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Shear Strength and Microscopic Behavior of Micaceous Kutch Soil

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Abstract

Micaceous soils are generally known for their high compressibility and low compacted density behavior. Mica particles have an influence on the compaction properties of soil due to their platy shape, ability to split into very thin flakes and the inter-space within the thin flakes. The mica flakes also impart resilience to the soil, which makes it difficult to compact. The spring nature of mica flakes helps them to recover their shape, when the stress is removed. The presence of mica particles in non-cohesive (sandy/silty) soil affects its grain packing. The particles of non-cohesive soils (sand, silt) are predominantly rounded particles, and the presence of mica in such soils tends to decrease the packing efficiency by increasing the size of void space within the soil mass. Mica flakes alter the packing of rounded particles (silt, sand) through bridging & ordering effects at significant percentage of mica content in soils. If mica content in soil is more than 10%, it has strong impact on compressibility, compressive strength and volume stability of micaceous soil. The current research is focused on the effect of water content on shear strength behavior of naturally available micaceous silty soil (Kutch, Gujarat). The resilience behavior of mica particles and the presence of water molecules in the inter-space of mica thin flakes were studied to understand the variation in shear strength behavior of micaceous Kutch soil (14% mica) due to the change in its water content. A series of shear strength tests were performed on micaceous Kutch soil at different water content varying from 0% to 23.5%. A series of XRD, SEM and AFM tests were also performed on Kutch soil to determine the mica content and understand the size, shape and geometric arrangement of particles (mica, silt, sand) within the soil mass.

Keywords: Mica, Shear strength, XRD, SEM, AFM, Micaceous soil

1. Introduction

The presence of mica in soil makes it undesirable for road pavement, embankment, and other civil engineering construction. Mica particle is comprised of a complex group of alumina and silica rich minerals and has ability to split into very thin flakes (May 2006). Mica particles are flaky shaped and exhibit high flexibility/ elasticity in its mechanical behavior. The presence of mica in soils used for civil engineering construction can be detrimental due to the effects of high compressibility and low compacted density, which mica imparts to the soil mass. Mica (muscovite) content more than 10% are not allowed in pavement and other civil engineering construction (May 2006). The presence of mica particles in silty/sandy soils (predominantly rounded particles) tends to decrease the packing efficiency by increasing the size of the voids. The resilience behavior of mica particles allows their thin flakes to deform under load and recover after the load is removed. Elastic behavior or resilience response of mica particles and its platy morphology influence the engineering behavior of micaceous soil significantly and encourage them to behave much differently under stress than more equi-dimensional silty/sandy soil particles (Harris et al. 1984). The larger surface area of micaceous soil as compared to the more rounded silt & sand soil particles require more water for surface coating. This combined with the ability of mica to absorb or store water within its micro-structure leads to the reduction in free water available in the soil mass. Effect of mica content on engineering properties of soil by preparing sand-mica mix was studied by few researchers (Tubey and Bulman 1964; Flempong 1994; Flempong 1995; Lee et al. 2007). Few researchers (Harris et al. 1984; Bokhtair et al. 2000; Lee et al. 2007) have explored the effect of mica on mechanical behavior of micaceous soil. Harris et al. (1984) performed research on Micaceous sand and reported that the compressibility and shear strength behavior of soil was observed to be significantly affected by the presence of 10% to 15% mica content in the soil. Bokhtair et al. (2000) performed a study on naturally available micaceous sand; however, mica content was found in soil to be within the lower range (2% - 6%). Shear modulus and constraint modulus of mica-sand mix with mica content varying in large amount was evaluated by Lee et al. (2007). However, shear strength behavior of naturally available micaceous soil with significant mica content (more than 10%) needs special attention and detailed exploration. In the current research, the effect of water content on shear strength behavior of naturally available micaceous silty Kutch soil was studied by performing a series of shear strength tests soil at different water content ranging from 0% to 23.5%.

