Effect of Adding Sand on Clayey Soil Shear Strength

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Abstract. The effect of adding sand on clayey soil shear strength is investigated in this study. Five different percentage of clay-sand mixtures are used; 100% clay with 0% sand termed 100C, 60% clay with 40% sand termed 60C-40S, 30% clay with 70% sand termed 30C-70S, 15% clay with 85% sand termed 15C-85S, and as well as 100% sand termed 100S. The used clay was obtained from Baghdad city in Iraq and classified as CH soil, while the used sand was taken from Al-Khider area from Iraq and classified as SW soil. The initial dry unit weight for all mixtures is 16 kN/m³. The results show that the variations of the soil shear strength properties with soil components content changes almost as polynomial function. The results show that the soil cohesion (C) decrease as the sand percentage increases, while the angle of internal friction (φ) increases as the sand percentage increases. The cohesion (C) decreases with 68%, 99%, 97% and 100% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C. While, the angle of internal friction (φ) increases with 148%, 410%, 471% and 676% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C. Finally, a predicted (fitting) equations are achieved for the variation of the clayey soil shear strength properties with sand content with good agreement.

Keywords: Clay soil; Sand soil; Shear strength; additives.

1. Introduction
Clayey soils, especially high plasticity one, show low shear strength parameters in general, particularly angle of internal friction (φ) in response to change their moisture content and may cause many engineering problems such as; low soil bearing capacity and low soil stability and etc. Thus the high plasticity clayey soils required to improve to overcome from one or more of above engineering problems. One of clayey soil improvement is adding sand as additives.

Many previous studies investigated the effect of adding sand or any similar material on clayey soils in order to enhanced the shear strength, volume change, permeability and, water retention properties of clay such as [1], [2], [3], [4], [5], [6], and [7].

Dafalla, (2013), [1], pointed out that as the clay content increases the cohesion increases and the angle of internal friction decreases. Al Rawi et al, (2018), [5], investigated adding sand additives to clayey soil with different percentage up to 20% of sand. They found that when the sand additives increase in the soils' cohesion decreases and in its friction angle increases and the soils' shear strength will increase.
in general. Kim et al, (2018), [6], studied the influence of adding different percentage of clay up to 30% on the shear strength of clay–sand mixtures. They found that as the clay content increases the internal friction angle increases to peak up to the clay content of 10%; it gradually decreased at clay content of 30%, with notable scatters of shear strength which may be due to existence of clay content in the mixtures. They performed photomicrographs which results showed that sand grains were surrounded by clay particles at higher clay contents and the voids were filled with clays with clay particles at lower clay contents.

2. Materials used
The fine-grained soil (clay) that used in this study was obtained from Baghdad city in Iraq, while the coarse-grained soil (sand) that used was taken from Al-Khider area from Iraq. The physical soil properties are summarized in Table (1) and Figure (1) shows the grain size distribution for both clay and sand used in this study. The used fine-grained soil (clay) is classified as CH soil according to USCS, while the used coarse-grained soil (sand) is classified as SW soil according to USCS.

| Test                      | Testing Standard | Clay | Sand |
|---------------------------|------------------|------|------|
| Specific gravity, Gs      | ASTM D-854       | 2.72 | 2.66 |
| Liquid limit, LL, %       | ASTM D-4318      | 60.0 | -    |
| Plastic limit, PL, %      | ASTM D-4318      | 29.3 | -    |
| Plasticity Index, PI, %   | ASTM D-4318      | 34.7 | -    |
| Fines, %                  | ASTM D-422       | 51   | 0.4  |
| USCS                      | CH               | SW   |
3. Samples preparation and Testing program.

The two components of soils (clay and sand) were mixed with five different percentage of clay-sand mixtures; 100% clay with 0% sand termed 100C, 60% clay with 40% sand termed 60C-40S, 30% clay with 70% sand termed 30C-70S, 15% clay with 85% sand termed 15C-85S, and as well as 100% sand termed 100S. The samples oven dried firstly then each component was weighted regarding to the specific percentage of mixture. The initial dry unit weight and initial water content for all mixtures are 16 kN/m³ and 10%, respectively. Then each sample was mixed in the testing ring and sealed by nylon bag for three days for curing and insure that the water distributed homogenously. In the direct shear test each sample was saturated with water at the stage of consolidation. The strain rate the used during the shearing stage was 1 mm/min.

The testing program involved classification and shear strength (direct shear) tests [ASTM D-3080]. Classification tests include specific gravity, Atterberg limits (Liquid limit (LL), Plastic limit (PL)) and grain size distribution. Series of shear strength tests were performed using direct shear device. The initial dry unit weight for all mixtures is 16 kN/m³, whereas the initial degree of saturation is 100%.

