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Influence of Plastic Fines on Compaction and Shear Strength Characteristics of Soil Mixtures

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Abstract:- One of the most important design input parameter needed for geotechnical design is soil's shear strength. 'Shearing Strength' of a soil is perhaps the most important of its engineering properties. This is because all stability analyses in the field of Geotechnical engineering, whether they relate to foundation, slopes of cuts or earthen dams, involves a basic knowledge of this engineering property of the soil. In practice, in selection of borrowed earth for construction of above mentioned structures, importance is paid to the quality of fines only as if quantity of fines is non-influential. It is necessary to understand the effect of quantity of fines on mechanical behavior of soil mixtures. With this objective, the plastic fines completely exclusive of coarse are added to the coarse fraction/sand completely free from fines in the proportion of 5% to 50% by weight of the sand. The compaction characteristics, shear strength values of mixtures in different proportion are determined. The results clearly indicated the fact that, there is a specific Critical Fines Content (CFC) for the mixture, such that the presence of plastic fines up to this critical fines content (CFC) is beneficial in terms of improving the gradation and increase in shear strength values. The CFC for the soil used in the study was found to be 30%. Hence, this study useful to the practicing Civil Engineers in predicting the behavior of soil mixtures based on the plastic fines content. Further, this study suggests the need for inclusion of quantity of plastic fines in addition to their quantity in relevant Codes of practice.

***Keywords**:- plastic fines, soil-mixtures, compaction, Shear Strength, SPSS, regression equations.*

I. INTRODUCTION

The occurrence and distribution of soils in nature is such that, the various types of soil can be found together in general, natural sand commonly consists of fines and sand particles with different proportions, and the fines content significantly affects the engineering properties of sandy soil. Several instances are reported wherein soil mass with highly plastic fines but in very low proportion are rejected even though its shear strength values are satisfactory. It is therefore necessary to investigate the role of plastic fines possessing objectionable PI value on the design parameter Shear Strength when the fines are in different percentages. Efforts are made in this direction in the present study.

II. OBJECTIVES

The primary objective of this study is,

- To study the influence of plastic fines on the Shear Strength characteristics of the soil mixtures.
- To understand the role of plasticity of fines on Shear Strength characteristics of the soil mixture at Optimum Moisture Content (OMC), Saturated Moisture Content (SMC).
- Identification of the "Critical Fines Content" for the soils used in this study, above which the plastic fines start influencing the geotechnical behavior of soil mixtures.
- To explore the possible correlation between the percentage fines and shear strength values.

III. SCOPE

The scope of present study is limited to, investigation of influence of fines on soil mixtures involving one type of sand and plastic fines only. Further, the scope is limited to observe the mechanism at macroscopic level i.e. in terms of Shear Strength.

IV. LITERATURE REVIEW

Until recently, few studies have reported on the behavior of granular sandy and/or clayey soil with different fines contents. Sreedhar, M.V.S., et al. (2009), investigated on the role of fines content on CBR value of sand-clay mixtures and proposed a Critical Fines Content (CFC). They reported that, fines in excess of CFC transform the load bearing mechanism from cohesion-less behavior to cohesive behavior governed by plasticity. Vu To-AnhPhan, et al. (2016), investigated on the effects of fines content on cohesion, internal friction angle and critical state in the consolidated undrained shear test of sand-fines mixtures. Luis E. Vallejoa and Roger Mawby (2000), investigated the porosity influence on the shear strength of sand-clay mixtures. The previous investigations mainly focused on the effects caused by intrinsic properties of clays and low plasticity. To date, no explanation has been put forward to account for the influence of high plasticity soil fines fraction on the Shear Strength and why these limits of fine material in the mixture exist at which it either doesn't controls, partially controls or has full control

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on the engineering properties of the mixtures. This study describes such a study.

V. METHODOLOGY

The methodology adopted in this study includes:

- Collection and characterization of materials
- Formulation and Scheme of Experiments
- Conducting Compaction and Shear strength tests as per scheme of experiments
- Analysis of results and formulation of conclusions.

