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Plasticity Characteristics of China Clay-Bentonite-Sand Mix Proportions

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Abstract. In geotechnical engineering, a thorough understanding of the fundamental behaviour of soils plays a pivotal role in the engineering design of earthen structures. The engineering be- haviour of coarse-grained soils is a physical phenomenon whereas for the fine-grained soil it is a physico-chemical phenomenon. The behaviour of fine-grained soil becomes more complex one due to the contradictory behaviour of principal clay minerals present i.e, Kaolinite, Montmoril- lonite in varying proportions in the soil matrix. Further, it is seldom observed that, owing to scare availability of coarse-grained soils at large quantity, forcing construction industry to use fine- grained soils having different clay mineralogy as an alternative material for a better construction. The plasticity characteristics of fine-grained soils predominantly control the engineering behav- iour to greater extent. In the present experimental study, a series of mix proportions of commercially available China clay, Bentonite along with Sand were artificially prepared in the laboratory representing Kaolinite and Montmorillonite soils behaviour. The physical properties of the mix proportion were determined as per BIS specifications. The plasticity characteristics of mix pro- portion were correlated with plasticity characteristics of natural fine-grained soils. The new plas- ticity chart was developed which is akin to the IS plasticity chart. The activity of the mix propor- tions were also analysed and compared with that of natural fine-grained soils.

Keywords: Clay mineralogy, Physical properties, Activity, Plasticity chart.

1 Introduction

Kaolinite and Montmorillonite are the two clay minerals present in the natural soils. In kaolinite due to attractive forces dominance, flocculent structure is seen in soil, whereas in montmorillonite due to repulsive forces dispersive structure is seen. The behavior of fine grained soil is distinct because of its physico-chemical in nature which is influ- enced by the soil clay mineralogy. A lot of financial requirements and time is required to study the Plasticity characteristics and activity of fine grained soils having different clay mineralogy around the world. In order to get over this problem, in the present experimental study the plasticity characteristics, activity of artificially prepared China

Clay- Bentonite sand mix proportions which is likely to represent the natural fine grained soil behaviour are studied. the new plasticity chart in conjunction with IS plasticity chart is also developed. this chart is also used in accessing the physical properties of clay. Acitivity of artificially prepared sand mix proportions chart is also developed and compared with nature soils. In this Experimental study data analysis of artificially prepared soils in laboratory representing the natural fine grained soils

2 Literature review

(1964) in their experimental work on clay mineralogy observed that mixtures of illite and bentonite are less active than mixtures of kaolinite and bentonite in the same properties and has lower swelling characteristics.
Doubleton et al. (1966) made an attempt to study on the factors affecting the relation between the clay minerals in soil and their plasticity and the relationships between clay content, plastic limit and liquid limit of natural montmorillonite and kaolinitic soils and of artificial mixtures have been examined and compared.
Bain (1971) has showed that a plasticity chart as aid to the identification and assessment of industrial clays. This identification can be done by using their Atterberg 'Plastic limit' and 'Plasticity index' values as parameters for an identification chart.
Sridharan et al. (2000) studied on shrinkage limit of soil mixtures. The study gives that shrinkage limits of the natural soil will not depend on plasticity characteristics.This study confirms this mechanism with the result obtained using clay-clay, clay-non cohesive soil, and non-cohesive soil mix system.
Polidori (2007) investigates on the liquid limit and plastic limit of six inorganic soils with fine silica sand. The study gives that knowing the two out three parameters, the value of other parameters can be obtained.
Ennio polidori (2009) study on activity of clays and activity chart aims to classify soils. The activity chart adapted to predict residual shear behavior of cohesive soils.
Ashis Kumar Bera (2011) made detailed experimental work on effect of sand content on engineering properties of fine grained soil mixed with sand .The study highlights the effect of mixing sand (%)on liquid limit, plastic limit of fine grained soil.
Uprety (2016) conducted test on index properties of the soils using cyclic triaxialshear test. They observed that the state of knowledge on the effects of plasticity on liquefaction characteristics of the fine grained soil.
Prasanna et.al (2020) made a study on index properties of kaolinite and bentonite sand mixtures. Index properties have an induce on the shrinkage characteristics, compaction, swelling, shear strength, bearing capacity of the kaolinite-sand mixtures and bentonite-sand mixtures. In their study, an effort was also made to match up the index properties of natural soil with that of artificial mix proportions.

Detailed literature review of Plasticity characteristics of kaolinite-bentonite- sand mixture is very scanty.

