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Compaction Characteristics of China Clay-Bentonite-Sand Mix Proportions

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Abstract: In geotechnical engineering practice, a better understanding of the fundamental behavior of soil will provide a focused insight to begin decisions on new and emerging geotechnologies. Owing to lack of availability of coarse-grained soils, fine-grained soils having different clay mineralogical compositions are being used as an alternative eco-friendly material for construction activities. The engineering behavior of such soils varies significantly due to the presence of kaolinite - the mineral which is least active and montmorillonite - the mineral which is most active in different percentage. To have a general trend behavior of these soils around the globe requires more time and financial implications. As per the present experiment done, we have tried to represent the natural fine-grained soils having clay minerals through artificially prepared soils in the laboratory by preparing a series of mix proportions of china clay-bentonite-sand in varying proportions. The physical properties of the mix proportions were determined as per BIS specifications. IS light and heavy compaction test were conducted on mix proportion akin to standard Proctor and modified Proctor tests. In addition, reduced standard and reduced modified Proctor tests (compacted at 60% of their respective energy level) were performed on the artificially prepared mix proportions. We made an effort to correlate the physical properties of the mix proportions with compaction characteristics. Very useful correlations were also developed between the compaction characteristics of the mix proportions, subjected to varying energy levels and clay mineralogical composition with plasticity characteristics. We also made an effort to compare the compaction characteristics of natural fine-grained soils having the similar composition of fines and clay mineralogy with that of mix proportions.

Keywords: compaction, clay mineralogy, energy level of mix proportions, china clay,bentonite.

1 Introduction

To know the enhanced engineering results of fine-grained soils can be enlightened with the experimental investigations. Compaction as the word itself denotes that, the way of increasing the soil density mechanically by lowering the volume of air.

Altering the prevailing site foundation soils to yield better results under design and operational loading conditions with the use of vibration compaction methods, vacuum consolidation, soil nailing, grouting methods and dewatering methods. Compaction force has two principle types namely, static force and vibratory force. Static force is simply dead weight of the machine applying the downward force to the soil surface. Vibratory force follows normally engine-driven mechanism, to establish a downward force along with the machine's static weight. Every soil type behaves differently with respect to compaction force. Coarse-grained soils are mainly concerned by rearrangement of seating arrangements of granules. To improve particle stability, frequently fines are introduced throughout the mix. The physio-chemical behavior of fine-grained soils are largely influenced by clay mineralogical compositions. The present experimental study is one such attempt to study the compaction characteristic of natural fine-grained soil through artificial mix proportions of kaolinite-bentonite sand mixtures in varying percentage by the very presence of the least active and most active clay minerals in different proportions.

2 Literature Review

The study of the compaction of mix proportions having different physical and chemical properties demographically presented in different parts of world has drawn a curious attention of many researchers in the history. Many attempts have been made to correlate the compaction characteristics and index properties of different clay mixtures and sand.

Howell et al. (1997) studied the effects of different types of processed clay soils, curing period and the mixing procedure on the laboratory compaction of sand-attapulgite clay, sand-granular bentonite clay, sand-powdery bentonite clay and sand-attapulgite clay-granular bentonite clay mixtures. They conducted compaction test by mixing small amount of attapulgite clay and granular bentonite. It was found that, with increase in percentage of attapulgite clay and granular bentonite there is a tendency of increase in maximum density and optimum moisture content.

Sridharan and Nagaraj (2000) have conducted a study on the compressibility behavior of remolded fine-grained soils and their correlation with index properties. The results indicate that, in the absence of shrinkage index, the plasticity index can be used to predict the compressibility characteristics with a better correlation than that of the liquid limit. Further in 2005, they brought out the effect of plasticity characteristics on the compaction characteristics for fine-grained soils.

Sivrikaya and Togrol(2008) have studied about the compaction behavior of fine-grained soils for varying compaction energy. They have proposed equations correlating the maximum dry density and optimum water content corresponding to the results obtained from standard Proctor and modified Proctor test with the index properties. Baskar Chitoori et al., (2011) have conducted the experimental investigation on the estimation of quantity of clay mineralogy in fine grained soils. It was found that the results obtained were used to determine the composite chemical characteristics of soils.