A. Collection and Characterization of materials:

The materials used in this study are natural sand as coarse fraction and black cotton soil as plastic fines.

- *Natural Sand*

Locally available river sand is used for the present study. The summary of the index and engineering parameters of the tests done in the accordance with the respective Indian Standard Specifications are shown in the Tables 1 and 2 given below. Based on the tests done, the soil is classified as well graded sand 'SW'.

S. No.	Properties	Values
1	Results of Sieve analysis	
	Gravel size %	3.80
	Sand size %	94.80
	Fines %	1.40
	Coefficient of uniformity of sample Cu	6.92
	Coefficient of Curvature Cc	1.05
2	Specific Gravity (G)	2.67
3	Classification of sand	SW

Table 1. Summary of Index properties of natural sand

S. No.	Properties	Values
1	IS Heavy Compaction Test	
	Optimum Moisture Content (OMC) %	12.10
	Maximum Dry Density(MDD) (kN/m^3)	18.20
2	Shear parameters from Direct Shear Test	
	At OMC	
	Cohesion 'c' (kN/m^2)	0
	Angle of Shearing resistance 'Φ'(degrees)	42
	At SMC	
	Cohesion 'c' (kN/m^2)	0
	Angle of Shearing resistance 'Φ'(degrees)	38.65

Table 2. Summary of Engineering properties of natural sand

B. Plastic fines

Black cotton soil collected from beside overhead water tank in front of NITW main road has been used as plastic fines for the present investigation. The summary of the results of both index and engineering properties are shown in the Tables 3 and 4 below. Based on the soil test results the soil is classified as 'CH'.

S. No.	Properties	Values
1	Wet Sieve analysis	
	Gravel size %	0.10
	Coarse Sand size %	18.60
	Silt size %	36.40
	Clay size %	44.90
2	Specific Gravity (G)	2.60
3	Atterberg's Limits	
	Liquid Limit (LL) %	50.50
	Plastic Limit (PL) %	20.20
	Plasticity Index (PI) %	30.30
4	DFSI %	46.00
5	Classification of soil	CH

Table 3. Summary of Index properties of plastic fines

S. No.	Properties	Values
1	IS Heavy Compaction Test	
	Optimum Moisture Content (OMC) %	14.10
	Maximum Dry Density(MDD) (kN/m^3)	17.30
2	Shear parameters from Direct Shear Test	
	At OMC	
	Cohesion 'c' (kN/m^2)	63.0
	Angle of Shearing resistance 'Φ'(degrees)	10.31
	At SMC	
	Cohesion 'c' (kN/m^2)	27.0
	Angle of Shearing resistance 'Φ'(degrees)	6.00

Table 4. Summary of Engineering properties of plastic fines

C. Proportioning of Materials

The soil mixtures were obtained by blending clay and sand uniformly of required proportions manually. The natural sand is washed thoroughly out of fines of size minus 75 microns and oven dried. Clean oven dried sand has been mixed with different proportions of black clayey soil to form different sand-clay soil mixtures. Fines content of the soil mixtures used as 5, 10, 20, 30, and 50 percent by weight of sand. While proportioning, care was taken to account for the coarser fraction present in clayey soil such that overall coarse and fines content of the mixture makes up to the designated proportion.

D. Compaction and Shear Strength tests

The IS Heavy compaction tests were done on mixtures of different fines content as per IS: 2720 (Part-7) -1980. The corresponding samples for Shear Strength by using Direct Shear Test (DST) were prepared at their respective OMC and SMC as per IS: 2720 (Part-13) -1980.

VI. RESULTS AND DISCUSSIONS

The results of different tests performed in this study are presented in this section. The variation of different test parameters is analyzed and relevant observations are made.

A. Grain size distribution

The variation in particle size distribution with increase in fines content shown in Fig.1.

