Effect of Plastic Fines on Geotechnical Behavior of Ennore Sand

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Abstract. The soil usually found in the combination of various size particles such as clayey-silt, sandy-silt and silty-sand etc. The geotechnical properties of soil such as index properties, permeability, compactability, shear strength and volumetric response rely on the gradation of the soil particles. In the present study, Ennore sand is used with varying kaolinite clay contents such as 0%, 5%, 10% and 15%. To determine the shear strength parameters of soil mixture, a series of large direct shear tests were conducted on Ennore sand-kaolinite clay mixtures. The specimens for direct shear tests were prepared at optimum moisture content and maximum dry density. The experimental results showed that shear strength increased with the increase in fines content up to 10% and after that, it was observed to decrease. The cohesion of soil mixtures were found to be increased with the increase in kaolinite content due to its plastic nature.

Keywords: Plastic fines, Shear Strength parameter, large direct shear test.

1 Introduction

The shear strength of soil is a combination of friction, cohesion, and interlocking between the soil grains. Coulomb (1776) and Terzaghi (1925) investigated the shear behavior of pure sand and pure clay, respectively. However the soils is found in combination, mixture of sand, silt and clay. The shear behavior of soil was influenced by the percentages of fines and coarse content. Carrroet. al (2009) performed drain and undrained triaxial tests under static and monotonic conditions on the sand contained plastic and non-plastic fines to investigate the mechanical behavior of sand. They found that the both peak and critical state friction angle of the soil increased with the increase in non-plastic fines, whereas completely reverse behavior was observed in sand with plastic fines. Kolay et al. (2005) investigated the shear strength characteristics of sand with varying content of fines in direct shear apparatus. The results of this study revealed that the internal friction angle was decreased whereas cohesion value was observed to increase with the increase in fines content. In the current study, Ennore sand was mixed with kaolinite clay. The large direct shear was conducted on Ennore sand-kaolinite mixtures to investigate shear behavior. The kaolinite clay content was varied as 0%, 5%, 10% and 15% by weight. The Ennore sand-kaolinite clay specimens were prepared at OMC and MDD, which was obtained by Standard Proctor tests.The relationship between shear stress and horizontal displacement, volumetric response and Mohr-Coulomb failure envelopes were derived to explore the shear behavior of soil.

2 Material Properties

Ennore sand is a standard soil and found in the seashore area of Tamilnadu, India. Three types of Ennore sand available commercially, based on their particle size, e.g., grade-1, grade-2, and grade-3. In the current study, grade-2 Ennore sand was used, which contained major soil particlesvarying from 0.5 mm to 1 mm. Kaolinite clay is a cohesive soil containingkaolinite clay mineral. The mixtures of Ennore sand and kaolinite clay was used in the present study. The basic geotechnical properties of Ennore sand are presented in Table 1.

Table 1.Basic geotechnical properties of Ennore sand

Properties	Values
Specific Gravity	2.63
Coarse Sand	0%
Medium Sand	92.7%
Fine Sand	7.3%
Minimum Dry Density	1.5 g/cc
Maximum Dry Density	1.7 g/cc
Visual appearance	Whitish Grey
Nature	Non-plastic

3 Experimental Program

In the present study, a series of large direct shear tests were performed on Ennore sand-kaolinite clay mixture at normal pressure of 139 kPa, 188 kPa and 237 kPa. The Ennore sand-kaolinite clay mixtures were prepared at varying kaolinite content such as 0%, 5%, 10%, and 15%.The Standard Proctor tests were performed on Ennore sand-kaolinite mixtures to obtain optimum moisture content and maximum dry density at each kaolinite clay content in Ennore sand. For direct shear test, soil specimens were prepared at their respective optimum moisture content and maximum dry density using moist temping method. The specimen prepared in direct shear box itself in three equal layer of height. The specimen size was 30cm*30cm in plane dimension and 15cm in height. The large direct shear apparatus was deformation controlled device and the deformation rate was kept 1mm/min for all the tests.

