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Parametric Study of Index Properties and Compaction Characteristics of Bentonite, Kaolinite and Sand Mixtures

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Abstract*: *Index properties and plasticity characteristics are the two important issues related to classification and in assessing swelling characteristics of fine-grained soils. It is seldom observed that, the clay mineralogy is playing the important role in deciding the characteristics of such soils which is due to the presence of least active clay mineral like kaolinite to the most active clay mineral like montmorillonite in addition to other clay minerals like illite, etc., in different proportions. Because of physico-chemical phenomenon due to the effect of clay minerals which exhibits contradictory behaviour i.e., kaolinite exhibiting flocculent effect in relative comparison to montmorillonite having dispersion effect. The various proportions of these clay minerals is generally be ascertained by means of XRD analysis, which is generally expensive. Most of these experimental studies of fine-grained soils are region-specific. In the present experimental investigation, in order to replicate natural soils having kaolinite, montmorillonite and sand in different proportions by design mix proportions of commercially available kaolinite, bentonite and sand mixtures. A detailed experimental investigation was done to assess the physical properties and compaction characteristics subjected to various compaction energy levels like reduced standard proctor (RSP), standard proctor (SP), reduced modified proctor (RMP) and modified proctor (MP). An attempt has been made, to form a relation between the index properties of the mix proportions with the plasticity and compaction characteristics, which can be useful in preliminary designs and which are found to be cost effective. An alternative method of assessing the principle clay dominance is also presented. A new plasticity chart for the design mix proportions was also developed for classification purpose.

Index Terms*: *Clay minerals, Compaction Characteristics, Design Mix Proportion, Plasticity Characteristics

I. INTRODUCTION

Compaction is a type of mechanical modification technique for improving the engineering properties of soils. Most of the structures are constructed on the well compacted fine-grained soils. Due to the scarcity of good sites, the marginal landfills are filled with fine-grained soils. It is due to unavailability of good sites leads to structures built on those problematic soils only. The behaviour of fine-grained soils is generally controlled by clay mineralogy of soil and their plastic characteristics. Fine-grained soils comprise of least active clay minerals like kaolinite, which is flocculent in nature, to most active clay mineral like bentonite having repulsive force dominance. In addition to illite and other clays, the plasticity and compaction characteristic are being controlled by extent by the very presence of the least active and the most active clay minerals in different proportions.

The physio-chemical behaviour of fine-grained soils are largely influenced by clay mineralogical compositions. The dominance of kaolinite and montmorillonite in the clay minerals, classification of clay minerals into kaolinite and montmorillonite in nature can be done sometimes it is also observed that Kaolinite and Montmorillonite soils are nearly being equal in proportions also available in nature. Further it is noteworthy to observe that most of the studies reported in the documented literature are region specific.

II. LITERATURE REVIEW

Several investigators like David et.al (1949), Jumkins (1958), Ring et.al (1962), Ramaiah (1970), Jeng et.al (1970), Wang et.al (1984), have described methods to estimate OMC and MDD of fine-grained soils for Light compaction energy level.

Relation between the Maximum dry density and the optimum water content is very important when compaction characteristics are involved. Investigators like Proctor (1933), Hilf (1956), Hogentolger (1936), Barden et al., (1970), Olson (1963), Nagaraj et al.,(1983) have explained about the different patterns representing plots of OMC v/s MDD of fine grained soils.

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Mc Rae (1958) has studied the effect of compaction energy on MDD and designed the compaction classification index.
Johnson et.al (1962), has studied about the chart for computing the appropriate OMC for light compaction energy level.
Blotz et.al (1998), developed an empirical formulation for estimation of MDD and OMC of twenty-two clay soil sample at compactive effort (E) using liquid limit.

Sridharan et.al (2000) made an attempt to correlate plastic limit to OMC and MDD for standard proctor compactive effort, depend upon the results obtained from the published and experimental studies.
Gurtug & Sridharan (2004) have studied about the fine-grained soils and their compaction characteristics with respect to different energy levels. They mentioned that, plastic limit is the best possible correlation to the compaction behavior and other than light and heavy compaction energy levels, there are two other categories in compaction, those are reduced standard proctor(RSP) and reduced modified proctor (RMP) .

The study by Sridharan & Nagaraj (2004) shows that plasticity index or liquid limit does not correlate well with the compaction characteristics of fine-grained soils.