3 Materials and Method

Soil mix proportion contains commercially available clay minerals like china clay and bentonite, along with natural river sand. China clay (kaolin) is a clay mineral that is part of industrial mineral with chemical composition $Al_2Si_2O_5(OH)_4$, it is chemically inert and prepared as a white powder. Bentonite is physically and chemically reactive. It shrinks or swells and exhibits cation exchange. The river sand was initially wet washed to remove the dirt and silts, Later it is oven dried for 24 hour at a temperature of 105±5˚C and it is brought to a normal temperature and sieved through 425µm. Commercially available bentonite and kaolin were obtained from Seema chemicals Bengaluru, were stored in air tight plastic container are mixed with well-prepared sand in varied proportions.
By keeping the bentonite constant the sand and china clay proportions were varied i.e., 10%B constant for mix ratio-1 with China clay varying from 10% to 80% and sand varying from 80% to 10%. Correspondingly 20%B, 30%B .., keeping bentonite constant with sand and kaolinite varying proportions were prepared up to mix ratio-8. Similarly keeping kaolin constant, with sand and bentonite varying mix proportions prepared. The collected data has been correlated with plasticity characteristics of natural fine grained soils and made an effort to develop new plasticity chart which is cognate to the Casagrande's plasticity chart.
The index property test on the mix proportions was carried out as per BIS specifications. In the present experimental investigation plasticity characteristics of a soil mix proportions are evaluated from the Atterberg limits (IS2720-PART 5 1985) to determine liquid limit, plastic limit and shrinkage

3 Experiment Re and Discussion

Figure 1 and 2 shows Variation of Liquid Limit with Percent Fines

Figure 1 shows the liquid limit with percent fines of MR-1 to MR-8.It can be observed that liquid limit increases from 31.5 to 127 percent (4 Folds) with the increase in percent fines in the artificial mix proportion. From Fig.2, for MR-1 to MR- 8 liquid limit increases from 31.5 to 69 percent (2.2 Folds) with the increase in percent fines in the mix proportion. This is due to the fact that increase in fines content results in increase in the water holding capacity, which is also a characteristic feature of a fine grained soil. From Figure 1 and 2 it can be also observed that liquid limit of mix proportions which is having higher percentage of bentonite is greater compare to the liquid limit of artificially prepared mix proportions which contain higher percentage of kaolinite which is mainly due to bentonite clay is composed of silica and alumina sheets arranged in such a way that it adsorb large amount of water forming water tight barrier. It is observed that an effective correlation is seen for both constant bentonite and constant kaolinite mix proportions.

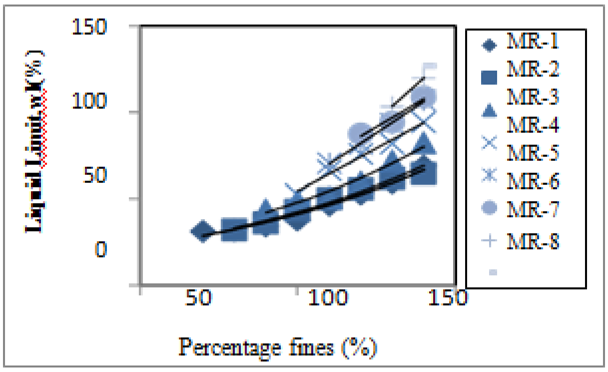

Fig. 1. Variation of Liquid Limit, WL (%) with Percent Fines, PF (%) for constant Kaolinite

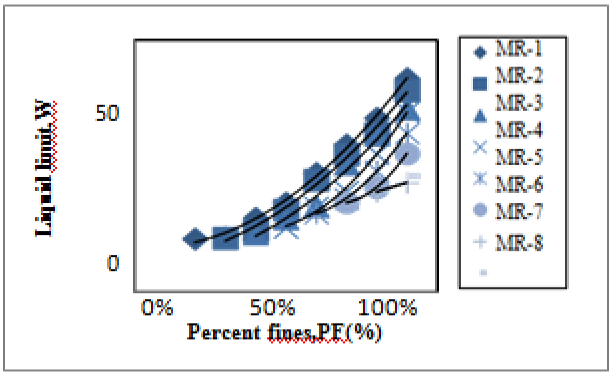

Fig. 2. Variation of Liquid Limit, WL (%) with Percent Fines, PF (%)