2. Material Properties and Specimen Preparation

The micaceous Kutch soil sample was collected at 4m depth of Dhori site located in the region of Kutch, Gujarat. Water table was found to be at 3.5 m depth (Hussain and Sachan 2017). Index properties and compressibility properties of soil was determined by performing grain size distribution test (Wet sieving, Dry sieving, Hydrometer), Atterberg's limit, specific gravity, compaction, and consolidation tests. Wet and dry sieve test data exhibited that the soil had 22% sand and 78% silt. Hydrometer test showed the absence of clay particles. The specific gravity of soil was found to be 2.73. Atterberg limits could not be performed due to the non-cohesive nature of soil. Standard proctor test was performed on the micaceous soil sample. MDD (maximum dry density) and OMC (Optimum moisture content) was obtained to be 1.62 g/cc and 18.2% respectively. Minimum dry density of micaceous Kutch soil was obtained to be 1.06 g/cc. In-situ density and in-situ water content of micaceous soil was obtained to be 1.78 g/cc bulk density (1.42 g/cc dry density) and 24% respectively. All the soil specimens were prepared using moist tamping technique, as mentioned by Hussain and Sachan (2017) and Pandya and Sachan (2018). Moist tamping technique was suggested better technique as compared to water sedimentation and air pluviation techniques to prepare uniform specimens of soils in the laboratory.

3. Mineralogy of Micaceous Kutch soil

Kutch soil at Dhori site was found to be the micaceous soil with visually identified mica particles, which indicated the mica content available in soil could be more than 10%. XRD tests were performed on collected soil sample, and XRD pattern (Fig 1) exhibited the presence of Muscovite mineral and mica content in soil to be 14%. The SEM and AFM images of micaceous Kutch soil were also obtained to evaluate the size and shape of the particles (Fig 2 & 3). Flaky mica particles were observed in the soil sample and the size of mica particles was found to be varying from fine sand to silt size, as shown in AFM image (Fig 3). SEM image of mica particles showed several layers of thin flakes and their inter-spaces (Fig 2). The results obtained from grain size distribution analysis showed that Kutch soil had 22% sand and 78% silt; which actually represented 22% sand & sand size mica particles and 78% silt & silt size mica particles.

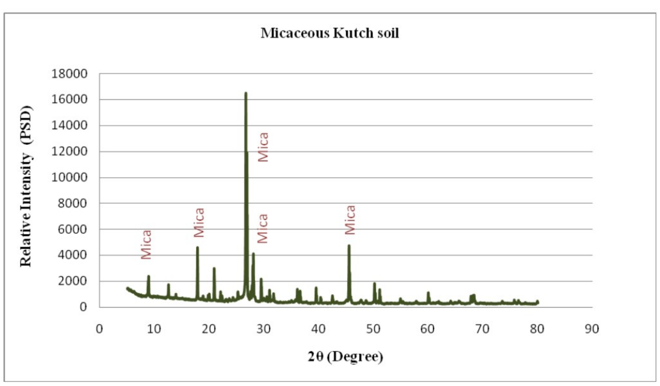

Fig. 1. XRD pattern of powdered sample of Micaceous Kutch soil

4. Results and Discussion

Reconstituted specimens of micaceous Kutch soil at different water contents were prepared by using moist tamping method (Hussain and Sachan 2017; Pandya and Sachan 2018). The specimens were prepared in shear box (60 mm x 60 mm x 25 mm) by providing 25 blows each layer in three uniform layers (wt of compactor=50 gm). Shear strength parameters of micaceous Kutch soil at water content of 0%, 0.28%, 1%, 3.4%, 5.4%, 7.8%, 11.3%, 15.1%, 18%, 20% and 23.5% were obtained. Shear strength tests for chosen water content were performed at normal stresses, 50 kPa, 100 kPa, 150 kPa and 200 kPa. No Wet condition was allowed during all the direct shear tests performed in the current study. Strain rate of 0.25 mm/min was kept throughout the test, and Failure was defined at the point of maximum shear stress. All the specimens used in shear strength tests were prepared at dry density of 1.42 g/cc (90% of maximum dry density) with varying water content. Maximum water content was kept 23.5% because of the difficulty in specimen preparation for water content more than 23.5%. The water molecules (for water content more than 23.5%) would have departed from the specimen due to the tamping action during specimen preparation for direct shear test. The reason could be attributed that the inter-space between thin flakes of mica particles (14% mica) were completely saturated with water at 23.5 % water content; thus additional water molecules (for water content more than 23.5%) would go into the pore space of soil mass. During the process of specimen preparation for direct shear test, the tamping action caused the water to depart from the saturated inter-space of mica particles leading to the significant decrease in water content of prepared specimen.