Sridharan & Nagaraj (2005) concluded that the shrinkage index (difference of liquid limit and shrinkage limit) correlates better to the compaction characteristics than the liquid limit or plasticity index of soils. The relationships and modifications of Standard Proctor and Modified Proctor were obtained.

Prasanna et.al (2015),based on the experimental study on fine-grained soils having different clay mineralogy observed that compaction characteristics of fine-grained soils irrespective of clay mineralogical composition correlates more effectively with plastic limit (W_P) in relative comparison to the liquid limit (W_L) and plasticity index (I_P).

These studies bring out the importance of compactive effort and the relationship of compaction characteristics with index properties. It is also observed that most of the studies are pertaining to standard Proctor and compactive effort. Thus any additional experimental investigation attempting to correlate index properties with compaction characteristics at different energy levels will enhance our understanding of compaction behaviour and correlation of compaction characteristics with index properties.

III. MATERIALS AND METHODS

For the present experimental study, kaolinite and Bentonite clays used were procured from commercially available source, which were stored in air-tight containers. The river sand from single source was procured, which was wet washed to remove the dirt and silts and then oven dried to remove organic content. This sand was mixed with stored samples of kaolinite and bentonite in varying proportions, to have the required different mix proportions. The bentonite(B) proportions was kept constant and the kaolinite(K) and sand(S) proportions were varied for each mix ratio(MR) i.e., 10%B constant for MR-1 with K varying from 10% to 80% and S varying from 80% to 10% . Likewise, with 20%B, 30%B, etc., constant with varying K and S proportions, MR-2 to MR-7 samples were prepared and the same has been used in the following experimental study.
Laboratory investigations for index properties and compaction characteristics for all the mix proportions were carried out as per IS specifications.

IV. TEST RESULTS AND DISCUSSION

As mentioned in literature review, it has been observed that the compactive effort increases, Maximum Dry Density (MDD) increases and the Optimum Moisture Content (OMC) decreases.

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Table.I Maximum and minimum values of MDD and OMC for all energy levels of all mix ratio.

Type of compaction	Mix Ratio	MDD (KN/m^3)		OMC (%)	
		Maximum	Minimum	Maximum	Minimum
RSP	MR-1	18.9	13	24	10.92
	MR-2	18.2	14.03	29.12	14
	MR-3	17.1	14.09	27.3	17
	MR-4	17.26	13.66	28.1	18.1
	MR-5	15.9	13.38	28.58	19.01
	MR-6	15.53	13.01	28.8	20.02
	MR-7	15.2	12.95	29.5	24
SP	MR-1	19.51	14.56	23.5	9.8
	MR-2	19.46	15.58	27.83	13.62
	MR-3	18.14	14.57	26.4	15.76
	MR-4	18.06	14.51	27.1	17.3
	MR-5	17.15	14.55	26.21	18.11
	MR-6	16.17	15.2	26.5	19.41
	MR-7	15.74	15.43	26.4	23
RMP	MR-1	21.08	15.73	21.6	8.94
	MR-2	21.02	15.96	27.21	12.45
	MR-3	20.5	16.92	24.4	15.4
	MR-4	19.50	15.87	25.7	16.5
	MR-5	18.81	15.98	24.53	17.01
	MR-6	17.91	16.07	23.8	18.03
	MR-7	16.48	16.18	24.6	21.7
MP	MR-1	22.51	16.31	20.45	7.92
	MR-2	23.22	16.3	26.3	10.42
	MR-3	21.41	17.32	23.1	14.46
	MR-4	20.18	16.60	24.6	15.5
	MR-5	19.27	16.71	22.89	15.69
	MR-6	18.87	16.62	22.5	17.12
	MR-7	17.52	16.82	23.1	19.3

Figures 1(a) and 1(b) represents inter-relations of OMC obtained from different compaction energy levels with liquid limit.

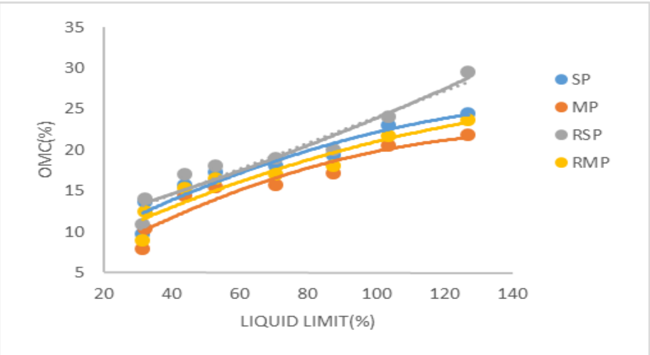

Fig. 1 (a) Correlation between OMC and W_L for different energy levels for MR-1.

