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Effect of Plasticity of Fines on Properties of Uniformly Graded Fine Sand

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Abstract. The present work encompasses a detailed study conducted on the effect of amount and type of fines on the properties of sand. The analysis is based on various tests including specific gravity, particle size analysis, consolidation tests, direct shear tests, etc conducted on 17 soil combinations. The soil combinations were prepared by mixing sand with fines (0 - 40%) of different PI ranging from 0-15%. The variations in specific gravity, particle size characteristics (D_{50}, C_u and C_c), limiting void ratios (e_{max} and e_{min}), angle of internal friction in loosest and densest possible state and compression index in loosest and densest state with respect to variations in the amount of fines and plasticity of fines is presented. Results indicate that there is a significant influence of fines on the properties of sand.

Keywords: silt, fines, low plastic clay, sand.

1 Introduction

Even though researchers separate soils based on particle size as sand, silt and clay, in the field, soil always exist as a combination of all these. There are many studies concentrating on the effect of fines on the shear behaviour of sand (Kuberis et al., 1988; Naeini and Baziar, 2004; Belkhatir et al., 2011) and liquefaction (Shen et al., 1977; Amini and Qi, 2000; Dash and Sitharam, 2009; Yolanda Alberto Hernández et al., 2015); but only a few studies have considered the other properties.

Yang and. Wei (2012) have analysed the change in critical state friction angle for Fujian and Toyoura sands. For clean sand without fines, the critical state friction angle tends to decrease with increasing roundness of sand particles. When those sands were tested with fines (round shape), the critical state friction angle of the mixture tends to decrease with an increase in fines content. But for fines with an angular shape, the critical state friction angle tends to increase with fines content. Vu To-Anh Phan et al. (2016) have conducted one-dimensional consolidation tests on sand-silt mixtures (with low-plastic fines at a constant void ratio and constant relative density and indicated that the behaviour of the mixtures were similar to those of loose sand. The effect of fines on void ratios was studied by Cubrinovski and Ishihara (2002).

The authors reported that the void ratio initially decreases as the fines content increases from 0- 20% and above 40% fines, the maximum and minimum void ratios were seen to increase steadily.

It is clear from the literature that the studies on the effect of plasticity of fines on the properties of sand are limited. Hence the present study is focussed on the effect of the amount of fines and the type of fines (or plasticity index of fines) on various properties of sand like specific gravity, limiting void ratios, grain size characteristics, angle of internal friction and compression index.

2 Material Tested

The soil materials utilized in the present study are natural sand, M sand, natural clay and kaolinite clay. The natural sand was collected from Turavoor region in Kerala state. The M sand was collected from a local quarry in Calicut, and the non-plastic silt powder was derived after sieving the M sand through 75-micron sieve. The natural clay was collected at a depth of 3m from Pantheerankavu which is 12 km far from south of Calicut city in Kerala. The index and strength properties of natural clay are listed in Table 1. The commercial kaolinite clay was procured from Sajeev and Co. Ltd. at Calicut district of Kerala state. The physical and chemical properties of Kaolinite clay have been provided by the manufacturer as shown in Table 2. The results of tests conducted on natural sand are listed in table 3.

Table 1. Index and Strength Properties of natural clay

Property	Value
Index property	
Specific gravity	2.56
Liquid Limit (%)	79
Plastic Limit (%)	48
Shrinkage Limit (%)	27
Plasticity Index	31
Clay size (%)	50
Soil classification	MH
Strength property	
Maximum dry density (kN/m^3)	17.5
Optimum moisture content (%)	32
UCS, kPa	64

Among the numerous trial combinations of low plastic soils mixtures processed, the combinations of 50% Kaolinite + 50% silt, 100% Kaolinite, and 20% clay + 80% Kaolinite mixtures were found to possess plasticity indices of 5%, 10%, and 15% respectively, and hence decided to be used for the current work. A total of 17 soil combinations were prepared by mixing the above-mentioned low plastic soil combinations to the fine sand. The effect of presence of fines in the sand matrix on its properties were investigated by conducting various test including grain size analysis, relative density tests, specific gravity, direct shear test and one-dimensional consolidation tests. The tests were performed as per IS test procedures at different percentage fines (0, 10, 20, 30 40%) and plasticity index of fines (0, 5, 10, 15%).