A series of shear strength tests were performed on pure mica (muscovite mineral) powder ($K_2O.Al_2O_3.6SiO_2$). Mica particles are light in weight and comprise of high void ratio in dry state, sample preparation at dry density of micaceous Kutch soil (1.42 gm/cc) was not feasible. All specimens of pure mica were prepared at 0.78 gm/cc dry density. Two series of direct shear tests were performed at 50kPa, 100 kPa and 150 kPa normal stresses for both dry and wet conditions. Fig 4 shows the shear strength test results of pure mica under dry and wet conditions. Cohesion was obtained to be zero, and angle of internal friction (ϕ) of mica was found to be 28^0 and 22^0 for dry and wet conditions respectively. The reason could be attributed that the water molecules could have entered in inter-space of thin flakes of mica particles as well as the space among the particles, which caused the reduction in friction between the mica particles. This led to the significant reduction in friction angle of mica at wet condition.

Fig 5 shows the maximum shear stress at different water content for different normal stresses (50 kPa, 100 kPa, 150 kPa and 200 kPa). Maximum shear stress was obtained to be highest for samples with water contents, 0.28% (W2) and 11.3% (W7) observed at different resilience peaks (Fig5). Sample W2 contained a small water content of 0.28%; where air-water interfaces might formed and created the surface tension effect. The surface tension of meniscus within the soil mass could be the reason for highest shear strength of micaceous Kutch soil at 0.28% (W2) water content in the form of first resilience peak. Further increase in water content showed significant reduction in shear strength of soil due to the collection of water within the inter-space of mica thin flakes as well as pore space between soil/mica particles. An increase in maximum shear stress was again observed at next resilience peaks at 11.3% (W7) water content. Post peak softening behavior was observed for specimens with 0.28% (W2) and 11.3% (W7) water content, as shown in Fig 6. It is important to note that these (W2, W7) were the locations where resilience peaks were observed. The reason of this response could be due to the better interlocking between particles at mentioned water content. Mica flakes alter the packing of rounded particles through pore filling ($L_{mica}/D_{soil} < 1$), bridging and ordering effects ($L_{mica}/D_{soil} \geq 1$) and mica-mica particle interaction at higher mica content (Lee et al. 2007).The shear stress versus horizontal deformation curve for sample W5 showed lowest value of shear stress indicating the least frictional resistance between the mica-soil particles due to combined effect of the presence of water molecule in inter-space of mica flakes and the bridging action of mica flakes on rounded soil particles causing the smallest resilience in the micaceous soil specimen at 5.4% water content.