Faseel Suleman and Shahid Azam (2014) conducted the compressive strength tests on compacted samples of natural clay of high plasticity and clay-sand mixtures containing 20%-40% sand. They observed that, the compressive strength decreases with an increase in sand content because of increased material heterogeneity and loss of sand grains from the sides during shearing.

Robert Proia(2016) has made an attempt to study about the compaction behavior of the sand-bentonite mixtures. It was found that the compaction characteristics were governed by the interaction between the two components each with its peculiar characteristics. With regard of dynamic compaction, it was observed that material exhibits a sand like behavior for limited percentage of bentonite and shows a bentonite like behavior for large percentage of bentonite, while for an intermediate percentage of bentonite a more complex behavior was noticed.

Bidual Bose (2019) has analysed the grain size distribution and compaction behavior of sand-bentonite mixtures. The outcome of sieve analysis reveals that with increase in bentonite content, the mean grain size decreases, with an increase in Cu and Cc. To make bentonite qualified to be used as a liner, there should not be any reasonable depletion when the optimum moisture and bentonite content increases along with the decreased dry density in the compacted sand-bentonite mixtures

Prasanna and Jyothi (2020) have studied the compaction characteristics of bentonite-sand, kaolinite-sand mixtures for different mix proportions. They observed that compaction characteristics can be effectively correlated with consistency characteristics such as liquid limit, plastic limit, and plasticity index. The shrinkage limit of the mix proportions of both bentonite-sand and kaolinite-sand decreases as the percentage of fines increases. They also developed a plasticity chart which is akin to IS Plasticity Chart.

3 Materials and Method

3.1 Materials

Locally available river sand was procured, wet washed and kept in hot air oven for 24 hours at a temperature of 105 ± 5º C. The oven dried sand was brought to room temperature and sieved through 425µm IS Sieve to have only fine-sand fraction. The sieved sand was stored in air tight plastic containers. The grain size distribution of fine sand fraction was done as per IS: 2720 (Part 4) 1985.

China clay is a clay mineral that is part of industrial mineral with a chemical composition $Al_2Si_2O_5(OH)_4$. It is a layered silicate, with a tetrahedral sheet of silica (SO_4) linked through oxygen atoms to one octahedral sheet of alumina (AlO_6)an octahedra. Kaolinite has a low shrink–swell capacity and a low cation-exchange capacity (1–15 mEq/100 g). It is a soft, earthy, usually white, mineral (dioctahedral phyllosilicate clay), produced by the chemical weathering of aluminium silicate minerals like feldspar.

Bentonite is a clay generated frequently from the alteration of volcanic ash, consisting predominantly of smectite minerals, usually montmorillonite Smectites are clay minerals, i.e. they consist of individual crystallites the majority of which are <2μm in largest dimension. Smectite crystallites themselves are three-layer clay minerals. They consist of two tetrahedral layers and one octahedral layer. In montmorillonite tetrahedral layers consisting of [SiO_4]-tetrahedrons enclose the [M(O_5,OH)]-octahedron layer(M=and mainly Al, Mg, but Fe is also often found). The silicate layers have a slight negative charge that is compensated by exchangeable ions in the intercrystallite region. The charge is so weak that the cations (in natural form, predominantly Ca2+, Mg2+ or Na+ ions) can be adsorbed in this region with their hydrate shell. The extent of hydration produces intercrystallite swelling. Depending on the nature of their genesis, bentonites contain a variety of accessory minerals in addition to montmorillonite. These minerals may include quartz, feldspar, calcite and gypsum. The presence of these minerals can impact the industrial value of a deposit, reducing or increasing its value depending on the application. Bentonite presents strong colloidal properties and its volume increases several times when coming into contact with water, creating a gelatinous and viscous fluid. The special properties of bentonite (hydration, swelling, water absorption, viscosity, thixotropy) make it a valuable material for a wide range of uses and applications.

Commercially available bentonite and kaolinite were obtained from Seema chemicals Bengaluru, were stored in air tight plastic containers. Artificially samples of sand-bentonite- kaolinite were prepared in the laboratory in different mix proportions.