Table 2. Properties of Kaolinite clay

Physical (Mass %)		Chemical (Mass %)	
Acid soluble	0.94	SiO_2	44
Water soluble	0.35	Al_2O_3	38
Oil absorption (mm/ 100 g)	35	Fe_2O_3	0.25
Specific gravity	2.62	TiO_2	0.35
pH	5 ± 0.5	CaO	0.05
Moisture percentage	1.5 ± 0.5	Na_2O	0.06
TDS	100	K_2O	0.05
		MgO	0.07

Table 3. Basic and index properties of sand

Property	Value
Specific gravity	2.62
D_{50}, mm	0.28
Uniformity coefficient, C_u	2.36
Coefficient of curvature, C_c	0.87
e_{max}	0.858
e_{min}	0.578

3 Results and Discussions

Test results for basic physical properties and some engineering properties on all the soil combinations adopted in the study are presented in the following sections.

3.1 Effect of particle size characteristics

A combined dry sieve and hydrometer analysis was performed on all the soil combinations to obtain the particle size distribution and the gradation curve of fine sand is shown in Fig.1. The values of average particle size, D_{50} were found from the gradation curves and its variation with respect to amount and PI of fines added is reported in Fig. 2. D_{50} gives an understanding of physical properties of the soil which in turn affect its strength and load bearing properties. It is clear from Fig. 2(a) that the D_{50} of sand decreases with the addition of fines at every tested value of PI. But, the plasticity index of fines has no much influence on the gradation of the soil (Fig. 2(b)).

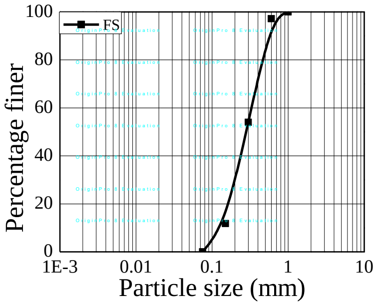


Fig. 1. Particle size distribution of sand

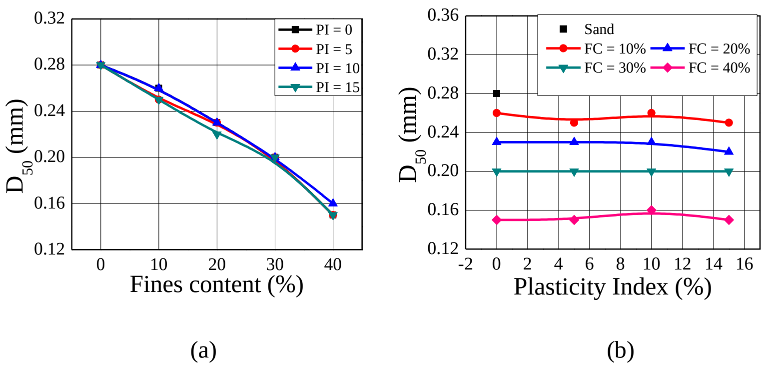
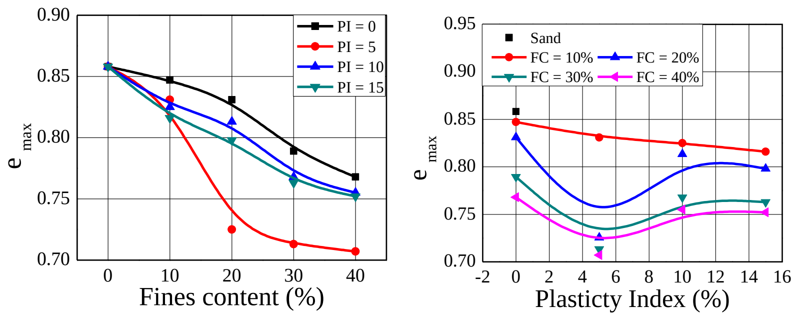


Fig. 2. Effect of (a) fines content and (b) plasticity index on D_{50}

3.2 Effect on void ratio

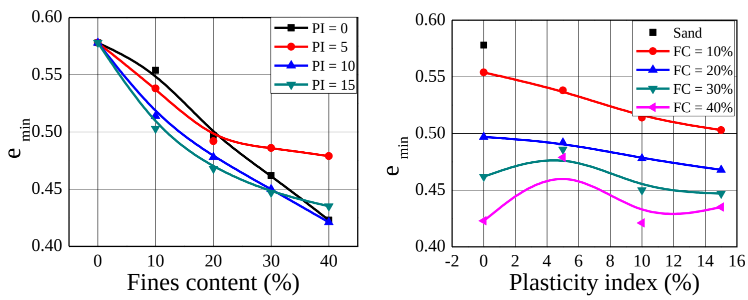
Relative density tests were performed as per the IS test procedure to arrive at the maximum density of all soil combinations. The minimum densities of soil combinations were attained by pouring it steadily with zero height using paper cone into the CBR mould of 150 mm size as per the IS code procedure. The average values of maximum and minimum densities of soil combinations are reported in tables after repeating the tests in thrice. Based on limited densities, the maximum and minimum void ratios are estimated by using the empirical equations and its variations are shown in Figs. 3 and 4.

