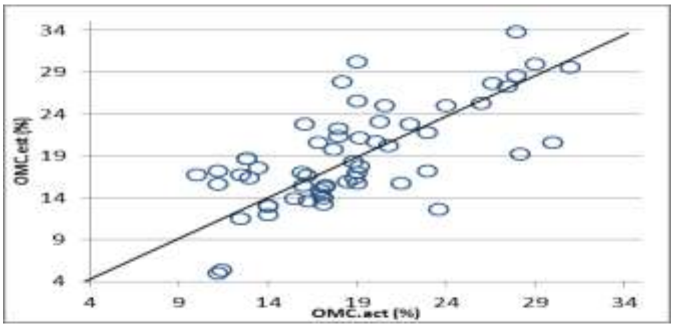

Fig.11 (a) Variation of OMC (actual) v/s OMC (estimated) obtained from Liquid limit- Combined Variation with Exponential Relationship.

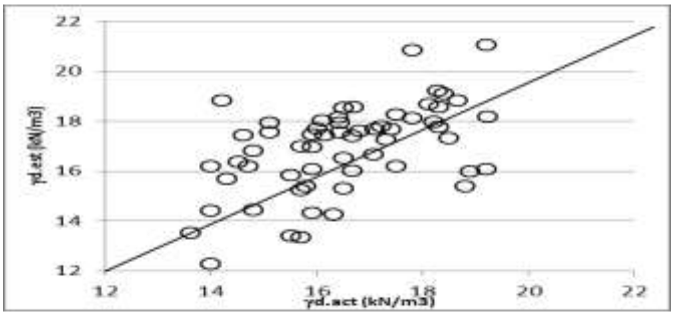

Fig.11 (b) Variation of OMC (actual) v/s OMC (estimated) obtained from Plastic limit - Combined Variation with Exponential Relationship.

Table 23 shows the relation between OMC (actual) and OMC (Estimated) for varying energy levels obtained from Liquid limit and Plastic Limit.

Table 23

Sl no.	Exponential Relation	R Value
1	$MDD_{Actual\ @LL} = 9.1715e^{0.0368*MDD\ est.}$	0.518
2	$MDD_{Actual\ @PL} = 10.639e^{0.0325*MDD\ est.}$	0.616

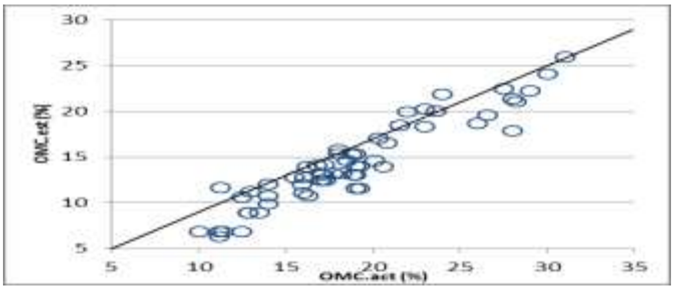

Fig.11(c) Variation of MDD (actual) v/s MDD (estimated) obtained from Liquid limit - Combined Variation with Exponential Relationship.

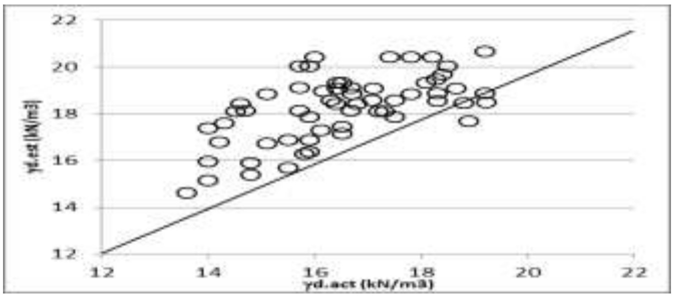

Fig 11.(d) Variation of MDD (actual) v/s MDD (estimated) obtained from Plastic limit - Combined Variation with Exponential Relationship.

Table 24 Shows the Correlation between MDD (actual) and MDD (Estimated) for varying energy levels obtained from Liquid limit and Plastic Limit.

Table 24

Sl no.	Exponential Relation	R Value
1	$OMC_{Actual\ @\ LL} = 8.1256e^{0.0424*OMC\ est.}$	0.632
2	$OMC_{Actual\ @PL} = 4.578e^{0.0581*OMC\ est.}$	0.910

Results obtained from Liquid limit relations tend to have more scattered information when compared to variations from Plastic limit. Hence Plastic limit data's are more reliable and plastic limit data's can be a dominant factor for estimating the compaction characteristic of China clay – Sand Mixtures.

5. CONCLUSIONS

Based on the detailed experimental study, the following conclusions are made

Liquid limit, Plastic limit and shrinkage limit of China clay-Sand mixtures can be predicted effectively with percent china clay.

Exponential and Polynomial relationships can be effectively used to correlate OMC and MDD (for different energy levels) of China clay- Sand mixtures with percent china clay.

OMC and MDD of China clay- Sand mixtures can be estimated with higher degree of accuracy with plastic limit in relative comparison to liquid limit for different energy levels. Polynomial relationships show a better compatibility when compared to exponential relationships while relating OMC and MDD of China clay- Sand mixtures with liquid and plastic limits.

With known plasticity index of China clay- Sand mixtures, the compaction characters of the China clay- Sand mixtures can be estimated mathematically with higher degree of accuracy.

Exponential and polynomial relationships can be established between dry density of the mixtures with plastic limit as the limiting water content and MDD of China clay- Sand mixtures.

OMC and MDD of the China clay- Sand mixtures can be interrelated for different energy levels.

OMC and MDD of natural soils having kaolinitic clay mineral dominance can be predicted by knowing the OMC and MDD of China clay- Sand mixtures for different energy levels with exponential relationships.

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