4 Results and discussions

4.1 Shear stress-horizontal displacement relationship

Fig. 1 represents the shear stress and horizontal displacement relationship of Ennore sand-kaolinite clay mixtures at normal pressure of 139kPa, 188 kPa, and 237 kPa. The results from the direct shear tests revealed that well-defined peak was not observed in Ennore sand-kaolinite clay mixtures for all the three normal pressures. The shear strength characteristics of Ennore sand-kaolinite clay mixtures increased with an increase in normal pressure indicating pressure dependent material response. The maximum shear stresses were mobilized within 6 mm of horizontal deformation. It further exhibited softening response for all the Ennore-kaolinite mixtures. The relationship between shear stress and horizontal displacement showed that the shear strength of Ennore sand notably increased by the addition of 5% kaolinite. For normal pressure 139 kPa, the shear strength of Ennore sand increased by 10.5%, 13.4% and 6.7% with the addition of 5%, 10% and 15% kaolinite content respectively. A similar response was observed for the tests performed at normal pressures of 188 kPa and 237 kPa. For 188 kPa normal pressure, an increase of 6.9% and 10.4% in shear strength was observed for kaolinite clay content of 5% and 10% respectively. There was an insignificant effect of 15% kaolinite clay on the shear resistance at normal load of 188 kPa. For the normal pressure of 237 kPa, an increase of 11.3%, 13.7%, 1.7% in shear strength was observed for kaolinite clay content of 5%, 10%, and 15% respectively. The Ennore sand and kaolinite mixtures exhibited maximum shear strength response at 10% of kaolinite clay content for all the three normal loads.

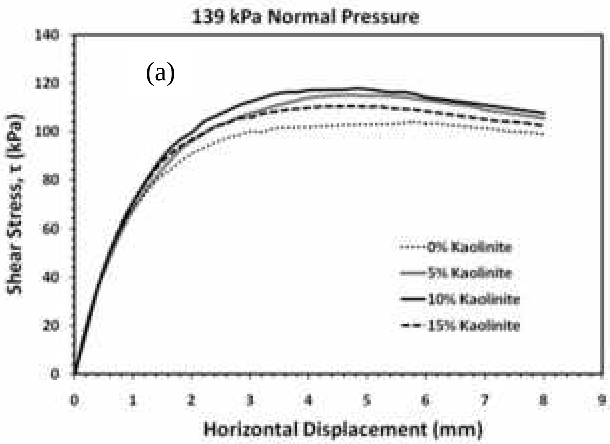


Fig. 1 Shear stress versus horizontal displacement relationship of Ennore sand-kaolinite mixtures at the normal pressures of (a) 139 kPa, (b) 188 kPa, and (c) 237 kPa.

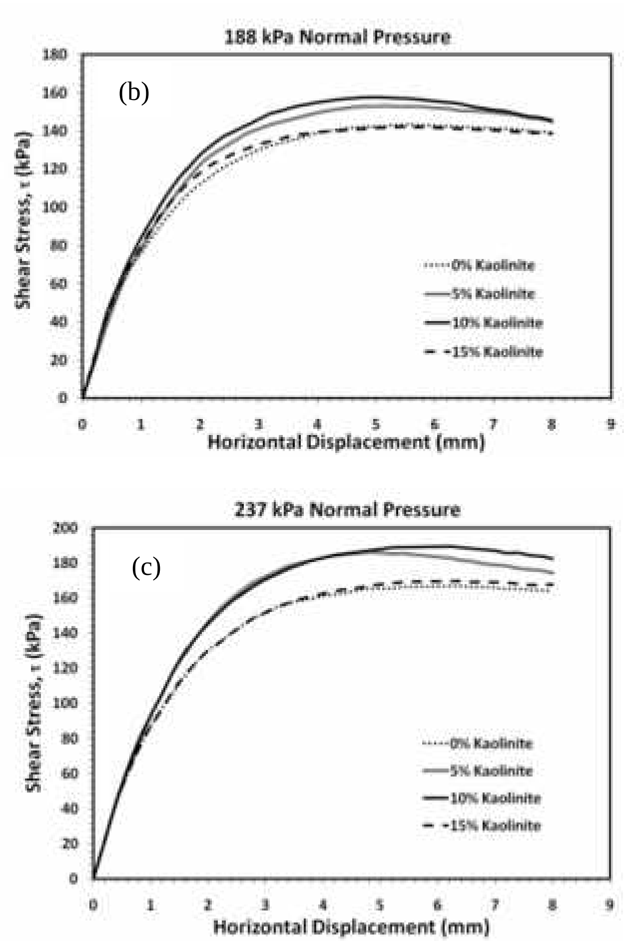
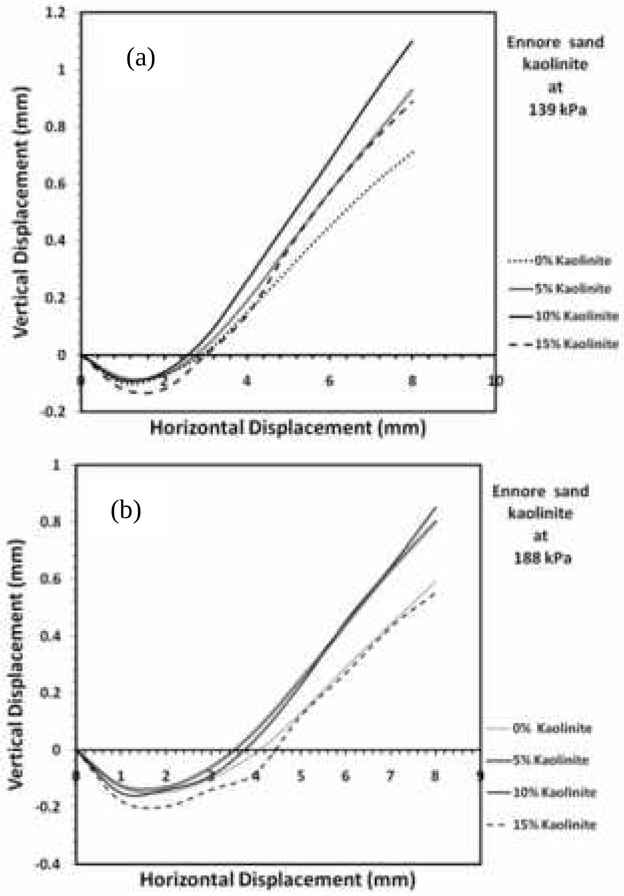