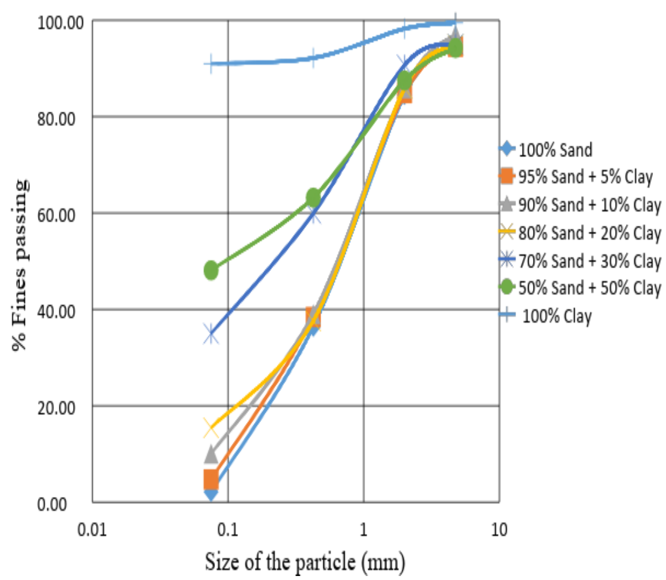

Fig 1:- Variation in particle size distribution with increase in fines content

B. Plasticity Index

S. No.	Sand (%)	Clay (%)	LL%	PL%	PI%	Unified Soil Classification
1	100	0	-	-	-	SW
2	95	5	-	-	-	SW
3	90	10	14	-	-	SP-SC
4	80	20	17	-	-	SM
5	70	30	21	14.60	6.40	SM-SC
6	50	50	29	15.70	13.30	CL
7	0	100	50.50	20.20	30.30	CH

Table 5. Summary of Atterberg's limits of specified soil mixtures

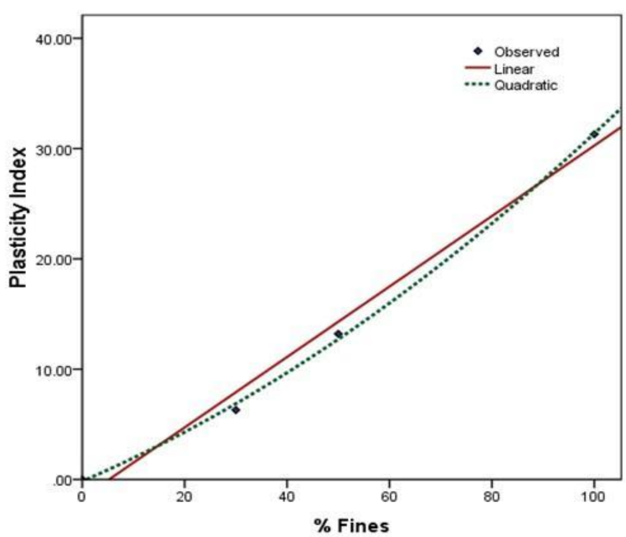

Fig. 2. Variation in Plasticity Index with increase in fines content

The Fig.2 shows a graph of the clay content and plasticity index in which a strong correlation exists between the two parameters. To determine the best fitting trend line several types of lines were fitted on the graph which included linear and quadratic functions. The correlation between the plasticity index and fines content is presented in equation (1) below.

$$PI = 0.001F^2 + 0.2\,F - 0.161 \qquad (R^2 = 0.999) \qquad (1)$$

Where PI = Plasticity Index
F = Percentage of fines content

C. Compaction characteristics:

The results of IS Heavy compaction tests performed on different soil mixtures are summarized in Table 6.