3.2 Method

Index tests. The index property test on various mix proportions was carried out as per BIS Specifications; such as, Specific gravity (IS: 2720-Part 3 /sec 2-1980) (ASTM D845-14): Standard test method for specific gravity of soils. Atterberg limits (IS:2720-Part 51985) (ASTM D 4318) Standard test method for liquid limit, plastic limit and plasticity index of soils were conducted. Casagrande cup is used to determine the liquid limit. This test is conducted to determine the soil water content with respect to the number of drops (25) required to bring a 13mm section of a groove cut into the soil sample together. Plastic limit can be found when a gravimetric water content at which a soil sample can be rolled by hand into a thread of 3.2mm diameter without breaking.

Compaction test. About 3kg sample of air-dried mix-proportions were prepared based upon the dry weights of the material and predetermined amount of distilled water were added. The samples were packed in an air tight polythene bag and left for a period of 24 hours to ensure uniform moisture distribution. Standard Proctor test were carried out as per IS:2720 (part 7) 1980 by compacting the mix proportions in three layers with the standard rammer of 2.6 kg giving 25 blows uniformly for each layer from a free fall of 310 mm. Representative sample of it was taken for water content determination. The process is continued till the sample is saturated. Similarly, modified Proctor test was carried out according to IS:2720 (part 8) 1983 with the whole sample compacting it in 5 layers with 25 evenly distributed blows on each layer from 4.9 kg rammer with free fall of 450 mm. In reduced modified and reduced standard Proctor test procedure and equipment for tests are essentially same as that used in modified Proctor and standard Proctor test respectively. Each layer received 15 number of blows of a rammer instead of 25 (it is 60% of the respective energy levels).

4 Results and Discussions

4.1 Figure 1 & 2 shows the variations of liquid limit with MDD for constant bentonite and constant kaolinite mix proportions for different energy levels

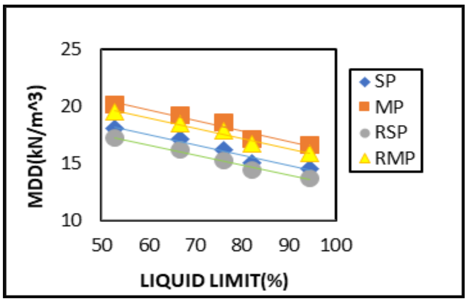

Fig. 1. variations of liquid limit, W_L(%) with MDD (KN/m^3) for constant bentonite

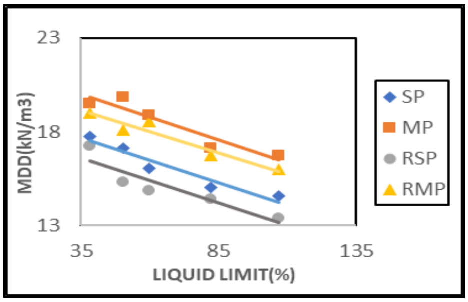

Fig. 2. variation of liquid limit, W_L(%) with MDD (KN/m^3) for constant kaolinite

From these figures it can be observed that, maximum dry density decreases with increase in the liquid limit. It is because of increasing fine content in the mix proportion which in turn increases, the water holding capacity which is also a characteristics feature of a natural fine-grained soils. The mix proportions can be identified by their liquid moisture contents. The corresponding liquid moisture content and maximum dry density are indicated in Table 1 following linear correlations. From these figures it can also be observed that maximum dry density of mix proportions, which is having high percentage of bentonite is lesser, when compared to maximum dry density of mix proportion which contain higher percentage of kaolinite. This mainly due to the bentonite clay which is composed of silica and aluminum sheets arrange in such a way that it absorbs large amount of water forming water tight barrier.

Table 1. Correlation equations of maximum dry density with Liquid limit for both constant bentonite and kaolinite

Clay minerals	Energy Levels	Regression Equation	R^2	R
Constant bentonite	MP	ɣd = -0.091wl + 25.18	0.95	0.97
	RMP	ɣd = -0.090wl + 24.43	0.97	0.99
	SP	ɣd = -0.091wl + 22.97	0.96	0.98
	RSP	ɣd = -0.090wl + 22.04	0.99	0.99
Constant Kaolinite	MP	ɣd=-0.0487wl + 21.702	0.89	0.94
	RMP	ɣd=-0.0448wl + 20.686	0.93	0.96
	SP	ɣd=-0.0474wl + 19.294	0.93	0.96
	RSP	ɣd=-0.0478wl +18.254	0.84	0.92

4.2 Figure 3 and 4 shows the variation of OMC and MDD obtained from different mix proportions irrespective of all energy levels with liquid limit of the mix proportions