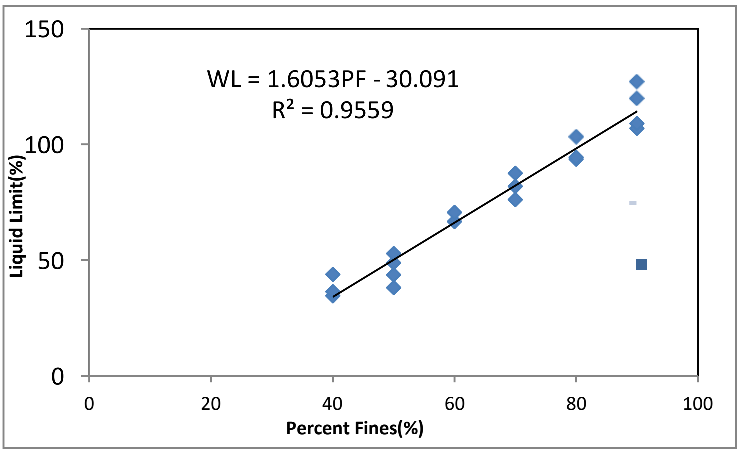

Fig. 3. Combined Variation of Liquid Limit with Percent Fines

Combined variation of liquid limit with percent fines is presented in Fig 3 and the relation is found to be is linear. The relationship between liquid limit and percent fines is given in Equation 1

$$W_L = 1.61PF - 30.1 \qquad (1)$$

Using this equation we can predict the value of liquid limit for any other value of percent fines without performing

Figure 4 and 5 shows Variation of Plastic Limit with Percent Fines

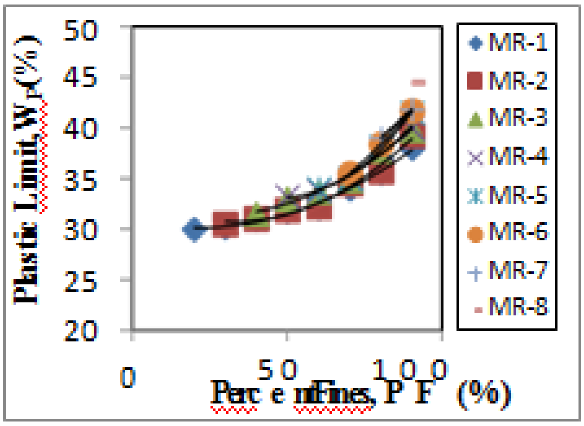

Fig.4. Variation of Plastic Limit W_p with percentage fines

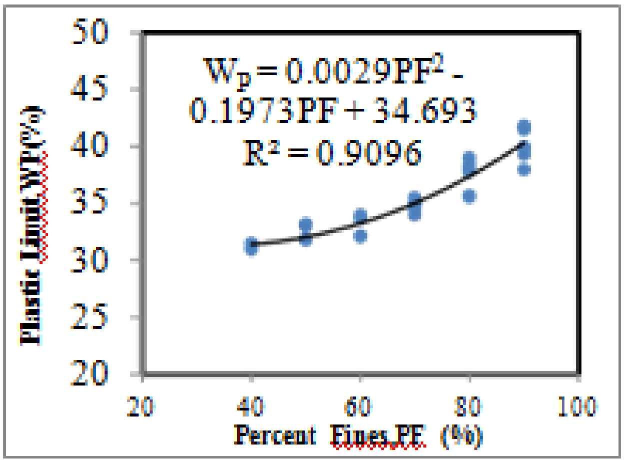

Fig. 5. Combined Variation (MR-1 to MR-8) of Plastic Limit with Percent Fines.

From Fig.4, Plastic limit of MR-1 to MR-8 increases from 30 to 44.50 percent. In Fig.1 the bandwidth of variation of liquid limit with percent fines is very high compare to that of plastic limit(Fig.4).Hence, plastic limit which is having small range of band-width is considered has one of the important plasticity characteristics rather than the liquid limit value alone.

This small range of bandwidth can be plotted (Fig 5) as a combined variation of plastic limit with percent fines which gives the best average polynomial equation shown in Eq 2. The plastic limit equation for a soil mix proportion is given by equation (2).

$$W_P = K1\ (PF) + K2\ (PF)\ 2 + 34.59 \qquad (2)$$

The Average value of intercept WP =34.59%, where the slopes K1 and K2 depends on the clay mine.