S. No.	Sand (%)	Clay (%)	OMC (%)	MDD (kN/m^3)
1	100	0	12.60	18.19
2	95	5	11.00	18.23
3	90	10	10.00	18.80
4	80	20	10.10	20.00
5	70	30	10.70	20.40
6	50	50	11.50	19.70
7	0	100	14.10	17.30

Table 6. Summary of Atterberg's limits of specified soil mixtures

- *Optimum Moisture Content*

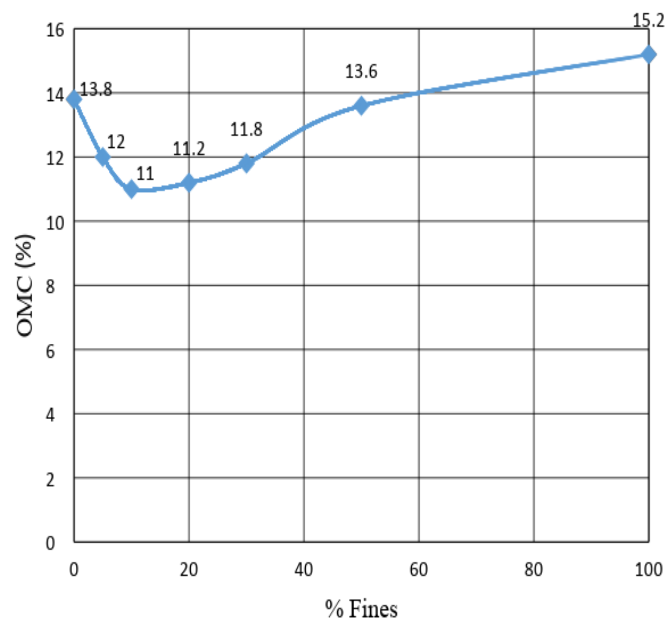

Fig 3. Variation in OMC with fines content

From the reference Fig 3 the following observations are drawn:

- The OMC value decreased upto 10% substitution and increased gradually as the fines content is increased. In general, the OMC of the soil increases with increase in clay fraction due to the more specific surface area contributed by the fines. However, the drop in OMC may be attributed to the fact that, the addition of fines up to 10% to 20%, have resulted in improvement of gradation and thereby enabling MDD even at lower OMC.

- In principle as the result of the large surface area of the clay fraction compared with the coarser fractions, the moisture required to form a layer to allow relative movement of particles during compaction increases with increasing clay content. Accordingly, in the present study, with the addition of fines in excess of 20%, a gradual increase in the OMC values is found.

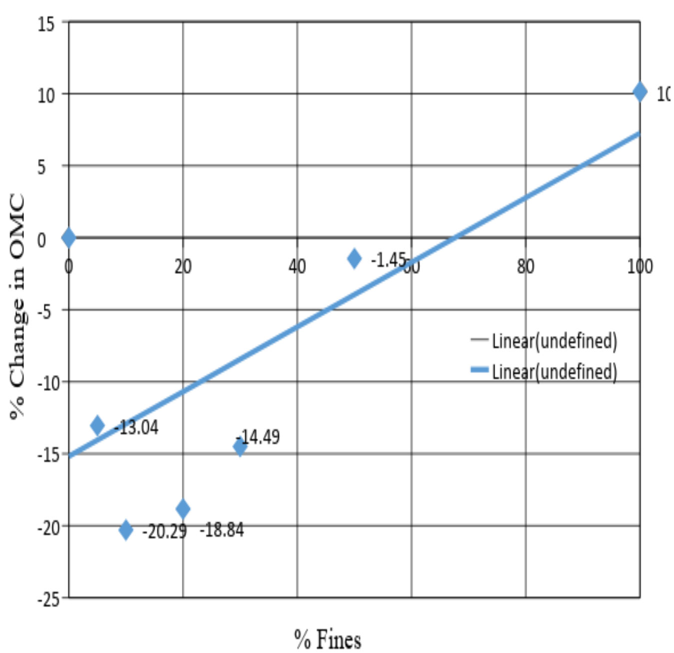

Fig 4:- Variation in percentage change in OMC with fines content

A maximum increase in percentage of OMC of about 13% is seen from 30% to 50% of fines which is shown in Figure 4.4. The relationship between percentage change in OMC and percent increase in fines has given the best trend line with a higher coefficient of determination and a corresponding polynomial series equation shown in equation (2) below.

