An Experimental Study on Effects of Non-Plastic Fines on Engineering Properties of Sand-Silt Mixture

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Abstract. Sandy soil as a foundation material largely depends on the engineering properties of a soil governed by its physical properties and behaviour, containing less or more amount of fines obtained through dredging operation. As IS: 6403 - 1981 and NAVFAC depicts approximate correlations between SPT N-value, angle of internal friction, relative density and dry unit weight for cohesionless material. But, the effect of a different range of percentage of fines on different sand gradations is not well covered. Hence, an attempt has been made to establish a relationship for different gradations of sand with different amount of fines. An experimental study on the sand along with silt under different conditions was conducted. The reconstituted well-graded samples containing different amount of silt i.e. 0%, 5%, 10%, 15% were subjected to a vibration table for relative density to obtain maximum and minimum dry density. For the shear strength & consolidation parameter samples were subjected to direct shear test and consolidation test at three relative density i.e. 30%, 60% and 90% at the displacement rate of 0.25 mm/min under the dry and saturated state. Laboratory results depict that up till transition fines content the angle of internal friction increases and a further increase in fines it decreases. Also, the compressibility increases for different relative density. From the results it is observed that the percentage of fines alter the engineering behaviour of sand.

Keywords: Sand-Silt, Relative Density, Direct Shear Test, Dry and Saturated Condition, Consolidation Test.

1 Introduction

Traditionally, sandy soil as foundation material has been widely in practice since long time. As the stability and safety of structure resting on sandy soil depends on shear strength and deformation of soil structure under the stresses. Moreover, large number of factors affect the shear strength of soil such as particle shape, particle size distribution, presence of fines (non-plastic/ plastic), denseness of soil, drainage conditions etc. But during the reclamation process of sand from the sources, contain small or large amount of fines. So, it becomes necessary to investigate on effect of non-plastic fines on these parameters of sandy soil.

A large number of existing studies [1-12] in the broader literature have examined the different aspects of clean sand behaviour through extensive and comprehensive studies & experiments. Additionally, few studies [1-3] have focused on up till what and how much degree the fines content affects the various parameter of sand. In granular soil, the arrangement of particles is referred as packing of particles. The packing of particles is strongly influenced by particle shape and its distribution. Moreover, on rearrangement or variation in packing of particles affect the engineering properties of soil. So, to improve the engineering properties of soil, changes in the packing of particles can be done. This can be achieved by the introducing the fines (i.e. below 75 micron and non-plastic) to fill up the voids. For optimum grain size distribution of voids in between the bigger size particles needs to be filled up with smaller size particle. Increase in shear strength mostly depends on particle contact and it is related to the porosity and void ratio.

An experimental study has been conducted to understand the phenomenon of packing of particles and how the fine content affects the minimum void ratio and maximum void ratio Lade and Yamamuro [1]. By performing few experiment, study has shown the theoretical relationship between the void ratio and percentage fines by the schematic diagram (see Fig.1).

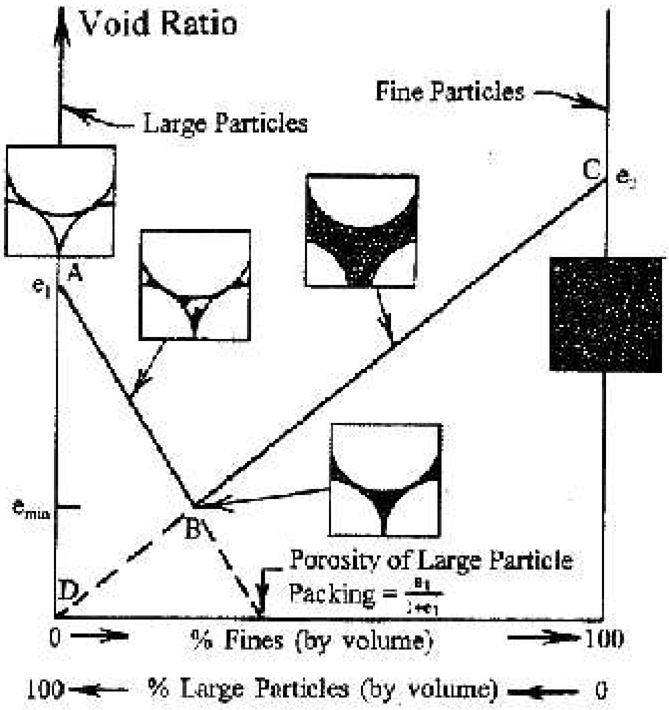

Fig. 1. Theoretical relationship between void ratio percentage fine content

Prior research [2-4] recommends, the strength of soil is expected to be constant until voids are completely filled with fines. When fines get in between the granular particles, strength rapidly reduces. At this stage amount of fines is known as "Transition Fine" content and it differentiate the dominating behaviour of mix.

