Effect of Bentonite Mudcake on the Interface Between Sandy Clay and Concrete

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Abstract

This paper presents investigation of behavior of bentonite mudcake between soil and concrete. A number of simple shear test have been performed on sandy clay and concrete specimens with and without bentonite mudcake at contact. The constitutive relations such as stress-displacement, dilative and the strength relations have been discussed in details. It was found that thin bentonite mudcake between sandy clay and concrete increases the shear strength, the sliding between soil and concrete in addition to the vertical displacement. The bentonite mudcake has a dual reaction; the upper face interacts with soil and the lower face interacts with concrete, showing different effects.

Keywords: Bored pile ; Bentonite mudcake; constitutive relations; sandy clay; concrete; compressibility; shear strength**.**

1. Introduction

Large Bored pile foundations are widely used to support heavy buildings around the world. Construction bored piles often needs using bentonite slurry to stabilize the borehole throughout construction. Using bentonite slurry may form weak layer between soil strata and concrete and this may diminish the capacity of the bored piles [1].

Construction period and bentonite slurry properties are main parameters influence the bearing capacity of bored pile. Many researches show that for short time of construction (less than 24 hours), bearing capacity does not decrease [2, 3, 4]. Increasing time of construction causes weak layer of bentonite that could not be removed through concrete pour. Properties of bentonite slurry such as viscosity is an important factor because it determines the degree of replacement of concrete tremie concreting [3, 4, 5, 6].

Maintaining the properties of the slurry within tolerable limits and placing the concrete in the same day of construction may decrease excessive filter cake occurrence and solve the problem of reducing skin friction [3]. However, contribution from recently researches did not endorse this recommendation. For instance, Brown 2002 [7] showed that reduction in side resistance occurs even if the construction is achieved in short time interval. Zhang et al, 2009 showed that mudcakes have high water content, higher void ratio, high compressibility, low friction and low shear strength compared to in situ soil. Besides, the situation of bored pile construction mostly does not help the engineer to construct in time and within tolerable limits of slurry properties. Effect of bentonite slurry on the bearing capacity is doubt. Accordingly, to that, systematic study about the interaction of bentonite between soil and concrete is involved and constitutive relation of the behavior would be demonstrated.

Direct shear and simple shear test are widely used to study the soil structure interface, however, studying the effect of bentonite on interfacial shear strength using simple shear test are not available. Recently, a direct shear apparatus has been used to study concrete rock interface and sand-steel interface [8, 9]. Shakir and Zhu [10] used a simple shear apparatus to study the interface between compacted clay and concrete, and between compacted soil and different concrete surfaces [11]. The simple shear test is more convenient to investigate the effect of bentonite since it is simple for use and can measure the sliding and deformation in split form.

In this research, there are two questions; how the mudcake can affect the interfacial shear strength when the simple shear test is used; and how to describe the constitutive relation. The objectives of present research were (1) performing many tests on soil concrete interface with and without mudcake at the contact (2) investigating the effect of mudcake with the soil concrete interface (3) describing the constitutive relation such as stress-displacement relationship, shear strength, dilatancy relationship. This research will contribute in inclusive understanding of the constitutive relation of mudcake between concrete and sandy clay and also to show the effect of bentonite on the interfacial shear strength.

2. Experimental tests

2.1 Simple Shear Apparatus

Figure (1) shows an image of interface simple shear apparatus used in this study, which is originally manufactured for Geohohai institute. The simple shear apparatus was adapted and used to test the interface between sandy clay and concrete under constant normal load. Adapting of apparatus implied using GDS "pressure volume controller" to apply controlled shear force. Proving ring based dial gauge was used to measure the applied shear force.

Box containers with inner size 107×107 mm were made from iron and filled by concrete mortar. The contact area between clay and concrete does not change because the concrete area is greater than contact area of the clay sample even when sliding displacement occurs. Stack of rings made from copper with diameter of 60 mm represents the container of sample. Minimizing the friction induced between rings implies lubricating them to make deformation of a clay mass occur freely. The height of sample was 10 mm. Normal displacement is measured by strain gauge with accuracy 0.001 mm/digit, which is the same type used for tangential displacement.