$$\Delta OMC = -0.0004F^3 + 0.0562\,F^2 - 1.8302\,F - 3.1888 \quad (R^2 = 0.944) \quad (2)$$

Where ΔOMC = Percentage change in optimum moisture content;

F = Percent Fines content

- ***Maximum Dry Density***

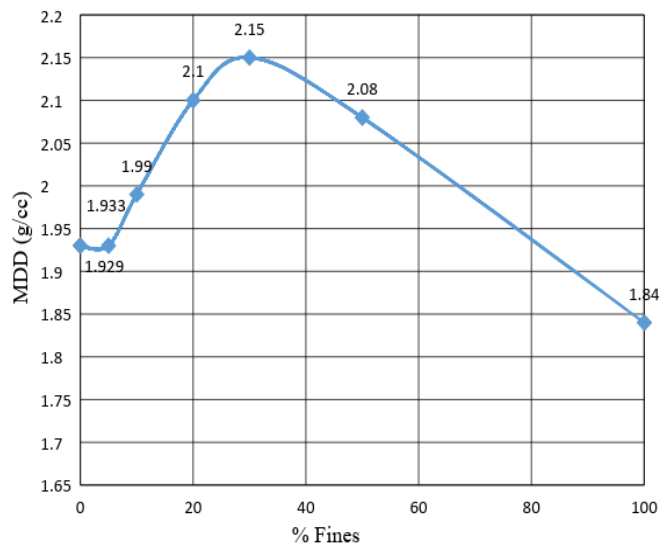

Fig 5:- Variation in MDD with plastic fines content

From the reference Fig. 5, the following observations are made.

- A marginal increase is observed in the maximum dry density of the soil mixture with only 5% addition of plastic fines. Since the applied loads are carried by the sand skeleton, these fines have little effect on the behavior of the mixtures, as they are just residing in largely empty void spaces.

- However, the MDD is increasing beyond 5%, showing a peak point at 30% and then decreasing steadily. The increase in MDD is due to the void spaces between the sand particles are occupied by the finer particles. Upto 30% substitution, the fines contributed to improvise the gradation of soil and hence resulted in increased MDD.

- However, fines in excess of 30% may have contributed to change the gradation to poorly graded and hence causing a reduction in MDD. Further, with higher fines content, the relative ease with which particles can move under compaction effort gets decreased due to cohesion, resulting in a lesser MDD.

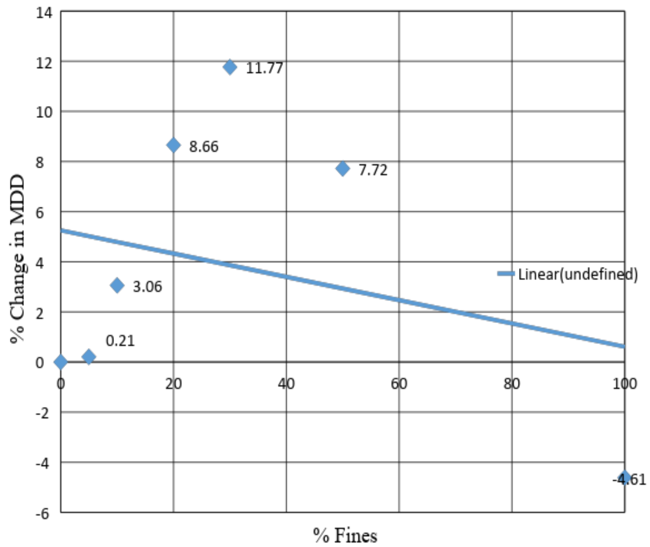

Fig 6:- Variation in percentage change in MDD with plastic fines content

A maximum percentage increase of 11.77% can be seen in the MDD value at 30% fines substitution as that of 0% fines which is shown in Fig. 6 which is due to the maximum density of 2.15 g/cc achieved at this level of fines fraction. The equation which gives the best relationship between the percentage change in MDD and fines content is a polynomial series which is given below in equation (3) below.

$$\Delta M = 0.00007F^3 - 0.0147F^2 + 0.7736F - 1.7693 \quad (R^2=0.942) \quad (3)$$

Where ΔM = Percentage change in MDD value

D. Shear Strength

The results of Direct Shear Test performed on different soil mixtures are summarized in Table 7.