The regression equations of plotted mix proportion in Fig.4 and its correlation coeffi-cients are tabulated in Table 1

Table 1. Correlation equations for MR-1 to MR-8 of Plastic limit with Percent fines

MIX RATIO NO.	CORRELATION EQUATION	R^2	R
1	W_P= 32.10PF^2-16.65PF+32.53	0.975	0.987
2	W_P = 24.90PF^2- 11.42PF+31.64	0.984	0.992
3	W_P = 33.57PF^2- 22.57PF+34.75	0.996	0.998
4	W_P = 47.85PF^2-41.9PF+40.58	0.994	0.997
5	W_P = -5PF^2+34.5PF+13.1	0.994	0.997
6	W_P = 120PF^2-163PF+89.3	1	1
7	W_P =37PF +6	1	1

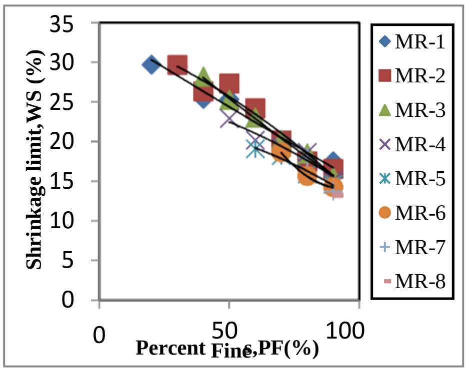

Fig. 6. Variation of shrinkage limit WS (%) with percent

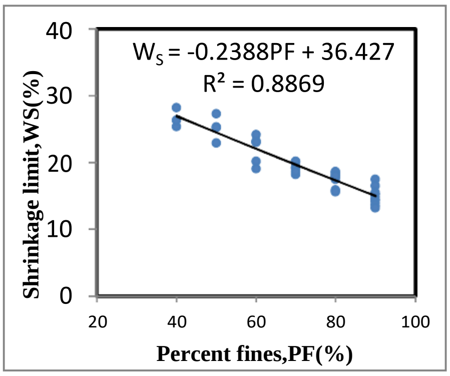

Fig. 7. Combined variation of shrinkage limit with percent fines

Figure 6 and 7 shows Variation Of Shrinkage Limit With Percent Fines

From Fig.6, it is observed that for MR-1 to MR-8, Shrinkage limit decreases from 29.68 to 13.2percent (2.24 folds). It can be observed that shrinkage limit is the opposite process of liquid and plastic limit of artificially prepared mix proportions.
Sridharan et.al (1998) shown that shrinkage limit is a function of grain size distribution of the natural soil, irrespective of the clay minerals of the soil and it does not depend on plasticity characteristics and it is for the different natural soil. Artificial mix proportion is the true representative of the natural soil behaviour. The best relation between the shrinkage limit and percent fines is the linear relationship. The equation remarked in Fig.6, refer to the average value of intercept, W_S =36.42%. , The general equation representing the relation between shrinkage limit and percent fines is given by Eq 3.

$$Ws = K3\ (PF) + 36.42 \qquad (3)$$

Where the W_S-slope K3 depends on the clay minerals present.

Correlation equations and its coefficients of MR-1 to MR-8 (Fig.6) are tabulated in Table 2.

Table 2. Correlation Equations for MR-1 to MR-8 of Shrinkage limit with Percent fines

MIX RATIO NO	CORRELATION EQUATION	R^2	R
1	$W_S = 1E\text{-}04PF^2 - 0.20PF + 34.384$	0.95	0.97
2	$W_S = -0.001PF^2 - 0.11PF + 33.703$	0.95	0.97
3	$W_S = 0.0004PF^2 - 0.29PF + 39.299$	0.99	0.99
4	$W_S = -0.001PF^2 - 0.03PF + 26.516$	0.92	0.96
5	$W_S = -0.0012PF^2 + 0.01PF + 22.253$	0.97	0.98
6	$W_S = 0.0078PF^2 - 1.47PF + 83.5$	1	1
7	$W_S = -0.431PF + 52.47$	1	1

Figure 8 shows Plasticity Chart of Artificial Mix Proportion

Figure 8 shows the plasticity chart of the artificial mix proportion which is cognate to Casagrande's chart. In the above chart mix proportions are classified into silt (M) and clay(C), based on their liquid limit (W_L) and plasticity index (I_P). The relation between plasticity index (IP) and liquid limit (W_L) is remarked in Eq-4 which is akin to A-line equation

$$I_P = 0.86(W_L - 30.5) \qquad (4)$$

This Artificially prepared mix proportions line normally spilt the clay and silt materials. This mix proportions are further subdivided into low (L) or high (H) plasticity based on the liquid limit.