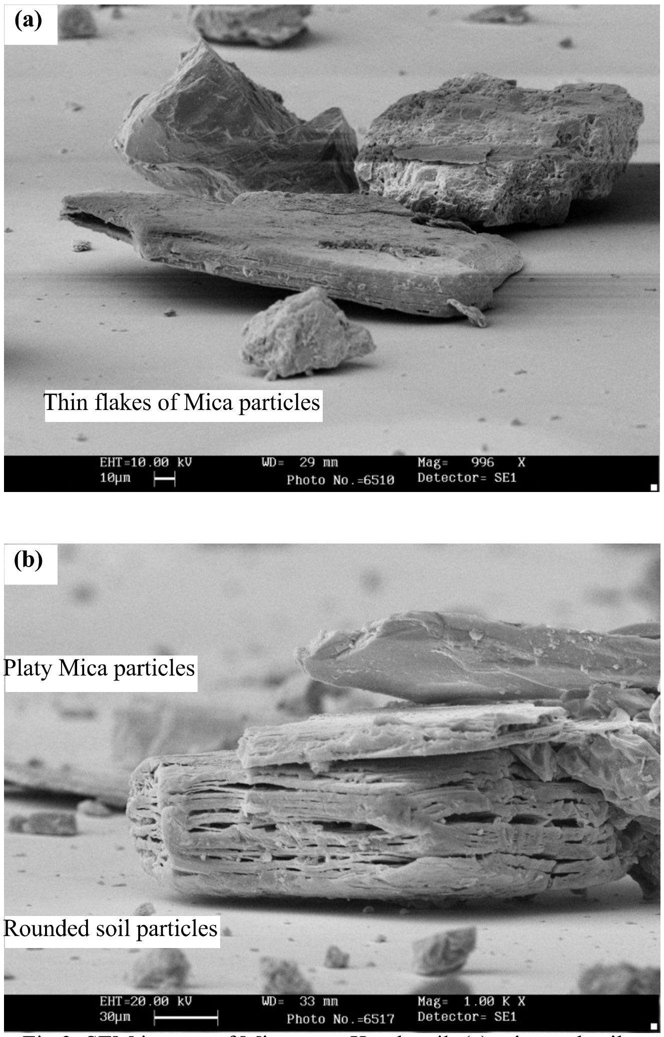

Fig.2. SEM images of Micaceous Kutch soil: (a) mica and soil particle; (b) thin flakes of mica particles

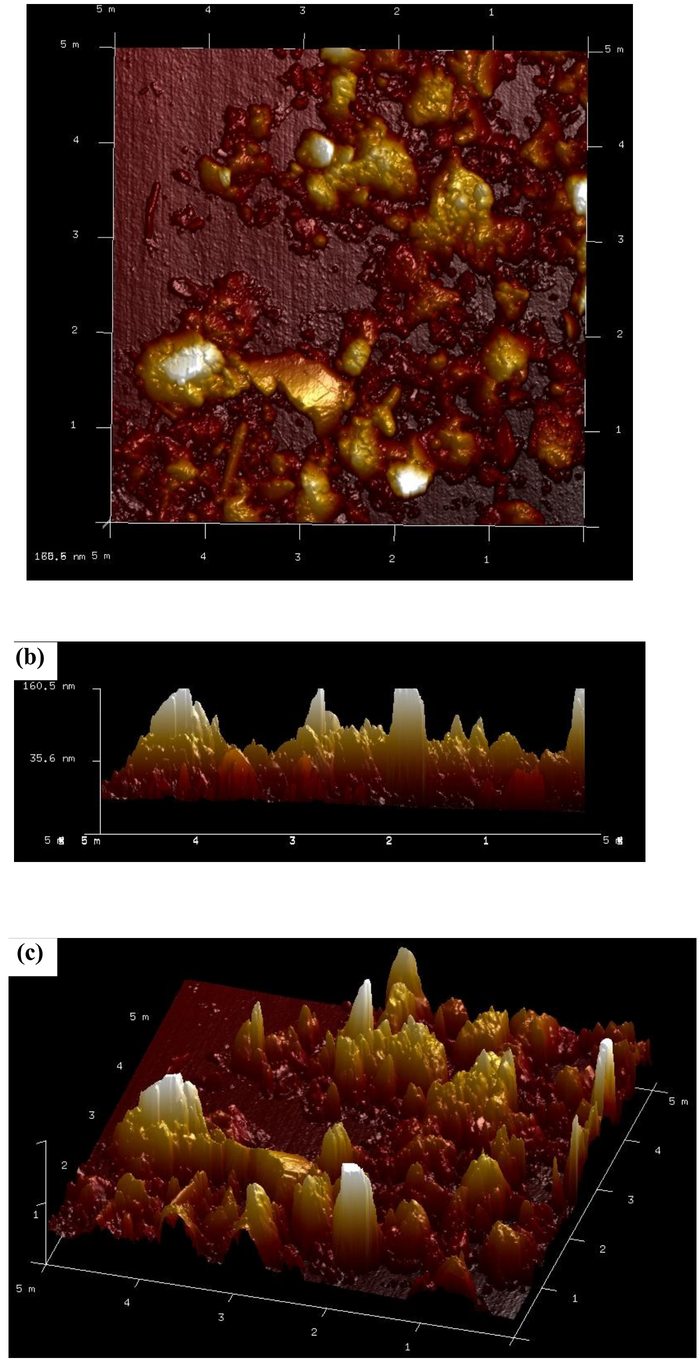

Fig. 3. AFM images of powdered Micaceous Kutch soil. (a) Plan view, (b) Elevation view, (c) 3-D view