S. No.	Sand (%)	Clay (%)	Shear Strength (kN/m^2) for assumed σ =100 kN/m^2	
			@OMC	@SMC
1	100	0	90.0	80.00
2	95	5	88.50	79.30
3	90	10	88.60	79.10
4	80	20	91.60	76.90
5	70	30	96.60	76.30
6	50	50	95.10	73.10
7	0	100	80.00	46.80

Table 7. Summary of Direct Shear Test results

- *Shear strength at OMC*

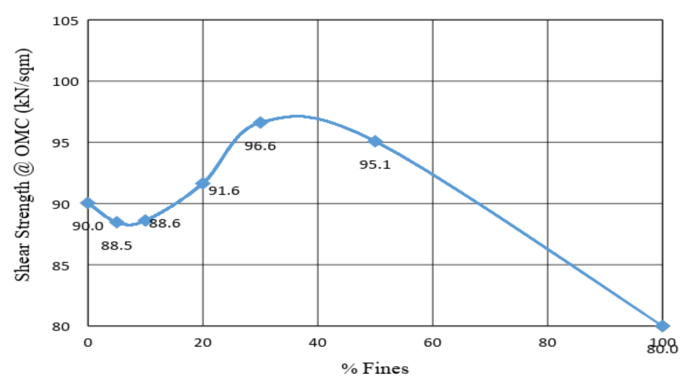

Fig 7:- Variation of Shear Strength values at OMC with plastic fines content

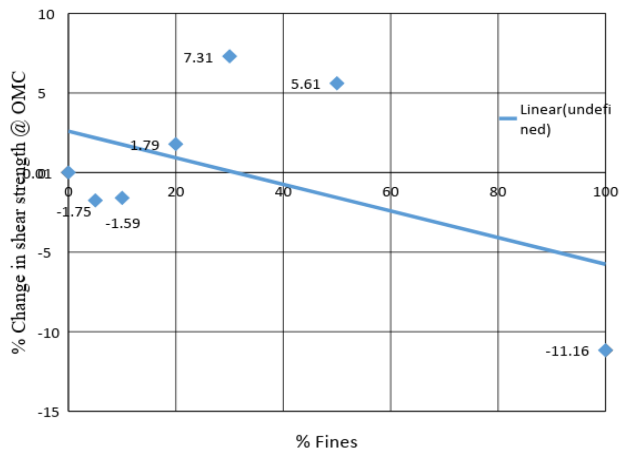

Fig 8:- Variation of percentage change in Shear Strength value at OMC with plastic fines content

The following observations can be made from the shear strength curves which are shown in Figures 7 and 8:

- Keeping the normal stress constant, the shear strength values at optimum condition are showing the same trend as that of MDD with the increase in fines percent which says that, the higher the MDD value, the higher is the shear strength of the soil mixture which is at a percentage of 30% fines fraction.
- At greater percentages, plastic fines are likely to form membrane around the sand particles contributing to reduced angle of shearing resistance and increase in cohesion.
- The increase in cohesion of a soil is produced by forces binding the particles together, and is independent of the normal stress. These binding forces are accounted for partly by the, surface tension forces at the air-water interface of the water films surrounding the particles and partly by the intermolecular forces acting between films of water adsorbed on the surfaces of neighbouring particles. Clay thus enables a soil to develop shear strength by virtue of the cohesive forces between the particles.
- When the plastic fines is greater than 50%, the sand and silt grains are essentially floating in a clay matrix and have little effect on the engineering behavior. A maximum increase in percentage of about 7.30% in shear strength value is seen at a fines content of 30% which can be seen in Fig. 8.