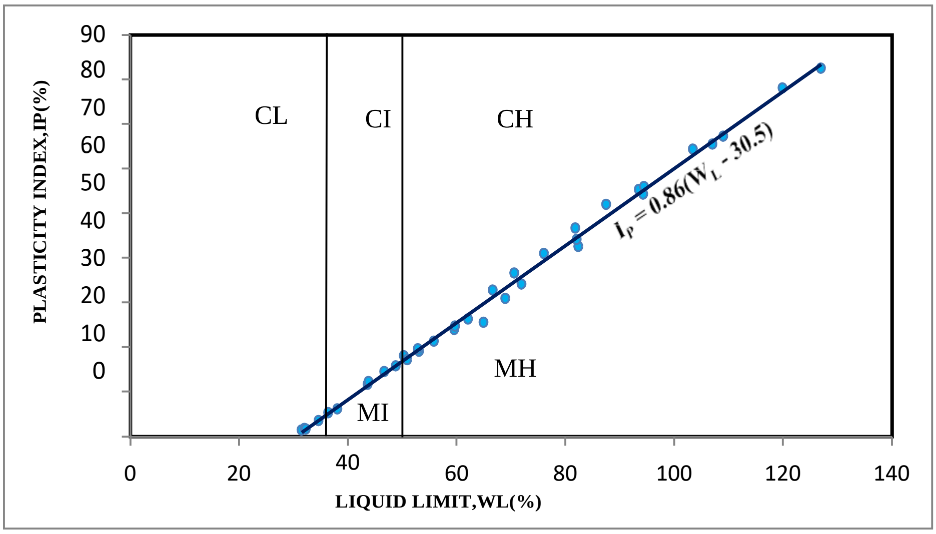

Fig. 8. Plasticity Chart of the Artificial Mix Proportion

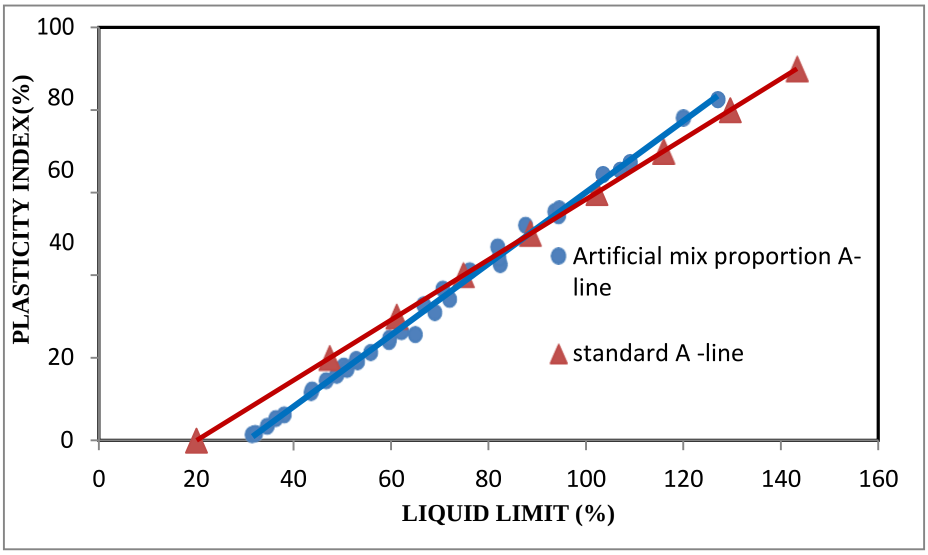

Fig. 9. Variation of Plasticity Index, IP with liquid limit, W_L of artificial mix proportion and natural soils.

An attempt has been made to compare the Casagrande's plasticity chart with plasticity chart of artificial mix proportion. From Fig.9, it is observed that they are in close agreement with one another.

Casagrande's A –line equation and artificially prepared mix proportion equation of soil mixtures are indicated in Table 3.

Table 3. Correlation equation

Mix proportion equation	$I_P = 0.87(W_L - 30.5)$	R=0.998
A-line equation	$I_P = 0.73(W_L - 20)$	R=1

Figure 10 shows Activity of artificially prepared mix proportions

The properties of clays and their behavior are mainly due to presence of certain clay minerals. Activity of a soil is equal to the ratio between plasticity index value and it's percent fines, least and highest activity values belong to pure clay minerals kaolinite and bentonite, respectively.