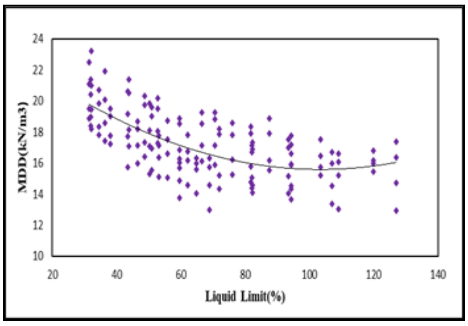

Fig. 3. variation of MDD (KN/m^3) with Liquid limit, W_L (%).

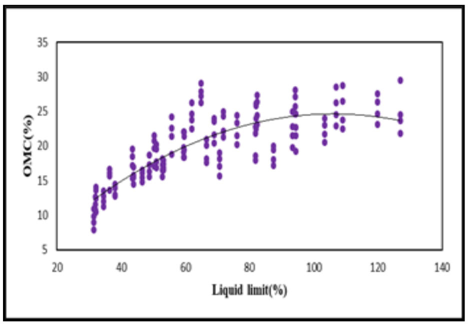

Fig. 4. variation of OMC (%) with Liquid limit, W_L (%).

From figure 3, it can be observed that MDD decreases with increase in the liquid limit for both constant bentonite and kaolinite group. From figure 4, it is observed that OMC increases with increases in the liquid limit for both constant bentonite and kaolinite group. Further MDD and OMC of the mix proportions have a polynomial best fit as given by equations 1 and 2 respectively.

$$MDD = 0.000W_L^2 - 0.168W_L + 24.28 \quad (1)\ R = 0.67$$

$$OMC = -0.002W_L^2 + 0.473W_L - 0.4693 \quad (2)\ R = 0.83$$

4.3 Figure 5 and 6 shows the variation of OMC and MDD obtained from different mix proportions irrespective of all energy levels with plastic limit of the mix proportions

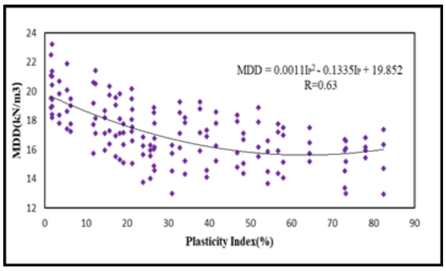

Fig. 5. variation of MDD(KN/m$^{3)}$ with plastic limit, W_P (%).

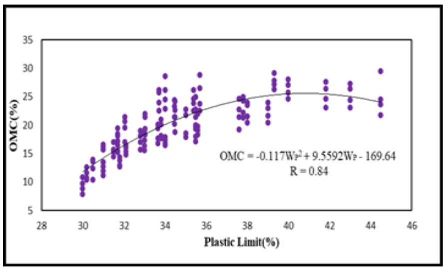

Fig. 6. variation of OMC (%) with plastic limit, W_P (%).

4.4 Figure 7 and 8 shows the variation of OMC and MDD obtained from different mix proportions irrespective of all energy levels with plastic index of the mix proportions

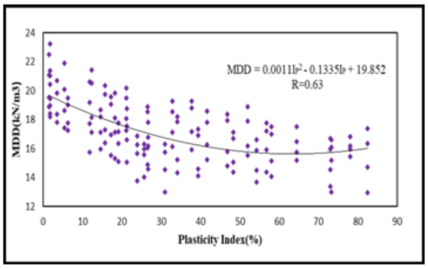

Fig. 7. variation of MDD(kN/m3) with index, Ip (%).

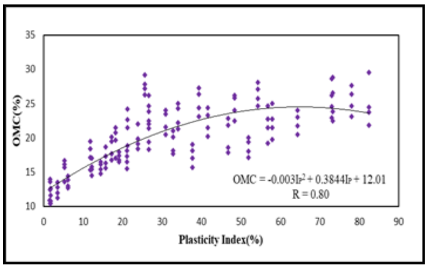

Fig. 8. variation of OMC(%) with Plasticity Plasticity index, Ip (%).

From figure 5 through figure 8 compaction characteristics of MDD and OMC can be effectively related with plastic limit and plasticity index with a polynomial best fit having Correlation coefficient ranging from 0.63 to 0.84.