It was observed that both the maximum and minimum void ratios decrease as the fines content increases at all tested values of PI of fines. The variation with respect to the PI of fines showed different trends with different fines contents. At low fines content (10%), both e_{max} and e_{min}, decreases with the increase in the plasticity of fines. At higher fines content, a contradiction was observed between the variations in e_{max} ande_{min}. At higher fines content, e_{max} shows an initial decrease with the increase in the PI of fines and then shows an increase. But the variation of e_{min} is exactly the opposite.



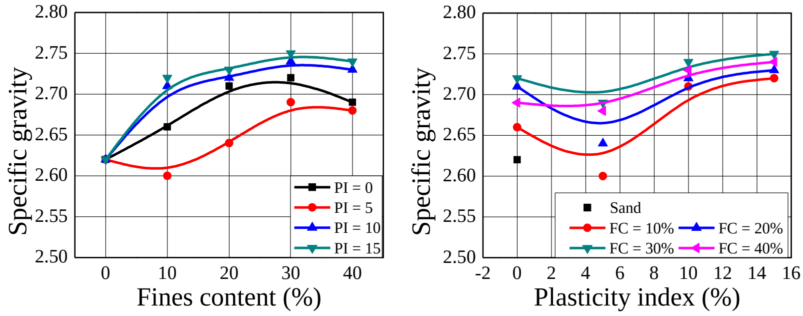
(a) (b)

Fig. 3. Effect of (a) fines content and (b) plasticity index on e_{max}



(a) (b)

Fig. 4. Effect of (a) fines content and (b) plasticity index on e_{min}



(a) (b)

Fig. 5. Effect of (a) fines content and (b) plasticity index on specific gravity

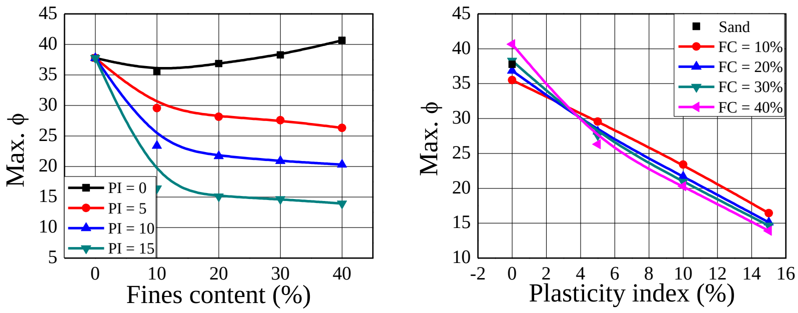
3.3 Effect on specific gravity

The specific gravity of all the soil combinations were found using pycnometer. Fig. 5(a) and (b) show the influence of fines on the initial specific gravity of natural fine sand which was found to be 2.62. It is clear from Fig. 5(a) that specific gravity increases with an increase in fines content. The influence of PI of fines on specific gravity of sand is shown in Fig. 5(b). The specific gravity of natural sand showed an initial decrease followed by a gradual increase with increase in PI of the fines added at all tested fines content.

3.4 Effect on angle of internal friction

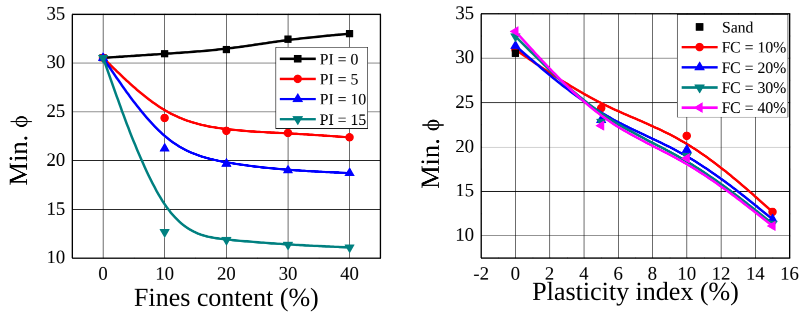
Direct shear tests were carried out in the small direct shear box (6 x 6 x 5 cm) to understand the changes in shear strength properties of natural sand due to addition of fines. The soil samples were filled in the direct shear box under loosest as well as densest states and tests were conducted at normal stresses ranging from 100-300 kPa. From the test data maximum and minimum angle of friction were found and are plotted in Fig. 6 and 7. It can be observed from Fig. 6(a) and 7(a) that the value of the angle of internal friction increase with the addition of non-plastic fines (both loosest and densest state of soil). But on addition of low-plastic fines to the sand an opposite trend can be seen with a decrease in friction angle corresponding to an increase in fines content.