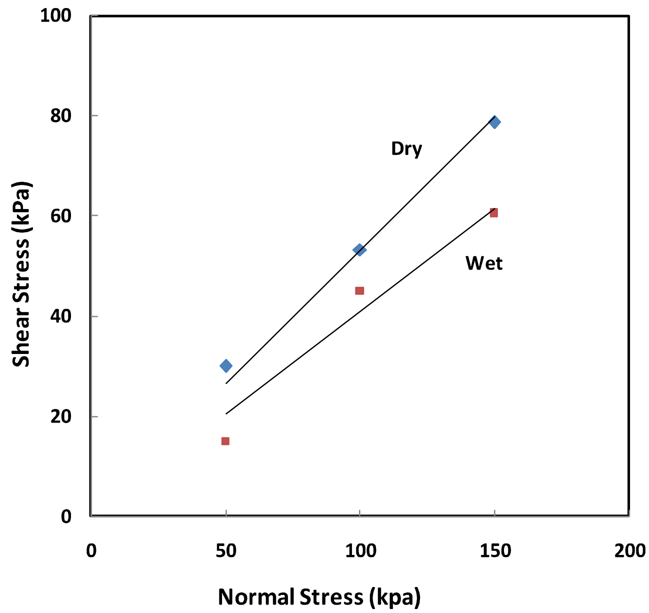

Fig.4. Stress paths of pure Mica (Muscovite mineral) under dry and wet conditions

Fig 7 shows the relationship of shear strength parameters (cohesion, friction angle) of micaceous Kucth soil due to change in water content. For all micaceous Kutch soil samples, cohesion was obtained to be zero. The friction angle was obtained to be maximum at three resilience peaks. Resilience peaks were observed at 0.28%, 11.3% and 20% water content. The increasing pattern of friction angle was observed at resilience peaks and decreasing pattern in between the resilience peaks. It is generally believed that the shear strength of soil decreases with the increase in water content. However, shear strength of micaceous soil exhibited different response as water molecules interacted with

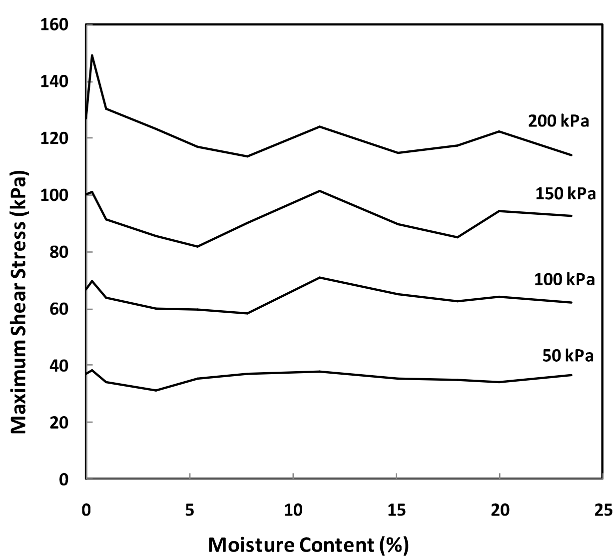

Fig.5. Effect of water content on Maximum shear stress of Micaceous Kutch soil

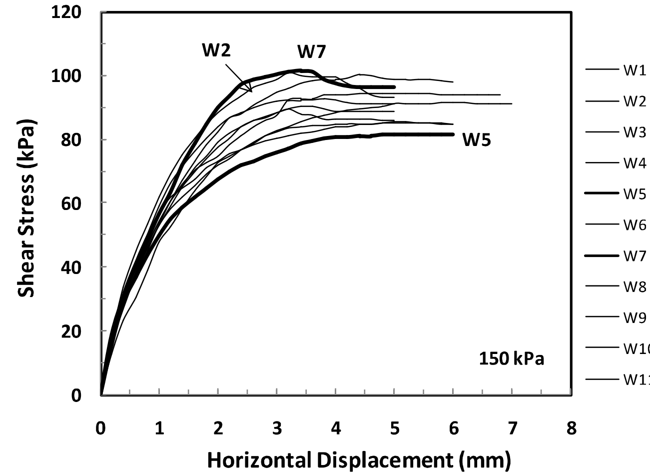

Fig.6. Stress-deformation curves of Micaceous Kutch soil at different water content performed at 150 kPa normal stress