Fig. 1 Continued.

4.2 Volumetric behavior

Fig. 2 illustrates the relationship of vertical and horizontal displacement for Ennore sand and kaolinite clay mixtures at normal pressures of 139 kPa, 188 kPa, and 237 kPa. The Ennore sand-kaolinite clay mixtures showed initial settlement during shearing stage. The soil particles might be rearranged during shearing and achieved denser packing. After initial settlement, the soil behavior was observed to be dilative for all Ennore sand-kaolinite clay mixtures. The dilative response of Ennore sand-kaolinite clay mixtures indicated the rolling over and rearrangement of sand particles during shearing. Ennore sand with 15% kaolinite clay content exhibited maximum initial settlement for all three applied normal loads. At higher kaolinite clay content, the clay particles were facilitated with easy rearrangement of granular fraction and also contributed to the compressibility of the clay matrix present at few contacts of the large sand particles. This might be due to the lubrication effect of kaolinite clay that enabled the soil particles to rearrange easily during application of normal load.



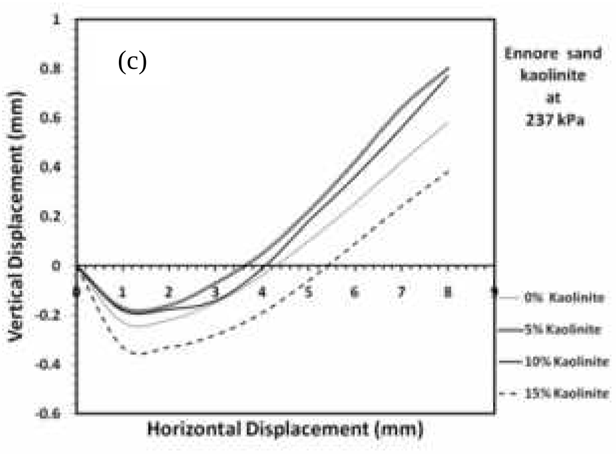


Fig. 2 Vertical versus horizontal displacement relationship of Ennore sand-Kaolinite mixtures at the normal pressures of (a) 139 kPa, (b) 188 kPa, and (c) 237 kPa.

4.3 Shear strength failure envelopes

Mohr-Coulomb failure envelopes of Ennore sand with varying kaolinite clay contents (0%, 5%, 10%, and 15%) are shown in Fig.3. It was evident from the failure envelope that the slope and intercept increased with the addition of 5%, 10% and 15% of kaolinite as compared to pure Ennore sand. The gain in shear strength parameters was found to be dependent on the kaolinite content. As the kaolinite content increased, the shear strength parameters were found to increase up to 10% of kaolinite clay content. At the 15% kaolinite content, the shear strength parameters reduced but always remained higher than that of the pure Ennore sand. A similar response was observed in shear stress and horizontal displacement relationship of Ennore sand with varying kaolinite clay contents.