An average reduction of 62.5% from the initial values were observed in friction angles when low-plastic fines of PI = 15% was added to sand (Fig. 6(b) and 7(b)). The reduction trends can be seen overlapping at all fines content. The angle of internal friction decreases significantly with increase in the plasticity of fines.



(a) (b)

Fig. 6. Effect of (a) fines content and (b) plasticity index on maximum angle of internal friction



(a) (b)

Fig. 7. Effect of (a) fin es content and (b) plasticity index on minimum angle of internal friction

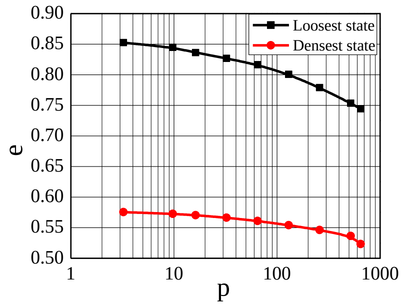
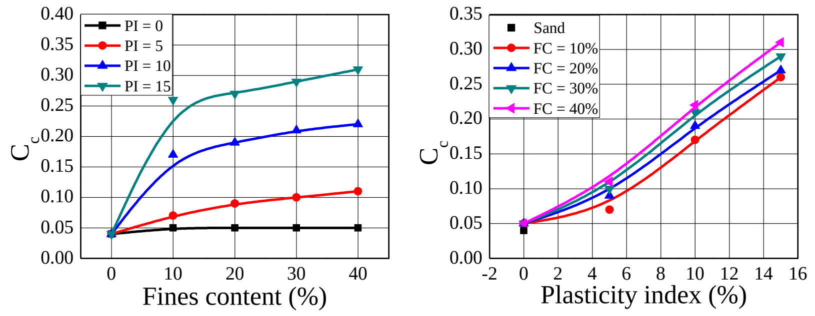
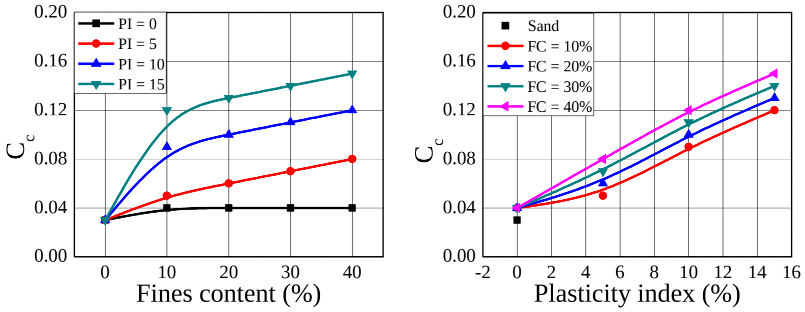


Fig. 8. e – log p plots of sand in loosest and densest state



(a) (b)

Fig. 9. Effect of (a) fines content and (b) plasticity index on C_c (loosest possible state)



(a) (b)

Fig. 10. Effect of (a) fines content and (b) plasticity index on C_c (densest possible state)

3.5 Effect on compression index

One dimensional oedometer tests have been conducted on all the soil samples in loosest and densest possible states. The e-log p curve of natural sand is shown in Fig. 8. Form this, the compression index is found as 0.04 in loose state and 0.03 in a dense state. The effect of fines on compression index of sand is shown in Fig. 9 and 10. It is clear from Fig. 9 (a) and 10(a) that the addition of low-plastic fines increases the compression index of sand. But the variation in compression index due to the addition of non-plastic fines is negligible. Fig. 9(b) and 10(b) indicate that at all tested fine content, Cc increases with an increase in PI of fines. Also, if the value of sand is excluded in Fig. 9 and 10, the remaining points will show a linear trend between C_c and PI.

4 Summary and Conclusions

The present paper discussed the effect of non-plastic and low-plastic fines on the properties of sand. Effect on grain size characteristics, limiting void ratio, specific gravity, angle of internal friction and compression index is elaborated. The following conclusions are derived:

1. The D_{50} of sand decreases with the addition of fines at every tested value of PI. But, if particular fines content is taken, the plasticity index of fines has no much influence.
2. Both maximum and minimum void ratios decrease as the fines content in creases at all testes values of PI of fines. The variation of e_{max} and e_{min} with respect to the PI of fines is contracting to each other.
3. Value of angle of internal friction is increased with the addition of non-plastic fines (both loosest and densest state of soil). But an opposite trend is found with the addition of low-plastic fines. The angle of internal friction de creases with increase in the plasticity of fines.

4. The addition of low-plastic fines increases the compression index of sand; but the effect of non-plastic fines is negligible. At all tested fine content, C_c increases with increase in PI of fines.

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