Addition of non-plastic fines at low content are not significant to participate in force transfer mechanism in sand-silt mixture, due to their nature, position & size. Thus space occupied by fines should be considered as void space, the stated problem can be simplified by introducing the term "Inter-granular void ratio (e_g)". The simple formulation suggested by Thevanayagam [3] for e_g of the mixture with low fine content can be determined by.

$$e_g = \frac{e + f_c}{1 + f_c} \quad (1)$$

where f_c is fines content and e is the global void ratio.

However, Inter-granular void ratio is not applicable to mixture with high fine content, Thevanayagam 2000 and Yang et al 2006a [3, 5]. Additionally, the concept of "Equivalent-granular void ratio (e_{ge})" [6-7] have been considered used to account the contribution of higher fine content & this approach requires an parameter 'b' that resembles the fraction of fines participating in force structure of soil skeleton, e is global void ratio, *fc* is fine grain content.

$$e_{ge} = \frac{e + (1-b) f_c}{1 - (1-b) f_c} \quad (2)$$

2 Methodology

For this study, sample was prepared by locally available Class-I & normal silica sand i.e. coarse sand (C) – 4.75mm to 2mm, medium sand (M) – 2mm to 0.425mm and fine sand (F) – 0.425mm to 0.075mm . To prepare the silt in laboratory, natural sample procured from the Gulf of Khambhat, Gujarat, was washed on 0.075mm IS sieve.

2.1 Preliminary Investigation

On blending coarse, medium and fine sand, three well graded sand samples were prepared mechanically i.e. C+M, M+F, C+M+F with the characteristics shown in Table 1 and Fig.2. The silt was prepared in the laboratory by hydrometer analysis as per ASTM D 422-63 [8] on the Khambhat sample after treating it by dispersing agent i.e. Sodium Hexametaphosphate, Sodium Carbonate; for the deflocculation of fine particles. Atterberg Limit tests on sample showed low liquid limit and plastic limit, thus as per Indian Standard Soil Classification System (ISSCS) sample was classified as non-plastic fines (silt) Table 2.

Table 1. Sieve analysis data of remoulded sample

Sr. no.	Sample	D_{60} (mm)	D_{30} (mm)	D_{10} (mm)	C_u	C_c
1.	Coarse + Medium sand	3.10	1.30	0.51	6.08	1.07
2.	Medium + Fine sand	0.60	0.28	0.10	6.00	1.31
3.	Coarse + Medium + Fine sand	1.19	0.40	0.12	9.90	1.10

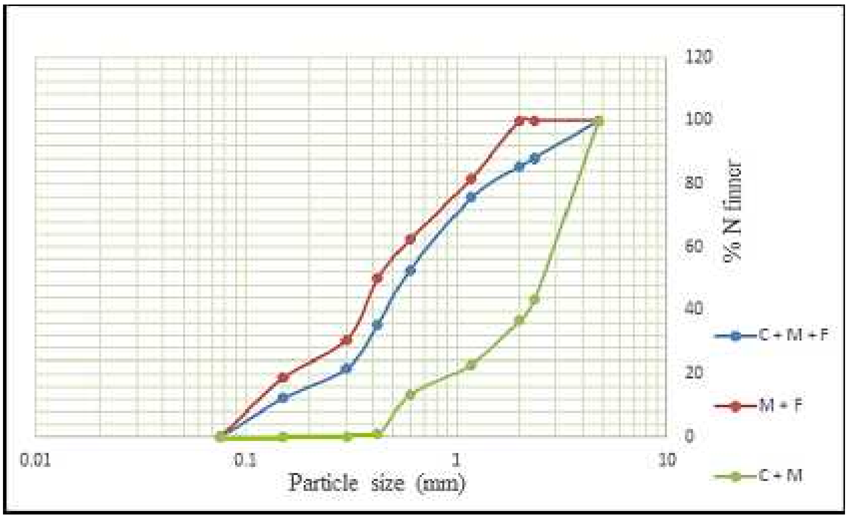

Fig.2. Grain size distribution curve

Table 2. Index Properties of silt sample

Sample	Specific Gravity (G)	Liquid Limit	Plastic Limit	Plasticity Index
Silt	2.68	21.6	-	NP

2.2 Experimental Program

In order to explain the effect of fines on the behaviour of sand-silt mixture, a series of Specific Gravity, Relative Density, Direct Shear and Consolidation test were conducted on sand-silt sample. To determine the maximum and minimum density of each reconstituted samples having 0%,5%,10% and 15% of silt respectively were subjected to relative density as per the IS:2720-Part XIV [9-10]. Strain controlled direct shear tests were conducted on sand-silt specimen at a strain rate of 0.25mm/min under dry and saturated state at relative density of 30%, 60% & 90% respectively. The same specimens were also subjected to Oedometer test as per IS: 2720-Part XV.