The most appropriate trend line to fit the plotted data between percentage change in shear strength and fines fraction is a polynomial which provides a predicted outcome for the shear strength at optimum moisture content. The formula for this curve is given in equation (4).

$$\Delta\tau_o = -0.04981F^3 + 0.0022F^2 + 0.1842F - 1.7153 \quad (R^2 = 0.919) \quad (4)$$

Where $\Delta\tau_o$ = Percentage change in shear strength at OMC

- *Shear strength at SMC*

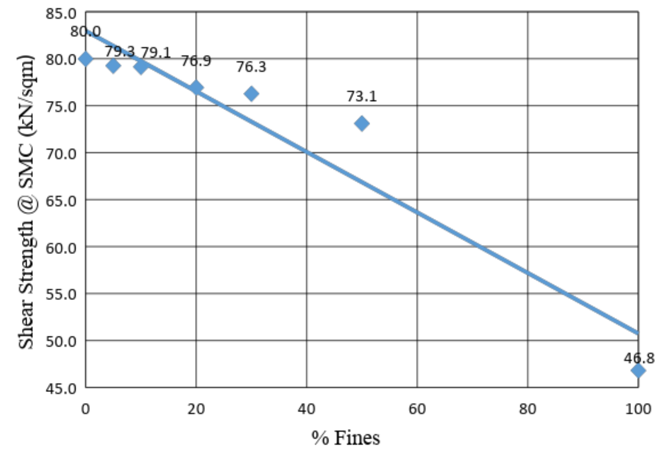

Fig 9:- Variation of Shear Strength values at SMC with plastic fines content

From the reference Fig. 9, following observations are made.

- A marginal decrease in the shear strength values at saturation state can be seen upto 10% fines content. Thereon a gradual decrease can be seen from 10% - 30% of fines substitution.
- A steep drop in the value at 100% of fines is seen which is due to the highest plasticity of the soil due to saturation.

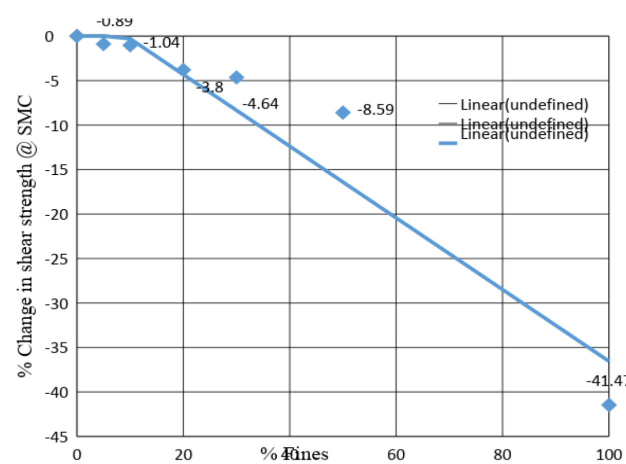

Fig 10:- Variation of percentage change in Shear Strength value at SMC with plastic fines content

A maximum decrease in shear strength value of 41.50% can be seen at 100% clayey soil at saturation which is shown in Fig. 10 with the resulting trend line a polynomial. The corresponding polynomial series equation is as given below in equation (5).

$$\Delta\tau_s = -0.00005F^3 + 0.0034F^2 - 0.2073F \qquad (R^2 = 0.999) \quad (5)$$

Where $\Delta\tau_s$ = Percentage change in shear strength at SMC

VII. REGRESSION MODELS

In Civil Engineering practice, in certain circumstances, there may not be adequate time or resources to get the engineering properties determined through laboratory or field tests. In such circumstances, prediction of such properties based on the easy to determine properties through correlations will be helpful. In view of this, efforts have been made in this study to constitute regression models using SPSS Software version 24.0 as presented below.

A. Correlation between Shear strength and Maximum Dry Density (MDD)

The following Fig. 11, shows the variation of percentage change in Shear strength at optimum moisture condition against percentage change in maximum dry density.