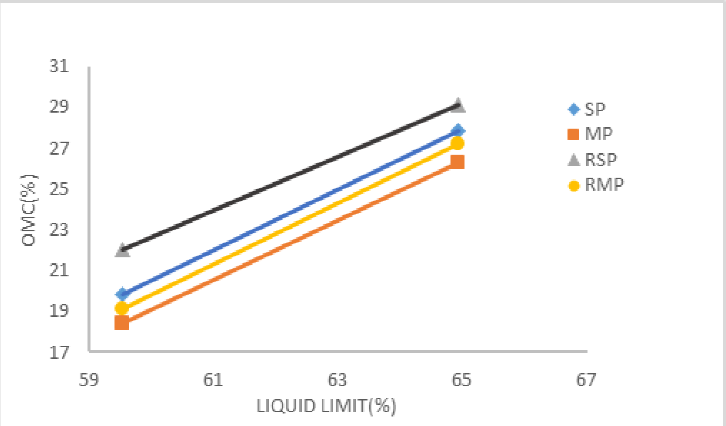

Fig. 1 (b) Correlation between OMC and W_L for different energy levels for MR-7.

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Table.II Correlation &Regression values for OMC vs Liquid limit of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = -0.0007x2 + 0.2301x + 5.6968	0.91	0.95
MP	y = -0.0008x2 + 0.2519x + 2.9676	0.90	0.95
RSP	y = 0.0003x2 + 0.1106x + 9.6771	0.92	0.96
RMP	y = -0.0005x2 + 0.2097x + 5.4579	0.89	0.94

It is observed that OMC increases with increase in liquid limit due to increase in water holding capacity of mix proportions.

Similar variation of increase in OMC with increase in liquid limit has been observed for the remaining mix ratios (MR-3 through MR-6).

Figures 2(a) and 2(b) represents inter-relations of MDD obtained from different compaction energy levels with liquid limit.

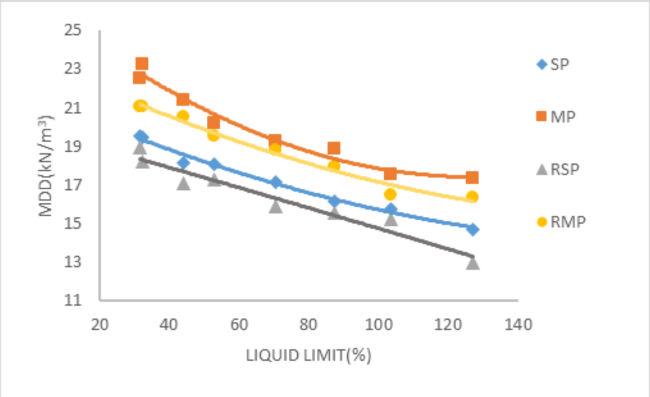

Fig. 2(a) Correlation between MDD and W_L for different energy levels for MR-1.

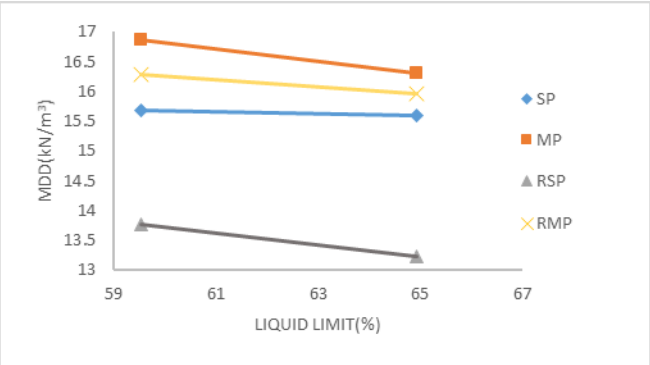

Fig. 2(b) Correlation between MDD and W_L for different energy levels for MR-7.

Similar variation of decrease in MDD with increase in liquid limit has been observed for the remaining mix ratios (MR-3 through MR-6).