2.2 Computing sliding and deformation displacement

Calculating tangential displacement requires readings of three gauges located at the concrete container, lower and upper ring of container rings (Figure 1). Figure 2 shows schematic diagram for the method of calculation the sliding and deformation displacement after applying the shear force. Sliding displacement equals to subtraction of displacement of bottom ring, which is located in contact with concrete from the displacement of concrete i.e. ($\Delta_s = \Delta_c - \Delta_l$). Subtraction of the sliding displacement from the displacement of the top ring of the sample container equals to the deformation displacement ($\Delta_d = \Delta_l - \Delta_u$). Total displacement is calculated by adding sliding displacement to deformation displacement ($\Delta_t = \Delta_s + \Delta_d$). Thus, in simple shear test, the displacement can be split into two components shear sliding displacement and shear deformation displacement, which increase the ability of understanding the behavior of interface.

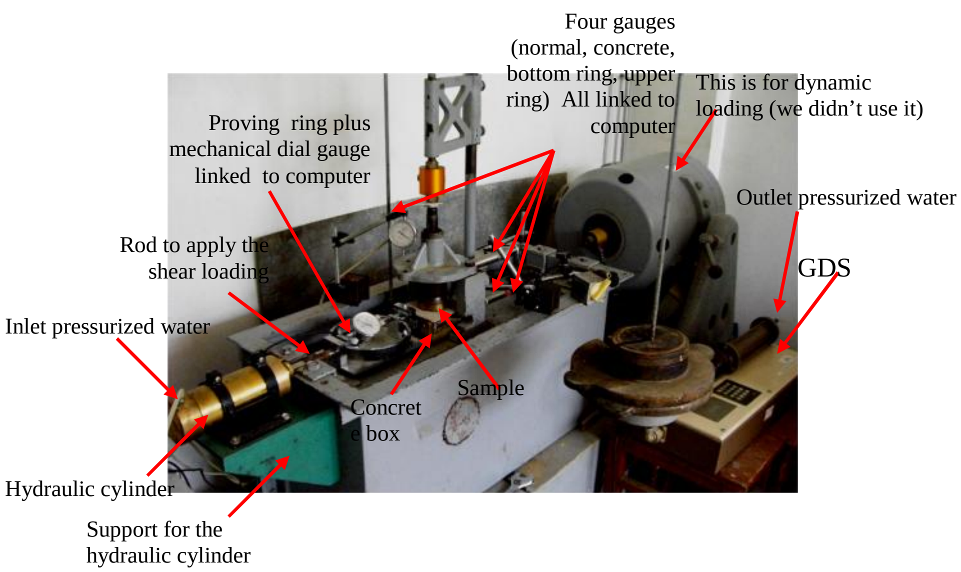


Figure (1). Simple shear apparatus.

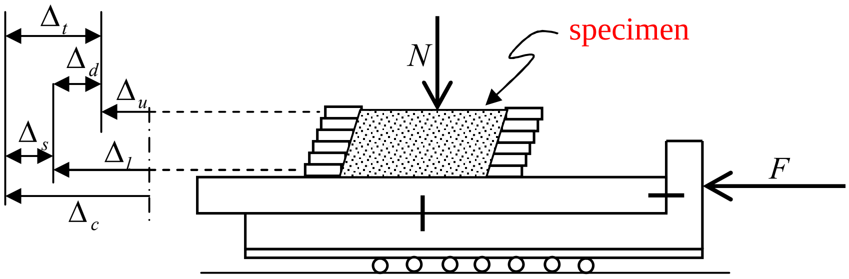


Figure (2). Schematic view shows sliding, deformation, and total shear displacement.

3. Materials and method of test

Preparing of concrete material considered getting practical compression strength and repeatedly testing with minimum wearing in the concrete surface. Five containers were made to pour the concrete mortar. These containers consist of four pieces welded to a plate at the bottom face. The concrete containers minimize the deformation in concrete during performing the test. The concrete was prepared by mixing the sand and cement with 60% water cement ratio, then the five containers were filled by the concrete mortar. The ratio of cement to sand was (1:2.5), and compressive strength is 23 MPa. Scratch was used to fill the concrete mortar into concrete containers and spatula was used to end the surface. Using the five containers of concrete in the interface testing program requires embedding them under wet sand for more than twenty-eight days. Concrete specimens are as follow: the first one is smooth and the other types are rough surface.