4. Results and Discussion

Figures (2-6), represent the direct shear tests results and each figure presents two relationships as (A) Horizontal strain versus shear stress relationship and (B) vertical stress versus shear stress relationship. The results show that the soil cohesion (C) decrease as the sand percentage increases, while the angle of internal friction (φ) increases as the sand percentage increases. Figures (2-6) show some noise in results which may attributed due to many reasons such as that the prepared samples are not perfectly homogenous or not equal density and may due to some human errors, but the significant point is that this scatter in results does not be effect on the general trend of soil behavior.
The results point out that in case of 100% clay (100C), the horizontal strain versus shear stress curve has multi-local peaks and the shear stress drops smoothly after reaching the peak value. Nevertheless, drop of shear stress after reaching the peak value trend to be more sharper as the sand percentage increases. Such behavior, the shear stress drops smoothly after reaching the peak value for pure clayey soil and this drop be more sharper as the sand percentage increases, may be attributed to the sliding between soil particles (or clusters in pure clay) in slip surface is more softer as comparison with coarse-grained soil particles (sand). Mukherjee et al, (2015), [3], and Al Rawi et al, (2018), [5], pointed out that as the sand percentage increases the interlocking between particles increases which result in more frictional resistance between the soil grains, and in other side leads to reduction on adhesion between soil particles. By other words, when the sand percentage increases the probability of existing coarse-grained soil particles (sand) in the slip surface at failure increases which makes the sliding between soil particles in slip surface is more roughness with more friction that releases more energy, as comparison with pure fine-grained soil.

As response of above behavior the drop of shear stress after achieve the peak value is more sharper as the sand percentage increases. Moreover, such response explains the behavior of the multi-local peaks in the intermediate percentages mixtures. The results of photomicrographs that carried out by [6] support this explanation. The results of photomicrographs showed that sand grains were surrounded by clay particles at higher clay contents and the voids were filled with clays with clay particles at lower clay contents.

![Horizontal Strain-Shear stress relationship](image1.png)  
![Vertical Stress-Shear stress relationship](image2.png)

**Figure 2.** Direct Shear test results for 100C mixture.
A: Horizontal Strain-Shear stress relationship

B: Vertical Stress-Shear stress relationship

**Figure 3.** Direct Shear test results for **60C-40S** mixture.

A: Horizontal Strain-Shear stress relationship

B: Vertical Stress-Shear stress relationship

**Figure 4.** Direct Shear test results for **30C-70S** mixture.

A: Horizontal Strain-Shear stress relationship

B: Vertical Stress-Shear stress relationship

**Figure 5.** Direct Shear test results for **15C-85S** mixture.
Figure 6. Direct Shear test results for 100S mixture.

Figure (7) shows the results of all five direct shear tests in one figure. Figure (7) points out, as mentioned above, that the soil cohesion ($C$) decrease as the sand percentage increases, while the angle of internal friction ($\phi$) increases as the sand percentage increases. Moreover, the position of failure line, in the vertical stress versus shear stress relationship, initially dropped down after adding some sand to pure clay then the line location rises as the sand percentage increases. This behavior is agreement with the results of [1], [5], and [6].

![Graph](image-url)

**Figure 7.** Vertical Stress-Shear stress relationship for all five mixtures used in this study (100C, 60C-40S, 30C-70S, 15C-85S, and 100S).

Figures (8-9) present the change of the cohesion ($C$) and the angle of internal friction ($\phi$), respectively, with the five different mixtures. Figures (8-9) show that the cohesion ($C$) decreases with 68%, 99%, 97% and 100% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C. While, the angle of internal friction ($\phi$) increases with 148%, 410%, 471% and 676% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C.
Figure 8. Variation of the cohesion (C) with the five different mixtures.

Figure 9. Variation of the angle of internal friction (φ) with the five different mixtures.

5. Prediction of the soil shear strength properties.
The aim of this study is to investigate how the shear strength parameters are changing when the sand content increases on clayey soil. The results show that the shear strength parameters response in same trend for all sand percentages used in this study (40%, 70%, 85%, and 100%), so the behavior can predict mathematically depending on the basic soil shear strength [parameters of the raw materials (original clay and sand)]. Figures (10-11) show that the variations of the soil shear strength parameters with soil components content change as polynomial function. To predict the soil shear strength behavior of mixtures it is better to investigate the shear strength parameters as a function of sand content with the basic soil shear strength of clay with initial dry unit weight for all mixtures is 16 kN/m³. The basic soil shear strength of clay (classified as CH) are; the cohesion (C) = 14.5 kN/m³ and the angle of internal friction (φ) = 4.2°. Equation (1) represents the polynomial fit equation for the cohesion (C), while Equation (2) represents the polynomial fit equation for the angle of internal friction (φ).

\[ C = 0.0018 S^2 - 0.3231 S + 14.544 \]  
\[ \phi = 0.0018 S^2 + 0.096 S + 4.1207 \]
Where $C = \text{soil cohesion in kN/m}^2$, $\phi = \text{angle of internal friction in degree (°)}$, $S = \text{sand content percentage (0 %–100 %)}$.

Figure 10. Variation of the cohesion ($C$) with sand content and the fitting curve.

Figure 11. Variation of the angle of internal friction ($\phi$) with sand content with the fitting curve.

6. Conclusions.
The effect of adding sand on clayey soil shear strength is investigated in this study with initial dry unit weight for all mixtures is 16 kN/m$^3$, thus, the following points can be drawn as conclusions:

- The soil cohesion ($C$) decrease as the sand percentage increases, while the angle of internal friction ($\phi$) increases as the sand percentage increases.
- The position of failure line, in the vertical stress versus shear stress relationship, initially dropped down after adding some sand to pure clay then the line location rises as the sand percentage increases.
- The cohesion ($C$) decreases with 68%, 99%, 97% and 100% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C.
- The angle of internal friction ($\phi$) increases with 148%, 410%, 471% and 676% as the sand percentage increases with 40%, 70%, 85% and 100% respectively from pure clay soil 100C.
Based on the soil shear strength of clay, two equations are achieved for the variation of the clayey soil shear strength parameters with sand content with good agreement.

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