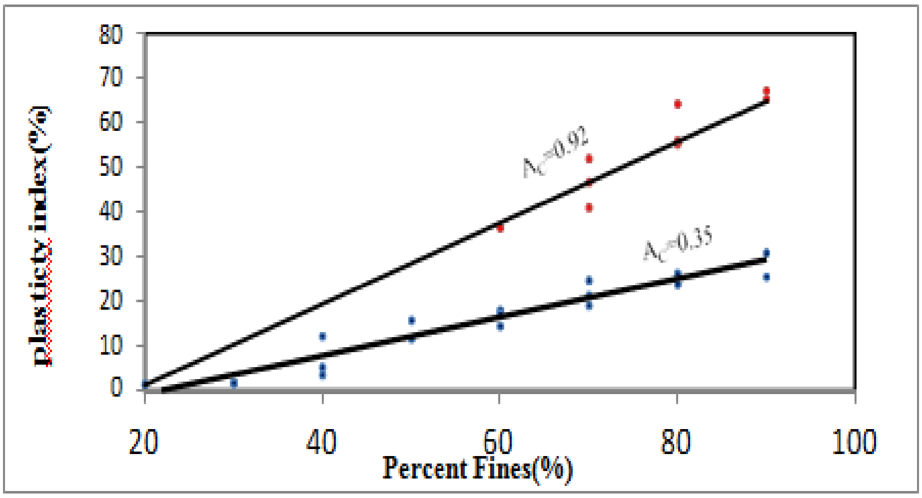

Fig.10. Activity chart of artificial mix proportions

In Fig. 10 activity chart is given for an artificial mix proportions, kaolinite have an activity values ranging from 0.1-0.35 and montmorillonite have 0.5-0.92 indicated in Table.4. The experimental study shows that artificial mix proportion activity values matches with that of the natural soils as proposed by Skempton in 1953.
Activity of the natural soil with artificial mix proportion is compared and tabulated in Table 4 and 5.

Table 4. Activity of artificial mix proportion

Mineral	Activity
Montmorillonite	0.5-0.92
Kaolinite	0.1-0.35

Table 5. Activity of natural clay minerals

Mineral	Activity
Montmorillonite	0.7-1.0
Kaolinite	0.4-0.5

Figure 11 shows Variation of Liquid Limit with Plastic Limit

Figure 11 shows the variation of plastic limit as a function of liquid limit in the mix proportions for different percentage of fines. The trend lines are parallel with a common slope of 0.079, if all the lines are extended, they pass through the axis of ordinate at Z= 0.058PF+28.95, which is a function of percent fines. The relationship of liquid limit, plastic limit and percent fines is given by Eq-5

$$W_P = 0.079W_L + (0.058PF+28.95) \quad (5)$$

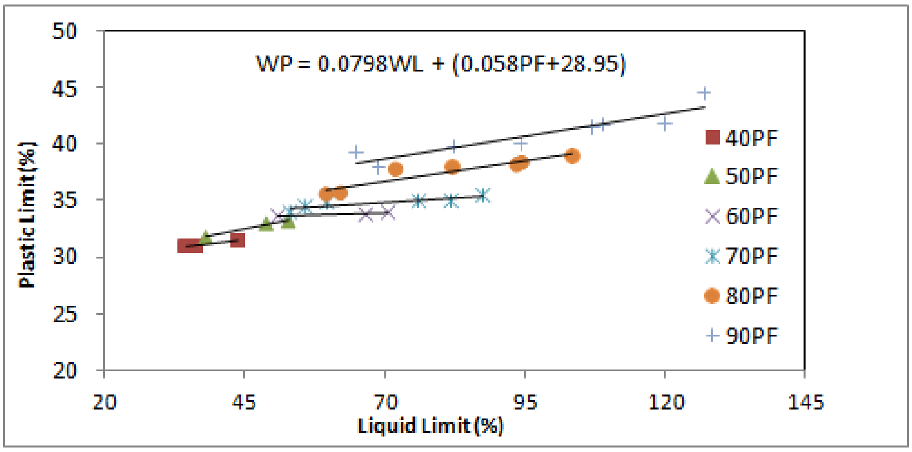

Fig.11. Variation of liquid limit with plastic limit.

Plasticity Index

In Figure 8 plasticity index is defined by difference between liquid limit and plastic limit. Plasticity index can be obtained by liquid limit and percent fines without the value of plastic limit. The relationship between plasticity index (IP), liquid limit (W_L) and percent fines is given by Equation 6

$$I_P = 0.86W_L - (0.058PF+28.9) \quad (6)$$

From Equation 6 for known value of W_L and PF, the value of plasticity index is esti- mated. Using equation 1 and 5 for different value of percent fines, the value of W_L and I_P can be estimated respectively without performing the test.