4.5 Figure 9 and 10 shows the variation of compaction characteristics -MDD with percent fines of the mix proportions for different compaction energy levels

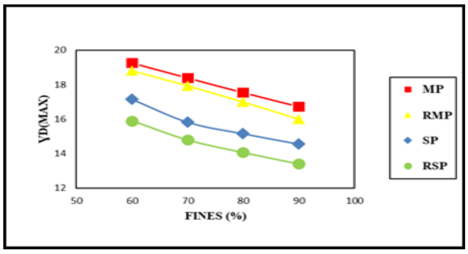

Fig. 9 **variation of MDD, γd_{max}(KN/m^3)** with percent fines, PF(%) for constant bentonite.

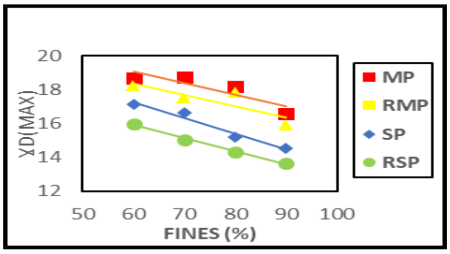

Fig.10.variation of MDD, γd_{max}(KN/m^3) with percent fines, PF(%) for constant kaolinite.

From figure 9 and 10 it can be observed that as the percentage of fines increases the value of maximum dry density linearly decreases. The variation of γd_{max} with percent fines of both constant bentonite and kaolinite looks almost similar. The effect of increasing the compaction energy results in an increase in the maximum dry density. However, the increase in the compaction energy doesn't a have linear relationship with the increase of compactive effort. As the percentage of fines increases, the compaction curve becomes flatter and the maximum dry density will be relatively low because, it requires more water for lubrication as the specific surface increases. Mix proportions form a gel due to the increase in moisture content of the mixture called double diffused layer, which causes the enlargement of the size of voids between the particles.

4.6 Figure 11 shows the variation of maximum dry density with optimum moisture content irrespective of the mix proportions and energy levels

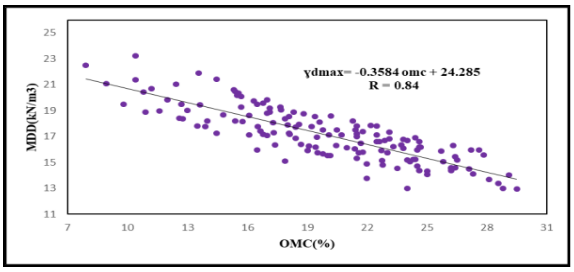

Fig. 11. variation of MDD, γd_{max}(KN/m^3) with OMC (%) different compactive energy levels.

From figure 11 it can be observed that variation of maximum dry density with optimum moisture content irrespective of the mix proportions and energy levels decreases. We can notice marginal variation and it decreases linearly as the percentage of fines increases in the mix proportions.

4.7 Figure 12 & 13 shows the variation of MDD and OMC with compactive energy.

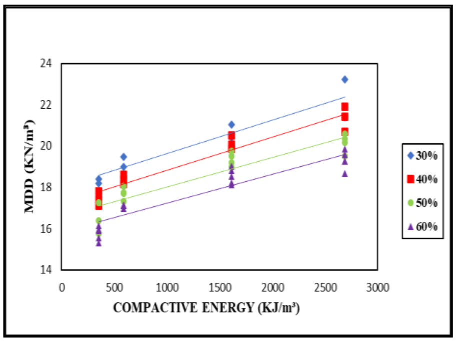

Fig.12. variation of MDD(KN/m³) with compactive energy.

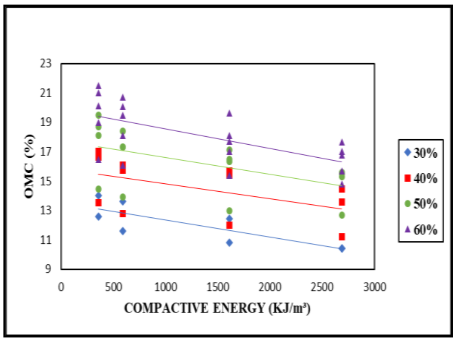

Fig. 13. variation of OMC (%) with compactive energy.