Table.III Correlation &Regression values for MDD vs Liquid limit of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = 0.0002x2 - 0.0807x + 21.709	0.98	0.99
MP	y = 0.0006x2 - 0.1483x + 26.863	0.97	0.98
RSP	y = -1E-05x2 - 0.0509x + 19.939	0.94	0.97
RMP	y = 0.0002x2 - 0.0891x + 23.728	0.98	0.99

Figures 3(a) and 3(b) represents inter-relations of OMC obtained from different compaction energy levels with plastic limit.

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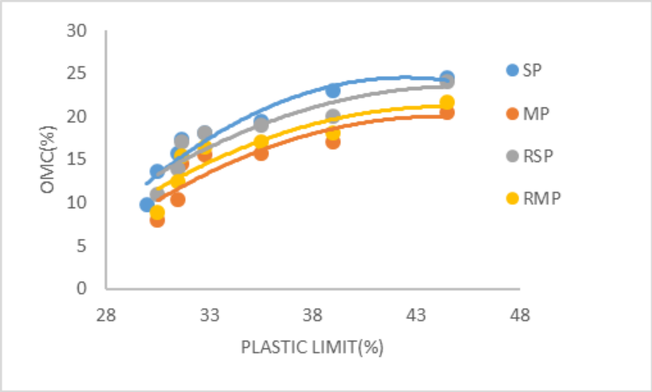

Fig. 3(a) Correlation between OMC and W_P for different energy levels for MR-1.

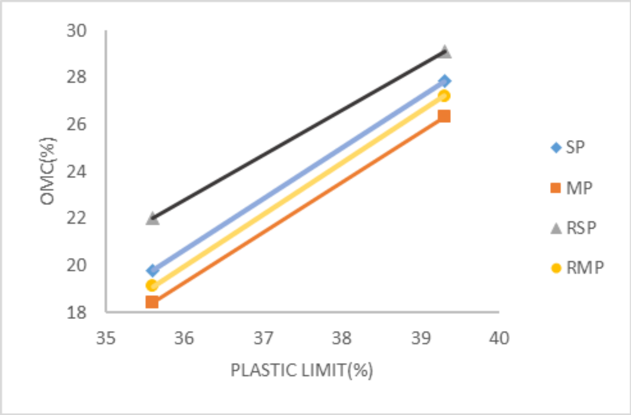

Fig. 3(b) Correlation between OMC and W_P for different energy levels for MR-7.

It is observed that OMC increases with increase in plastic limit due to increase in water holding capacity of mix proportions.

Similar variation of increase in OMC with increase in plastic limit has been observed for the remaining mix ratios (MR-3 through MR-6).

Table.IV Correlation & Regression values for OMC vs plastic limit of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = -0.0785x2 + 6.6676x - 117.11	0.91	0.95
MP	y = -0.0518x2 + 4.5832x - 81.324	0.79	0.89
RSP	y = -0.0468x2 + 4.2412x - 72.523	0.84	0.91
RMP	y = -0.0489x2 + 4.3498x - 75.641	0.80	0.89

Figures 4(a) and 4(b) represents inter-relations of MDD obtained from different compaction energy levels with plastic limit.

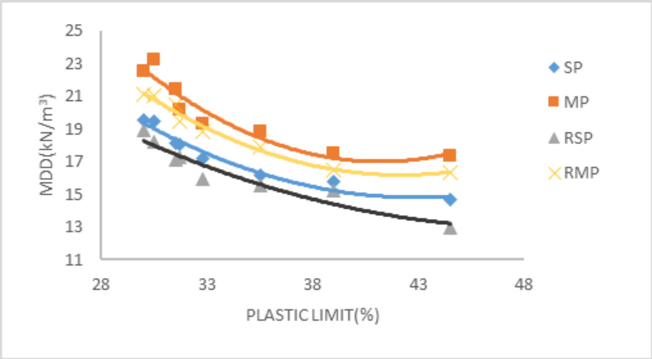

Fig. 4(a) Correlation between MDD and W_P for different energy levels for MR-1.