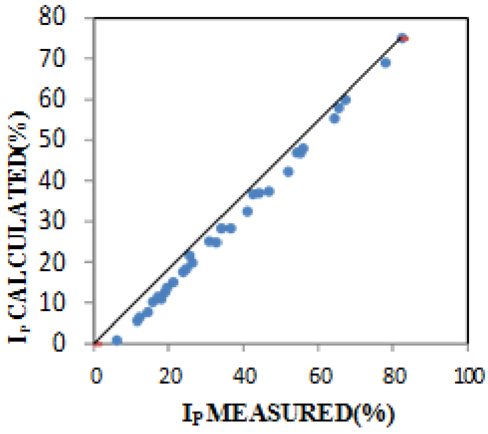

Fig. 12. Comparison between measured and calculated plasticity index

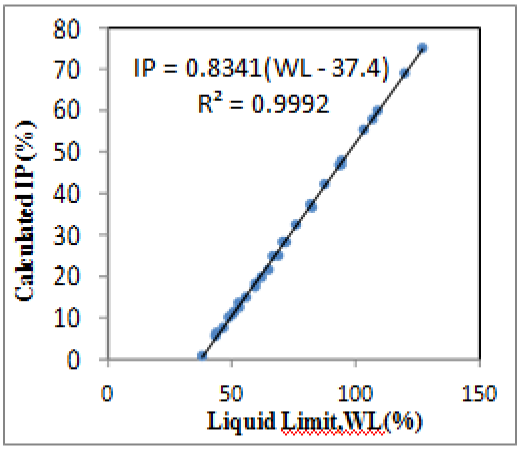

Fig. 13. Plasticity chart of calculated plasticity index with liquid limit

Figure 12 shows the relation between the calculated and measured data of plasticity index . Calculated plasticity index can be obtained by Equation 5 (which is graphically given) and made an attempt to compare the IP measured and calculated data of the artificially prepared mix proportions. It can be observed that the values are in close agreement with one another.

Figure 8 and 13 shows the plasticity chart for measured and calculated value of plasticity index with liquid limit for an artificially mix proportions. Both the correlations are in close agreement with the Casagrande's plasticity chart.

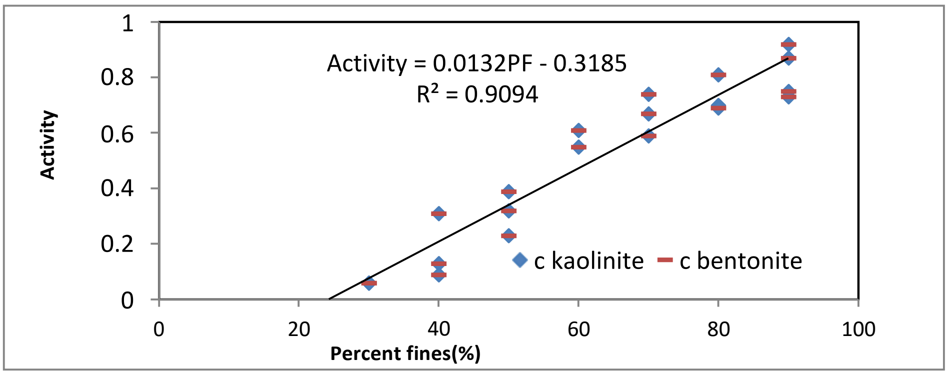

Fig. 14. Variation of activity with percent fines

Activity of the soil depends on the percent fines. Variation of activity with percent fines shown in Fig 14, for constant bentonite and constant kaolinite. Tthe correlation between activity and percent fines is given in Eq 7 with correlation coefficient

$$A = 0.013PF - 0.319 \quad (7)$$

$$R^2 = 0.9094$$

Figure 15 and 16 shows Relationship of plasticity characteristics of natural with that of artificial soil mixtures.

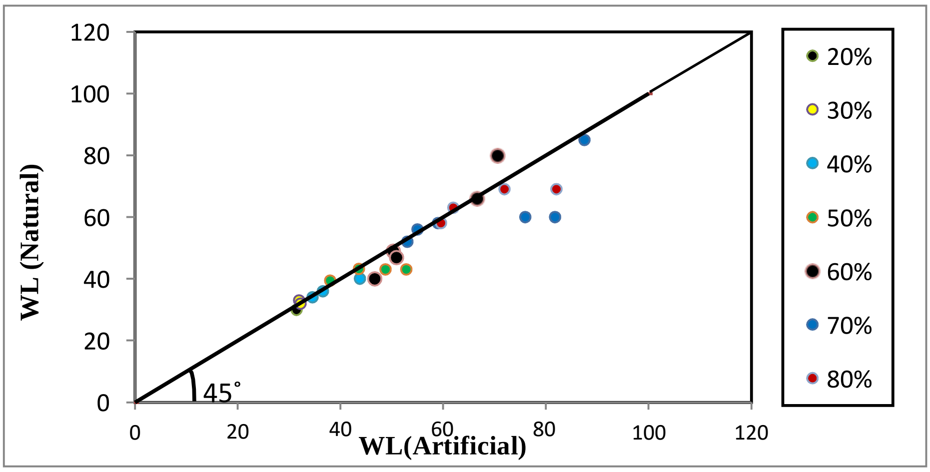

Fig. 15. Liquid limit of Natural with artificial soil mixture

In Fig.15, the liquid limit of artificial mix proportion with that of natural having percent fines which is having same percentage as that of mix proportions and it is observed that from 20 to 80percent fines, lies on the line of equality. Hence it can be concluded that artificial mix proportion prepared in the laboratory has similar plasticity characteristics of natural soils.