Table 2. variation of compactive energy for different energy levels

Type of Compaction Test	Compactive Energy (kJ/m^3)
Reduced standard Proctor	355.25
Standard Proctor	592.09
Reduced modified Proctor	1613.94
Modified Proctor	2689.9

Table 2 presents the magnitude of compative energy imparted to mix-proportions at various compaction test. Figure 12 and 13 represents the compaction energy level how it varies with maximum dry density and optimum moisture content. It can be observed that well defined pattern of compaction curves for different percentage of fines. For the given mix proportions compaction energy increases with maximum dry density and decrease with optimum moisture content.

4.8 Figures 15 through 18 shows the variation of MDD of natural soils with MDD of artificial soils for different energy levels.

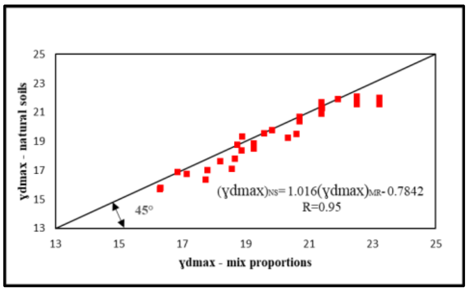

Fig. 15. variation of MDD(KN/m^3) of natural soils with MDD (KN/m^3) of mix proportions of modified Proctor test.

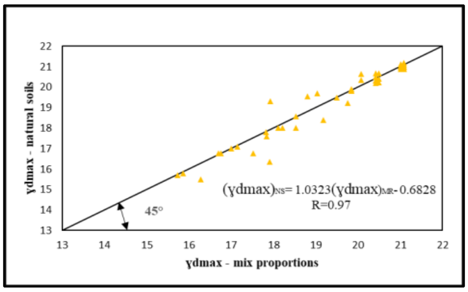

Fig.16. variation of MDD(KN/m^3) of natural soils with MDD (KN/m^3) of mix proportions of reduce modified Proctor test**.**

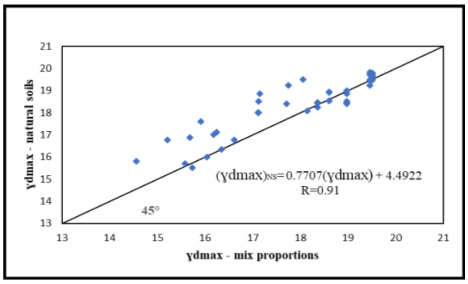

Fig. 17. variation of MDD (KN/m^3) of natural soils with MDD(KN/m^3) of mix proportions of standard Proctor test.

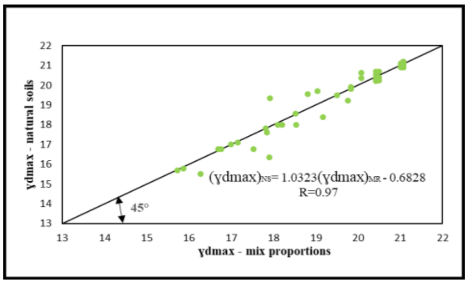

Fig.18. variation of MDD (KN/m^3) of natural soils with MDD(KN/m^3) of mix proportions of reduced standard Proctor test.

4.9 Figure 19 shows the variation of OMC of natural soils with OMC of mix proportion of standard Proctor test.

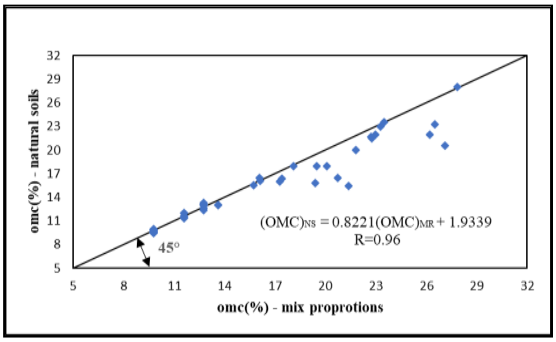

Fig. 19. variation of OMC(%) of natural soils with OMC(%) of mix proportions of standard Proctor test.