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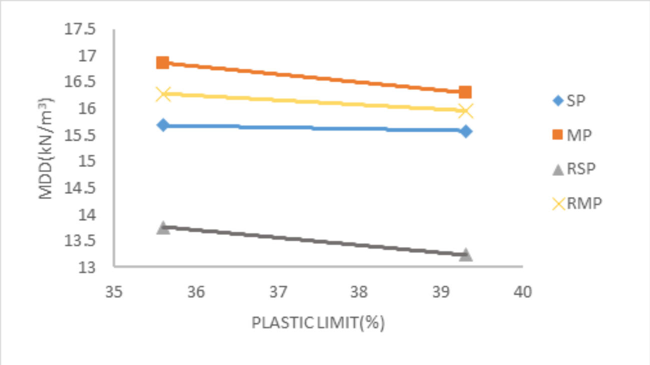

Fig. 4(b) Correlation between MDD and W_P for different energy levels for MR-7.

Similar variation of decrease in MDD with increase in plastic limit has been observed for the remaining mix ratios (MR-3 through MR-6).

Table.V Correlation &Regression values for MDD vs plastic limit of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = 0.0274x2 - 2.3493x + 65.188	0.96	0.98
MP	y = 0.0453x2 - 3.7278x + 93.703	0.90	0.95
RSP	y = 0.015x2 - 1.4636x + 48.694	0.91	0.95
RMP	y = 0.034x2 - 2.8639x + 76.561	0.97	0.98

Figures 5(a) and 5(b) represents inter-relations of OMC obtained from different compaction energy levels with plasticity index.

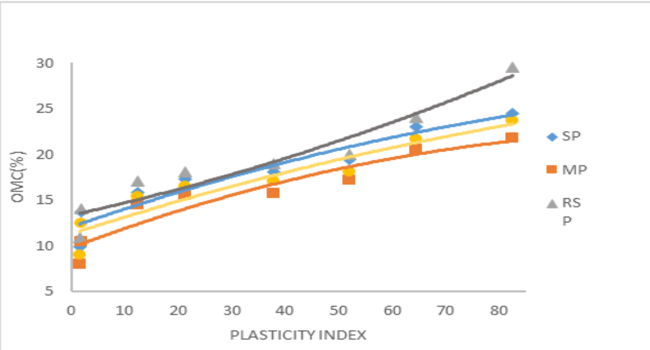

Fig. 5(a) Correlation between OMC and I_P for different energy levels for MR-1.

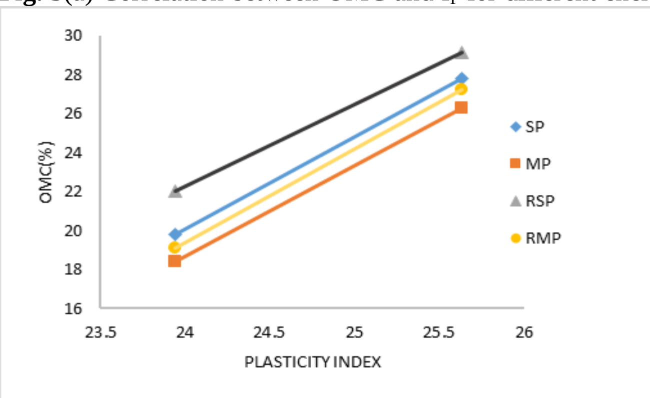

Fig. 5(b) Correlation between OMC and I_P for different energy levels for MR-7.

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Similar variation of increase in OMC with increase in plasticity index has been observed for the remaining mix ratios (MR-3 through MR-6).

Table.VI Correlation &Regression values for OMC vs plasticity index of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = 0.0002x2 - 0.0718x + 19.458	0.98	0.99
MP	y = 0.0007x2 - 0.1246x + 22.939	0.97	0.98
RSP	y = -0.0001x2 - 0.0528x + 18.387	0.94	0.97
RMP	y = 0.0002x2 - 0.0778x + 21.234	0.97	0.98

Figures 6(a) and 6(b) represents inter-relations of MDD obtained from different compaction energy levels with plasticity index.