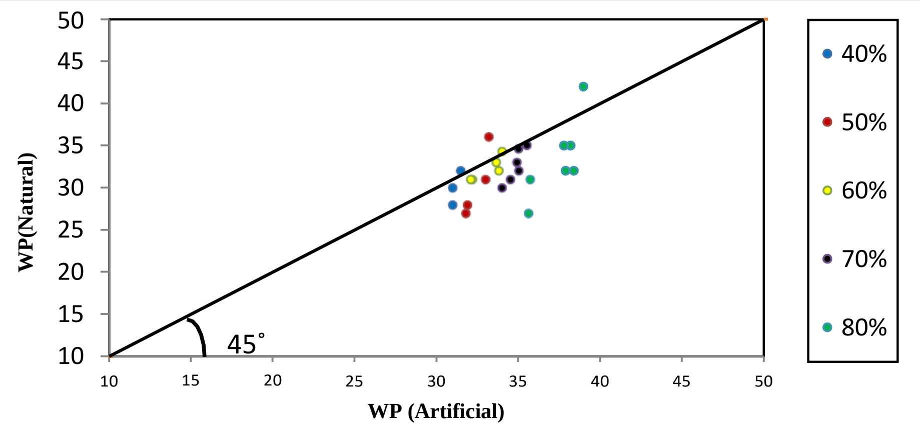

Fig. 16. Plastic limit of Natural with artificial soil mixture

Figure 16 shows the variation of plastic limit of natural soils obtained from the author's experimental work with that of the plastic limit of mix proportions obtained from present experimental study. It is observed that the range of plastic limit values vary from 30 to 40%.

It can be concluded that the plasticity characteristic of natural fine grained soils (W_L, W_P) can be estimated with the help of artificial mix proportions with a fair degree of accuracy.

4 Conclusions

On detailed study the following conclusions can be made

1. Liquid limit and plastic limit increases with increase in percent fines in the mix proportion, which is due to increase in fine content results in the water holding capacity. Liquid limit of mix proportion having higher percentage of Bentonite is greater compare to having higher percentage of Kaolinite this is due to formation of water tight barriers.
2. Shrinkage limit decreases due to grain size distributions of the natural soil and doesn't depend on plasticity characteristics. Shrinkage limit and percentage of fines shows linear relationships, which shows that, artificial mix proportion is the true representative of the nature soil behavior.
3. Plasticity chart of artificial mix proportion is compatible to the Casagrande's plas- ticity chart and activity values of artificial mix proportions matches with the natural soil.
4. A graphical equation is defined to estimate the value of plasticity index for any other value of percent fines and an effort has been made to contrast the measured and calculated data.
5. The liquid limit and plastic limit of artificial mix proportion and natural soils are

compared and it is observed that both the soils position on the line of equality. This concludes that artificial mix proportion prepared in the laboratory has similar plasticity characteristics of natural soils.

References

1. Ashis kumar bera (2011) 'effect of sand content on engineering properties of fine grained soil' EJGE, Vol-16, 1275-1286.
2. Ennio Polidori (2007) 'Relationship between the Atterberg limits and clay content', Soils and foundations, vol.47, No 5, 887-896.
3. Ennio Polidori (2009) 'reappraisal of the activity of clays, activity chart' Soils and foundations, vol.49, No 3, 431-441.
4. H Bolton seed et al.(1964) 'clay mineralogical aspects of the atterberg limits' journal of the soil mechanics and foundations division, Vol. 90, issue 4, Pg. 107-131.
5. J. A.Bain (1971) ' a plasticity chart as an aid to the identification and assessment of industrial clays' clay minerals, No 9, 1.
6. M. J. Dumbleton and G. West (1966) ' relation between clay minerals in soils and their plasticity', clay minerals, No 6,179.
7. Prasanna et al (2020) 'a study on index properties of kaolinite and bentonite sand mixtures' AIP conference proceedings 2204 (1),020009.
8. Sridharan, A. and Prakash, K. "Shrinkage Limit of Soil Mixtures," Geotechnical Testing Journal, GTJODJ,Vol.23, No. 1, March 2000, pp