The experimental study considered sandy clay soil, which is prepared mixing clay and sand. The dry density of clay is 1.65 $\boldsymbol{g/cm^3}$ and the optimum water content is about 18%.

For the sand, the dry density is 1.9 g/cm^3 and the optimum water content is about 12%. Table 1 shows the properties of sand such as the diameter opposite to 10%, 30% and 60% finer (D_{10}, D_{30}, D_{60}) as well as the coefficient of uniformity (C_u) and coefficient of curvature (C_c). Sandy clay soil was made by artificially mixing 75% of sand and 25% clay. The sample was prepared by compacting soil inside container of rings with constant dry density.

Preparing of bentonite slurry needs mixing small quantity of bentonite powder with water and waiting for four hours for hydration. The testing needs placing a thin layer of bentonite slurry on the sample by spatula then placing the sample on the concrete for five minutes. Last step is to apply constant normal loading and shear force.

Table (1a). Sand soil properties.

L.L. (%)	P.L. (%)	PL.I. (%)	Gs (%)	Dry Density (g/cm^3)	Wc (%)
35.08	19.98	15.10	2.68	1.65	18

Table (1b). Sand soil properties.

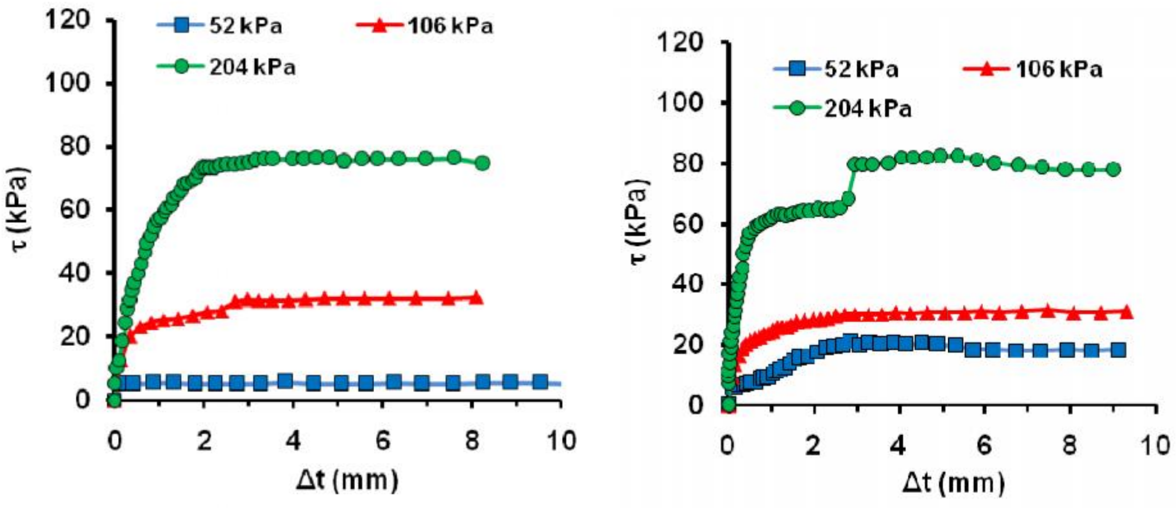
Soil Unified Classification	D_{10}	D_{30}	D_{60}	$C_u = D_{60}/D_{10}$	$C_c = D_{30}^2/(D_{60} \cdot D_{10})$
SP	0.16	0.3	0.45	2.8	1.25

4. Results

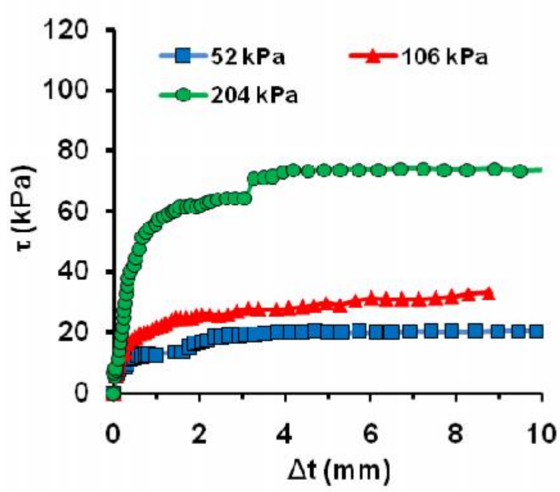
4.1 Stress-displacement results

The research considers testing of the interface between sandy clay and concrete with and without bentonite mudcake at contact. One concrete specimen has smooth surface and four concrete specimens have rough surfaces were used in order to take the average. Because of the lake of space, some results are selected. The paper presents the results of interface between sandy clay and two types of concrete; smooth and rough with/without bentonite slurry at the contact.