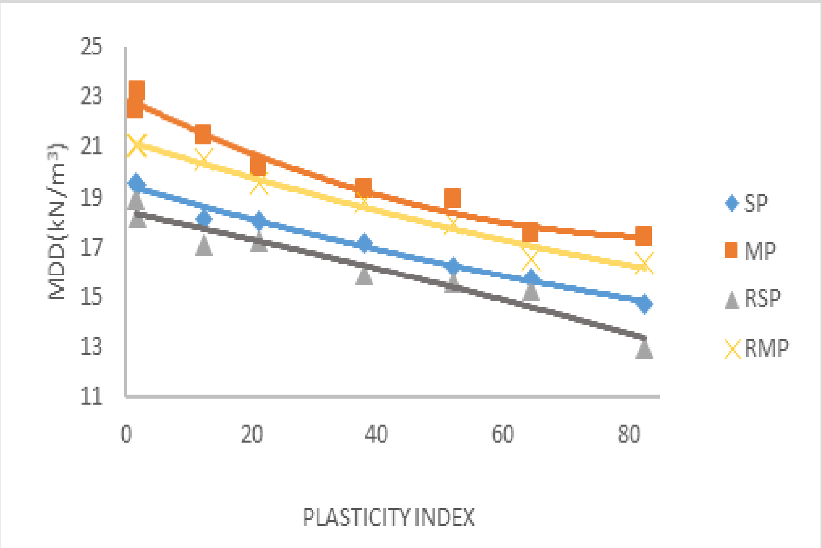

Fig. 6(a) Correlation between MDD and I_P for different energy levels for MR-1.

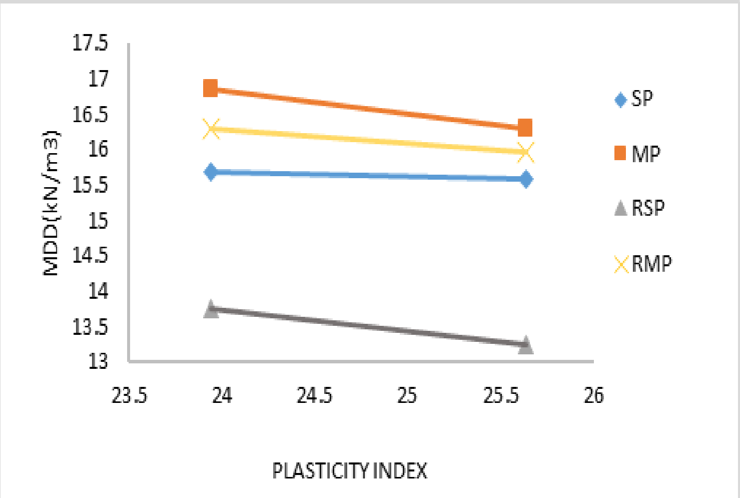

Fig. 6(b) Correlation between MDD and I_P for different energy levels for MR-7.

Similar variation of decrease in MDD with increase in plasticity index has been observed for the remaining mix ratios (MR-3 through MR-6).

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Table.VII Correlation &Regression values for MDD vs plasticity index of MR-1 for different compaction energy levels.

Energy Level	Regression Equation	R^2	R
SP	y = -0.0007x2 + 0.2029x + 12.05	0.911	0.95
MP	y = -0.0009x2 + 0.219x + 9.7921	0.898	0.94
RSP	y = 0.0007x2 + 0.1283x + 13.331	0.920	0.95
RMP	y = -0.0005x2 + 0.189x + 11.294	0.892	0.94

Figure 7(a) represents correlation of shrinkage limit with percent fines for different compaction energy levels for MR-1 through MR-7.

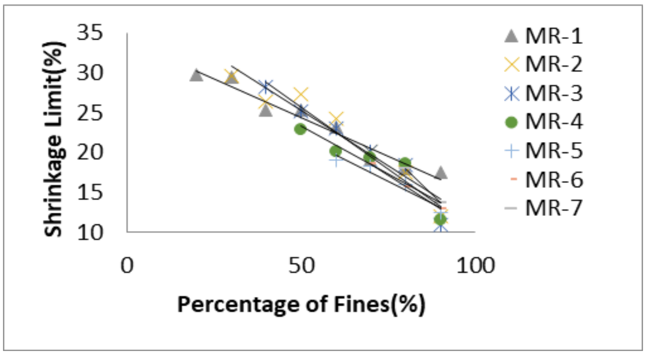

Fig. 7 (a) Correlation of shrinkage limit with percent fines for different compaction energy levels for MR-1 through MR-7.

From fig 7 (a), it is observed that the value of shrinkage limit decreases with increase in percentage of fines due to packing phenomenon of fines present in mix proportions. This tendency highlights that shrinkage limit can be regarded to be reorientation of fines present in fine-grained soils rather than plasticity character.

Figure 7 (b) represents the plasticity chart developed for the mix proportions.