$(\gamma_{dmax})_{Natural\ soils} = 1.016\ (\gamma_{dmax})_{mix\ proportions}$ with a regression 0.784 (3)

Figures 15 through 20 shows the variations of maximum dry density of natural soils obtained from authors own experimental work with that of the maximum dry density of mix proportions obtained from the present experimental study from 45º- degree line (called equality line). Natural fine-grained soils having both kaolinite and montmorillonite clay minerals in fines component from author's own study were carefully selected to map percent fines in the natural soils with that of the mix proportions and considered for the comparative study. A careful study of these figures depicts that, the compaction characteristics of natural fine-grained soils can be accurately estimated with that of maximum dry density and optimum moisture content obtained from artificial mix proportions.
To develop a good and reliable correlations we must have a high value of coefficient (R^2). The correlation is an index of the goodness of fit between the two values used to develop the correlation. It provides a quantitative index to predict values and to incite the accuracy for the future predictions. For models of natural soils and mix proportions, the value of R^2 varies between 0.83 to 0.94.

4.10 Figure 20 shows the variations of OMC, MDD of natural soils with OMC, MDD of mix proportion of standard Proctor test.

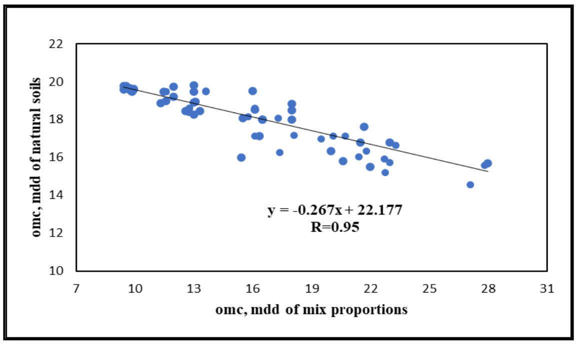

Fig.20. variation of OMC(%), MDD(KN/m^3) of natural soils with OMC(%), MDD(KN/m^3) of mix proportion of standard Proctor test

5 Conclusions

The experimental study permits to promote the following conclusion which should be valid for bentonite-kaolinite-sand mix proportions.

1. Atterberg limits show that small amounts of bentonite and kaolinite present in the mix proportions are able to influence the liquid limit but not the plastic limit.
2. For all types of mix proportions studied, the maximum dry unit weight increases as the bentonite-kaolinite content increases up to 30% then decreases for all energy levels.

3. The optimum moisture content increases for fines, increasing from 20% to 90% of kaolinite and bentonite sand mixtures for all energy levels.
4. Compaction characteristics of bentonite, kaolinite and sand mixtures can be efficiently correlated with liquid limit, plastic limit and plasticity index as given by the equations.
5. The compaction characteristics of natural fine-grained soils having kaolinite bentonite clay minerals in different percentage can be accurately estimated by means of compaction characteristics of mix proportions.

References

1. Bakar Chitoori (2011),'Experimental investigation on the estimation of quantity of clay mineralogy in fine-grained soils', Journal of Geotechnical and Geoenvironmental engineering, Vol.137 pp997-1008.
2. Bidula Bose (2019), 'Compactionbehavior and grain size alteration of sand–clay mix', International Journal of Innovation Technology and Exploring Engineering, Vol.9 pp. 4106-4110.
3. Ennio Polidori (2007), 'Relationship between the Atterberg limits and clay content', Japanese Geotechnical Society, Vol. 47 pp.887-889.
4. Faseel Suleman Khan, S.A., (2014),'Compressive strength of compacted clay-sand mixes',Hindawi Publishing Corporation ,Vol.2014 .
5. Howell, J.L.Shackelford, C. D., Amer, N. H., and Stern, R. T.,(1997), 'Compaction of sand –processed clay soil mixtures', Geotechnical Testing Journal , Vol. 20 pp. 443 -458.
6. Prasanna and Jyothi (2020), 'Compaction characteristics of bentonite, kaolinite and sand mixtures of different mix proportions', International Journal of Recent Technology and Engineering.
7. Robert Proiae et al. (2016), 'Experimental investigation of compacted sandbentonite mixtures', www.sciencedirect.com, Procedia Engineering 158 pp. 51-56.
8. Sridharan and Nagraj (2000), 'Compressibility behavior of remolded fine-grained soils and their correlation with index properties', Canadian Geotechnical Journal, Vol.37 pp.712-722.
9. Sivrikaya and Togrol (2008), 'Estimating compaction behavior of fine-grained soils for varying compaction energy', Canadian Geotechnical Journal, Vol.45(6) pp.877-887.