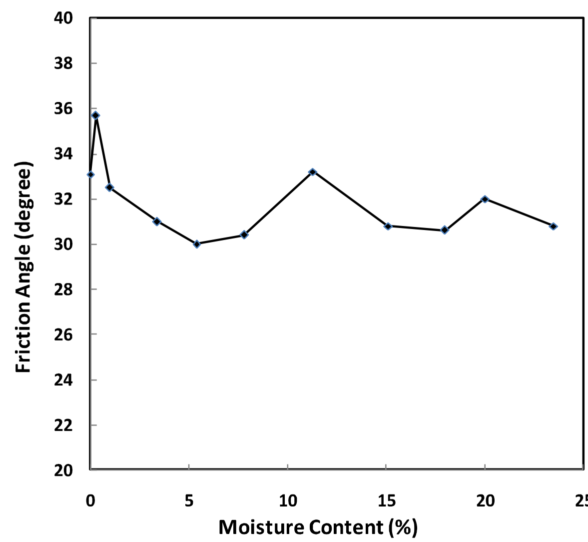

Fig.7. Effect of water content on friction angle of Micaceous Kutch soil

mica particles of soil. In micaceous soil, shear strength was observed to be the function of followings: i) presence of water molecule in inter-space of mica particles, ii) ordering & bridging effect of mica on soil particles, iii) resilience of mica particles due to the combination of these two effect at given water content.

5. Conclusions

This research is based on the effect of water content on shear strength behavior of naturally available micaceous silts. A series of shear strength tests was performed on Kutch soil samples collected at Dhori site for varying its water content from 0% to 23.5%. The soil was found to be the micaceous soil with visually identified mica particles indicating the mica content more than 10%. XRD tests were performed on Kutch soil and found to have 14% of mica (muscovite) in Kutch soil. The SEM and AFM images of micaceous Kutch soil showed flaky shape of mica particles available in varying sizes in Kutch soil (fine sand to silt sizes). SEM image of mica particles showed many layers of thin flakes and their inter-spaces. Shear strength of pure mica powder (muscovite) was also obtained under Dry and Wet conditions of direct shear tests. Key observations from this study are summarized as follows:

1. Shear strength analysis of pure mica exhibited higher value (28^0) of friction angle in dry condition and lower value (22^0) in wet condition. The reason could be attributed that the water molecules could have entered in inter-space of thin flakes of mica particles and saturated them, which caused the change in ordering & bridging effect of mica on soil particles. This led to the significant change in geometric arrangement of mica-soil particles leading to the change in void ratio as well as associated shear strength parameters.
2. Shear strength of micaceous soil showed significantly affected by the change in water content in the micaceous soil. The increasing pattern of shear strength of micaceous Kutch soil was observed at resilience peaks and decreasing pattern of shear strength was observed between the peaks. Resilience peaks were observed at 0.28%, 11.3% and 20% water content.
3. Cohesion was found to be zero for micaceous Kutch soil for its all water contents. Friction angle at resilience peaks were obtained to be 35.7^0, 33^0, 32^0 at water contents of 0.28%, 11.3%, 20% respectively.
4. Post peak softening response of micaceous Kutch soil was also at resilience peaks (0.28%, 11.3%, 20%). The lowest value of shear stress and friction angle was observed at 5.4% water content indicating the lowest resilience response of micaceous Kutch soil due to combined effect of the presence of water molecule in inter-space of mica flakes and the bridging action of mica flakes on rounded soil particles causing the smallest resilience in the micaceous soil specimen at 5.4% water content indicating lowest friction angle.

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