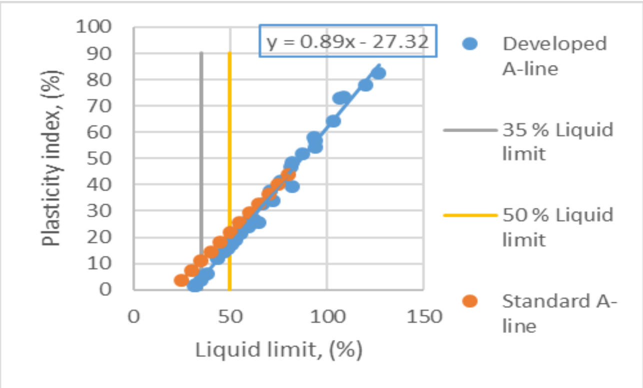

Fig. 7 (b) New plasticity chart developed for mix proportions.

The equation obtained for the plasticity chart developed for the mix proportion can be deduced as

$$\mathbf{I_P = 0.89\ (\ W_L - 30\ )}$$

which is akin to equation of A-line i.e.,

$$\mathbf{I_P = 0.73\ (\ W_L - 20\ )}$$

proposed by Arthur Casagrande.

Figures 8 (a) through 10 (b) represents the variations of OMC and MDD of all the mix ratio for different compaction energy levels with their respective liquid limits, plastic limits and plasticity index.

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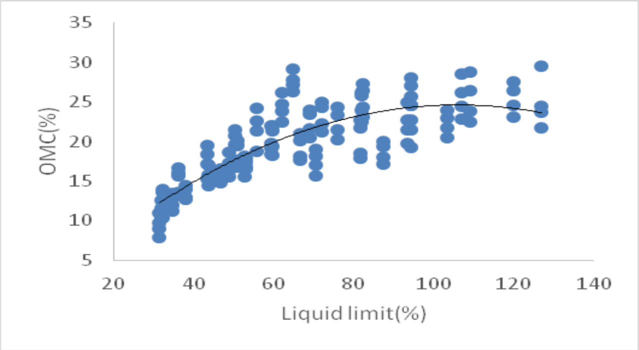

Fig. 8 (a) Correlation between OMC and W_L for different energy levels for MR-1 through MR-7.

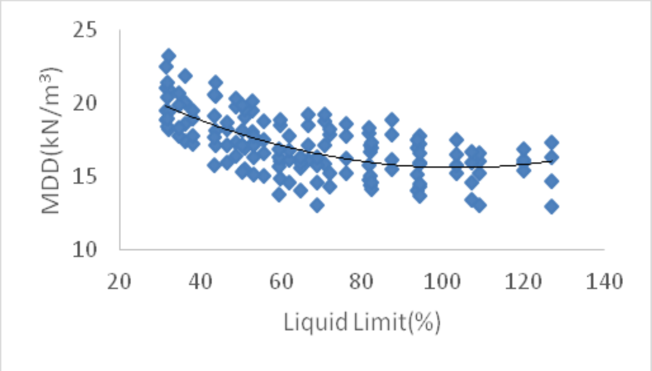

Fig. 8 (b) Correlation between MDD and W_L for different energy levels for MR-1 through MR-7.

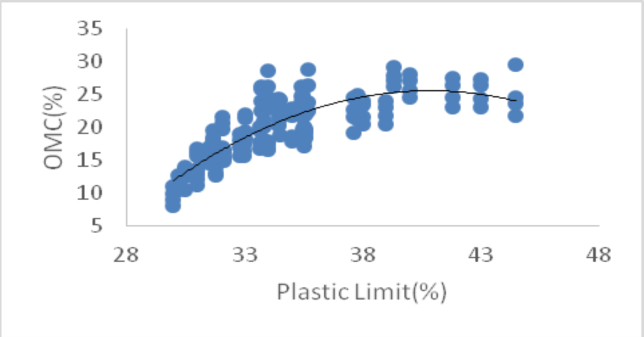

Fig. 9 (a) Correlation between OMC and W_P for different energy levels for MR-1 through MR-7.