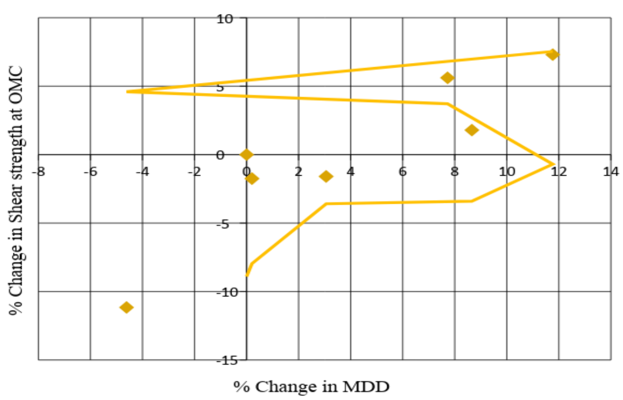

Fig. 11. Percentage change of MDD vs. Shear strength at OMC values

The resulting regression analysis after correlating Shear strength with MDD is expressed by the following linear equation (6) with its corresponding correlation coefficient R^2 as shown.

$$\Delta\tau_o = 0.9461*\Delta M - 3.5923 \qquad (R^2=0.825) \qquad (6)$$

Where $\Delta\tau_o$ = % change in shear strength values at OMC
ΔM = % change in MDD value

B. Correlation of Shear strength with PI and MDD

Following is the comparative analysis curves in Fig. 12, showing the variation of percentage change in shear strength at saturation condition and MDD and PI with respect to increasing percentage of fines fraction in a soil mixture.

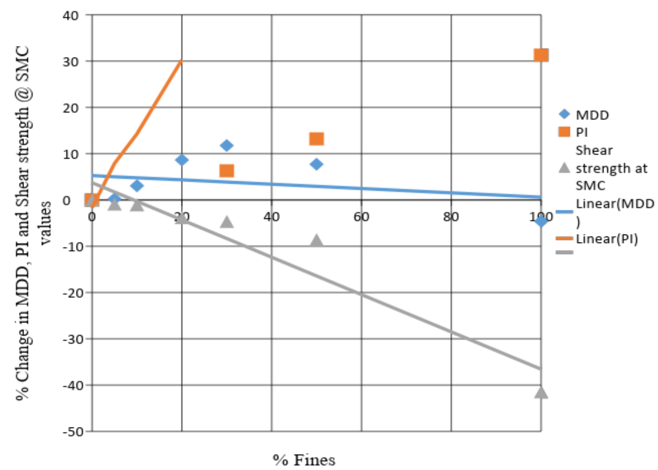

Fig 12:- Percentage fines vs. percentage change in Shear strength at SMC, MDD and PI values

The resulting regression analysis after correlating Shear strength at saturation condition with PI and MDD is expressed by the following multiple linear equation (7) with its corresponding correlation coefficient.

$$\Delta\tau_s = -0.099 + 0.503*\Delta MDD - 1.216*PI \qquad (R^2 = 0.979) \quad (7)$$

VIII. CONCLUSIONS

Based on the experimental results found in this project, the following conclusions are made.

- In general, it is found that, the plastic fines content has a definite influence on the shear strength characteristics of the soil mixtures.
- As the fines content increases up to a critical value is known as “Critical Fines Content (CFC)” the MDD, Shear Strength at MDD & OMC values increases considerably due to improvement in gradation of the mixture and hence the improvement in mechanical stability of the mixture.
- For the materials used in this study, the CFC was 30% and the increase in MDD and Shear strength values was up to 11.77% and 7.30% respectively.
- The effect of plasticity was more pronounced in saturation state. As the fines content increases the Plasticity Index increases; the Shear Strength at MDD & SMC values continuously decreases owing to the increase in plasticity of soil mixture.

On the whole, this study helped in understanding the influence of plastic fines on compaction and shear strength characteristics of the soil mixtures. This study revealed that, in moist conditions, plastic fines up to CFC is beneficial. However, the presence of plastic fines in full saturation state results a steady drop owing to increase in plasticity. Further, this study brought out correlations useful in predicting the drop in characteristics of the mixtures as a function of fines content.

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