3 Results & Discussion

On the basis of above experimental study, maximum and minimum void ratio was computed analytically as shown in Table 3. These analytical values simulates the theoretical concept (see Fig. 1) given by the previous study [11-15]. Through the obtained data it has been observed that void ratio decreases as the fine content increases, shown by the graphical representation (see Fig. 3, 4, 5).

Further their influence on shear strength under dry & saturated condition at different relative densities has been experimentally studied by Table 4 & 5. Result shows that angle of internal friction is higher in dry state as compared to saturated state. In case of C+M+F the shear strength increases upto 5% fines both in dry and saturated state due to complete filling up of voids. On further addition of fines, they gets in between the coarse particles and shows decreases in shear strength.

Compressibility of the reconstituted samples prepared on the basis of dry density obtained from relative density seems to be increase on addition of fines, Table 6.

Table 3. Laboratory tests result

Sample	Silt (%)	Specific gravity	Minimum density (g/cc)	Maximum density (g/cc)	Dry density (g/cc)	Minimum void ratio	Maximum void ratio	Void ratio (e)	Relative density (%)
C+M	0	2.740	1.74	2.02	1.82	0.356	0.575	0.505	30
					1.9			0.442	60
					1.99			0.377	90
	5	2.740	1.77	2.08	1.85	0.317	0.548	0.481	30
					1.94			0.412	60
					2.04			0.343	90
	10	2.721	1.84	2.19	1.93	0.242	0.479	0.410	30
					2.04			0.334	60
					2.15			0.266	90

Sample	Silt (%)	Specific gravity	Minimum density (g/cc)	Maximum density (g/cc)	Dry density (g/cc)	Minimum void ratio	Maximum void ratio	Void ratio (e)	Relative density (%)
C+M	15	2.721	1.88	2.22	1.97	0.226	0.447	0.381	30
					2.07			0.314	60
					2.18			0.248	90
M+F	0	2.685	1.69	1.99	1.77	0.349	0.589	0.517	30
					1.86			0.444	60
					1.96			0.370	90
	5	2.667	1.72	2.03	1.8	0.314	0.551	0.482	30
					1.89			0.411	60
					1.99			0.340	90
	10	2.667	1.73	2.07	1.82	0.288	0.542	0.465	30
					1.92			0.389	60
					2.03			0.314	90
	15	2.667	1.72	2.12	1.82	0.258	0.551	0.465	30
					1.94			0.375	60
					2.07			0.288	90
C+M+F	0	2.703	1.71	1.98	1.78	0.365	0.581	0.519	30
					1.86			0.453	60
					1.95			0.386	90
	5	2.685	1.76	2.04	1.84	0.316	0.526	0.459	30
					1.92			0.398	60
					2.01			0.336	90
	10	2.685	1.75	2.1	1.84	0.279	0.534	0.459	30
					1.94			0.384	60
					2.06			0.303	90
	15	2.685	1.79	2.11	1.88	0.273	0.500	0.428	30
					1.97			0.363	60
					2.07			0.297	90