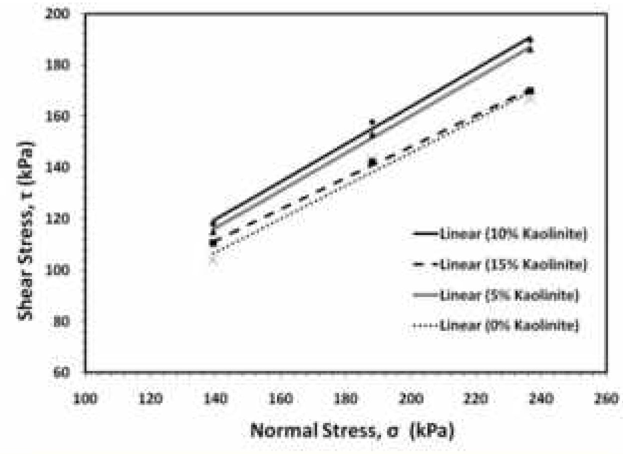


Fig. 3 Mohr-Coulomb Failure Envelopes of Ennore sand-kaolinite mixtures

The shear strength of Ennore sand-kaoliniteclay mixtures increased with the increase in kaolinite clay content. The maximum value of shear strength was acquired at 10% of kaolinite clay. Significant reduction in shear strength was observed at 15% kaolinite clay content at normal pressures of 139 kPa, 188 kPa,and 237 kPa. However, the shear strength of all the Ennore sand-kaolinite clay mixtures was observed to be higher than that of the pure Ennore sand. The observations revealed that the kaolinite clay content had a significant impact on shear strength parameters of Ennore sand-kaolinite clay mixtures. The shear strength parameters of Ennore sand-kaolinite clay mixtures are presented in Table 2. The results indicated that the friction angle increased slightly with theincrease in kaolinite content and attained the maximum value of 36.4 degrees at 10% kaolinite, after that the friction angle decreased to 31.3 degrees at kaolinite content of 15%.As the kaolinite content increased, the voids between the sand particles were filled with kaolinite clay with the simultaneous decrease in sand-to-sand contacts. At low kaolinite content, voids of Ennore sand were occupied by kaolinite clay particles and the number of sand-to-sands contacts was comparable to that of pure Ennore sand. The low clay content exhibited negligible effect on the shear strength behavior as contact between sand particles remained nearly unchanged. By increasing kaolinite content to 15%, the kaolinite clay particles replaced with sand content, thereby decreasing the number of sand-to-sand contacts and consequently led to reduced shear strength as compared to 10% kaolinite content. However, the higher kaolinite content induced significant cohesion, which dominated the response and subsequently led to higher shear strength compared to pure Ennore sand. Due to the loss of contact between Ennore sand particles, the friction angle was decreased. Apart from the friction angle, kaolinite content had a significant impact on the cohesion of the Ennore sand-kaolinite mixture (Table 2). The cohesion value of the soil is mainly affected by the clay content. As samples were prepared at optimum moisture content, the added kaolinite induced the plasticity to the Ennore sand-kaolinite mixture and increased the compactness of the specimen. The plasticity of Ennore sand-kaolinite mixtures was observed to increase with increasing kaolinite content and was reflected in the cohesion values exhibited by the specimens with the simultaneous reduction in friction angle.

Table 2. Shear strength properties of Ennore sand-kaolinite mixtures

Kaolinite clay	**Cohesion, c**	**Friction angle, ϕ**	**shear strength at 139 kPa**
(%)	(kPa)	(Degree)	(kPa)
0	0	36.1	101
5	13	36.2	115
10	16	36.4	118
15	26	31.3	111

Conclusions

A series of large direct shear test were performed on Ennore sand- kaolinite mixtures at varying kaolinite clay contents. The results of the study are summarized as follows:

- The shear strength of Ennore sand-kaolinite clay mixture was observed to increase with the increase in kaolinite clay content and achieve maximum value at 10% kaolinite content. After that reduction in shear stress was observed at 15% kaolinite content.
- The volumetric response was exhibited initial settlement followed by dilation for all Ennore sand-kaolinite mixtures. The maximum initial settlement was observed in mixture with 15% kaolinite clay content.
- The internal friction angle increased slightly with theincrease inkaolinite content and attained the maximum value of 36.4 degrees at 10% kaolinite, after that the friction angle decreased to 31.3 degrees at 15% kaolinite.
- The cohesion value of Ennore sand-kaolinite clay mixtures was observed to increase with increasing kaolinite content. That could be attributed to the plastic nature of kaolinite clay.

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