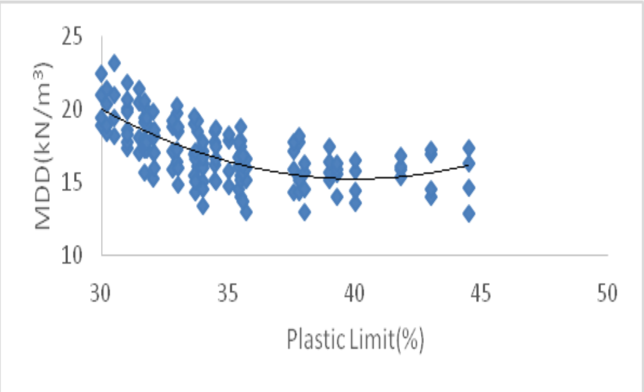

Fig. 9 (b) Correlation between MDD and W_P for different energy levels for MR-1 through MR-7.

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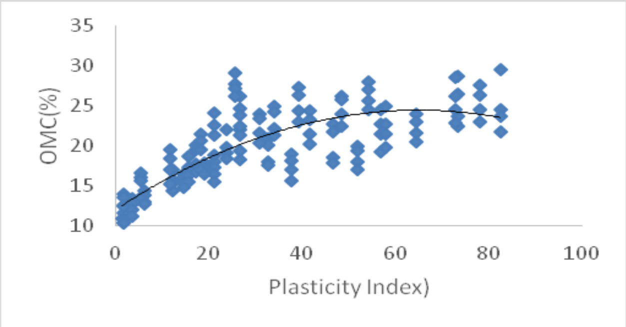

Fig. 10 (a) Correlation between OMC and I_P for different energy levels for MR-1 through MR-7.

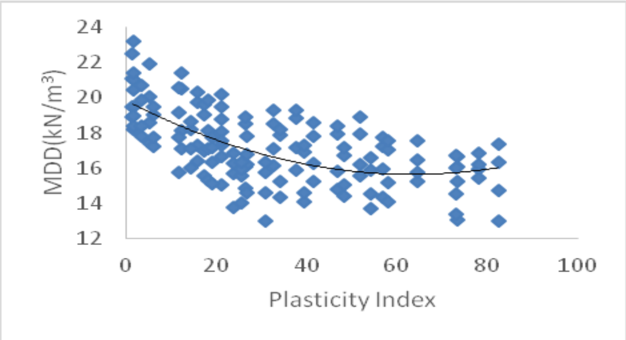

Fig. 10 (b) Correlation between MDD and I_P for different energy levels of samples of Table-1.

Table.VIII Correlation &Regression values of figures 8 (a) through 10 (b) for different compaction energy levels.

Fig no.	Regression Equation	R^2	R
8 (a)	$y = -0.0022x^2 + 0.4735x - 0.4693$	0.6835	0.8267
8 (b)	$y = 0.0008x^2 - 0.1682x + 24.282$	0.4305	0.6561
9 (a)	$y = -0.117x^2 + 9.5592x - 169.64$	0.7028	0.8383
9 (b)	$y = 0.0475x^2 - 3.8065x + 91.479$	0.4634	0.6807
10 (a)	$y = -0.003x^2 + 0.3844x + 12.01$	0.6428	0.8017
10 (b)	$y = 0.0011x^2 - 0.1335x + 19.852$	0.403	0.6348

The variations obtained for all the mix proportions for different compaction energy levels shown in fig. 8 (a) through 10 (b) is due to the fact that physio-chemical behaviour of fine-grained soils are largely influenced by clay mineralogical compositions, also the clay mineralogical composition has a definite bearing on the compaction characteristics and it is controlled by soil fabric.

From figures 8 (a) through 10 (b), the bandwidth of variation of OMC and MDD for different compaction energy levels of all mix proportions are different, even though they are having same liquid limit, different plasticity characteristics and clay mineralogy .

The variations obtained for the plasticity characteristics and compaction characteristics of the prepared mix proportions as shown from fig 8 (a) through 10 (b) are comparable and are in correlation with the similar and detailed experimental study results obtained for the natural soils in the documented literature.

V.CONCLUSIONS

By the detailed study, the below conclusions were made as follows:

1. Plasticity chart developed for mixed proportion is akin to IS plasticity chart.
2. Compaction characteristics of Bentonite, Kaolinite and sand mixtures can be efficiently correlated with liquid limit, plastic limit and plasticity index, which is analogous to the variation of compaction characteristics as natural soils with plasticity characteristics as reported in the documented literature.
3. Shrinkage limit of mix proportions has a tendency to decrease as percent fines in the mix proportion increases which clearly shows that shrinkage limit is a packing phenomenon rather than plasticity characteristics.

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