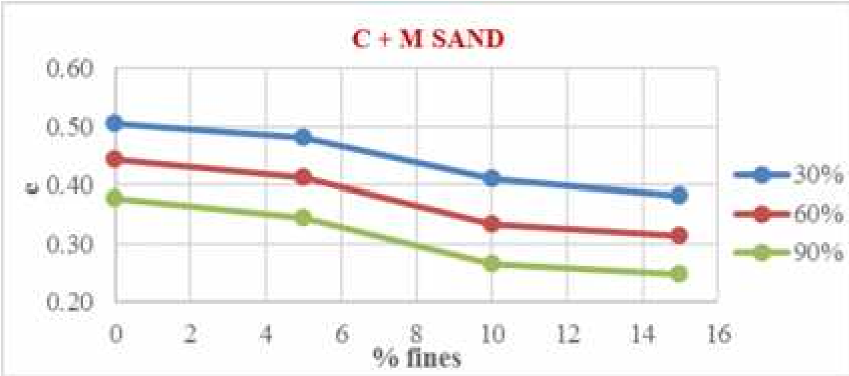

Fig. 3. Relationship between void ratio & percentage fine for C+M sample

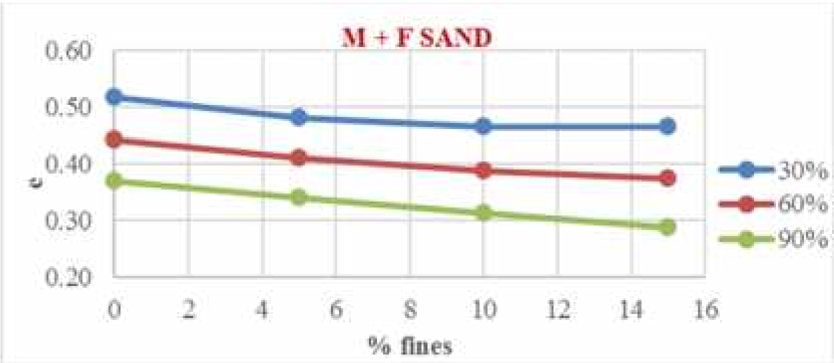

Fig. 4. Relationship between void ratio & percentage fine for M+F sample

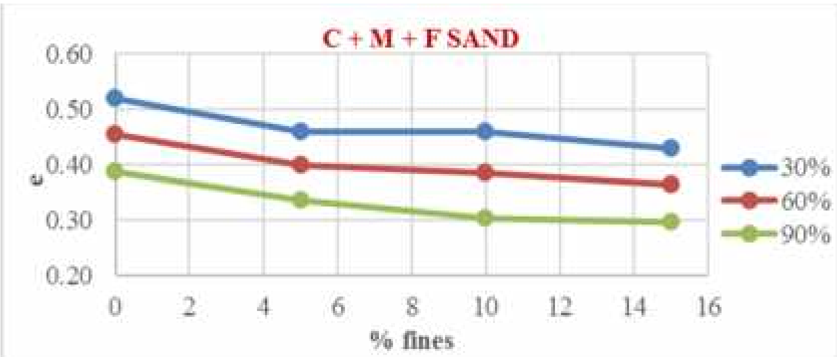

Fig. 5. Relationship between void ratio & percentage fine for C+M+F sample

Table 4. Angle of internal friction data of reconstituted sample under dry state

SOIL SAMPLES	ANGLE OF INTERNAL FRICTION (ϕ)											
% SILT	0%			5%			10%			15%		
RELATIVE DENSITY	30	60	90	30	60	90	30	60	90	30	60	90
C+M	43.55	45.42	47.24	45.4	46.17	46.41	46.62	47.59	48.13	47.67	48.8	48.9
M+F	33.38	37.78	42.13	35.82	38.38	43.04	37.45	41.41	46.63	38.49	45.46	47.32
C+M+F	37.63	39.72	43.92	40.95	42.09	45.60	39.80	41.43	45.14	37.73	39.69	42.04

Table 5. Angle of internal friction data of reconstituted sample under saturated state

SOIL SAMPLES	ANGLE OF INTERNAL FRICTION (ϕ)											
% SILT	0%			5%			10%			15%		
RELATIVE DENSITY	30	60	90	30	60	90	30	60	90	30	60	90
C+M	42.35	43.42	44.11	41.84	44.12	45.40	42.33	44.83	46.31	36.96	39.02	43.54
M+F	32.37	35.82	38.18	34.90	38.00	39.97	35.21	40.31	41.18	33.71	34.15	35.90
C+M+F	34.00	37.15	40.65	38.07	39.70	41.98	37.64	38.39	41.26	34.14	36.16	37.33

Table 6. Coefficient of volume compressibility data on increases in effective stresses

SOIL SAMPLES	m_v (cm^2/kg)											
% SILT	0%			5%			10%			15%		
RELATIVE DENSITY	30	60	90	30	60	90	30	60	90	30	60	90
C+M	0.0048	0.0047	0.0041	0.0056	0.0048	0.0041	0.0059	0.0051	0.0043	0.0075	0.0067	0.0045
M+F	0.0048	0.0041	0.0034	0.0049	0.0042	0.0034	0.0050	0.0035	0.0028	0.0043	0.0035	0.0028
C+M+F	0.0041	0.0040	0.0040	0.0050	0.0042	0.0042	0.0056	0.0049	0.0042	0.0059	0.0059	0.0043

4 Concluding Remarks

This study clarifies the effect of non-plastic fines on the engineering properties of sand-silt mixture through analytical and experimental program. Results acquire from the tests have been discussed above and the following conclusion is drawn:

- On increases in fine content, increases in dry density is observed.
- Void ratio decreases as the fine content increases up till the transition fine content.
- In case of C+M+F sand the angle of internal friction increases upto 5% under both dry and saturated condition as all the voids are nearly filled up and further on addition it decreases for 10% and 15% non-plastic fines, as its gets in between the coarse particles.
- In case of C+M and M+F specimen the angle of internal friction increases upto 15% fines in Dry state but in saturated state it increases upto addition of 10% fines and on further addition it decreases.
- Coefficient of volume compressibility obtained from oedometer goes on increasing for each specimen on addition of fines from 0% to 15%.
- For the M+F specimen coefficient of compressibility decreases on addition of 10% and 15% of fines.
- This shows that on addition of non-plastic fines the compressibility of soil sample increases for 30%, 60% and 90% relative density.

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