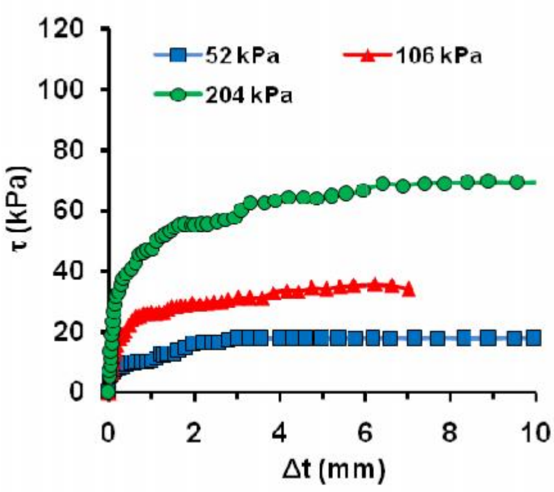
Figure (3 a,b) shows the result of applied shear stress (τ) versus total displacement (Δt). The test was performed between sandy clay with smooth and rough surface concrete but without bentonite slurry at contact. The shape of curves are hyperpolic and they show the same shape even when the interface tested with smooth and rough-surface concrete. The same comment is recorded for the case when bentonite slurry is used Figure (3c,d). It is also noticed that normal stress has no effect on the shape of curves, however on the size it has. Generally, as the test conducted under high normal stress, shear strength increased noticeably.



(a) **(b)**



(c)

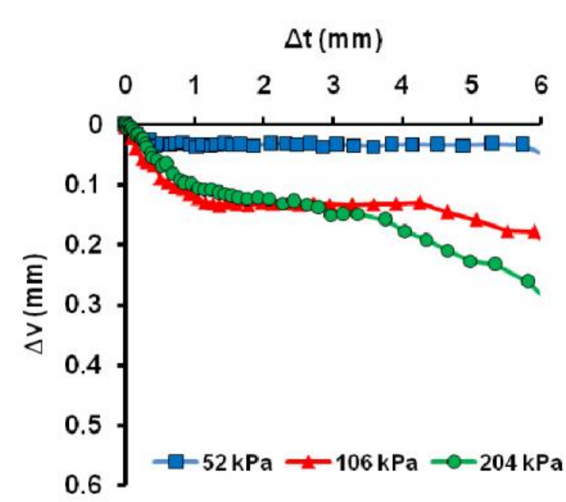


(d)

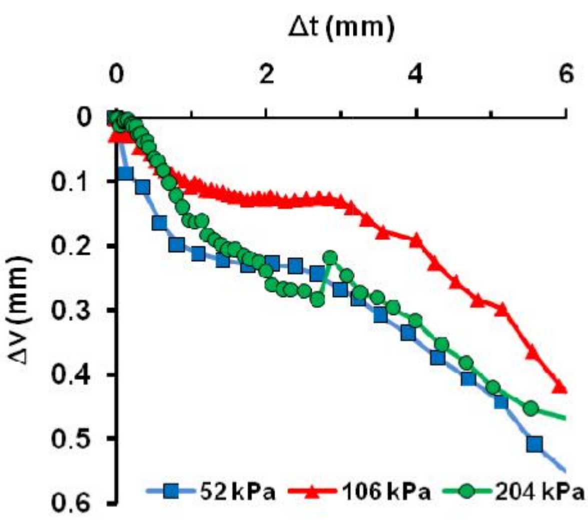
Figure (3). Relation of applied shear stress (τ) versus total displacement (Δt). (a: Sandy clay soil-smooth surface concrete) (b: Sandy clay soil-rough surface concrete; c: Sandy clay soil-smooth surface concrete with bentonite (mudcake) at contact; d: Sandy clay soil-rough surface concrete with bentonite (mudcake) at contact).

4.2 Vertical -shear displacement relations

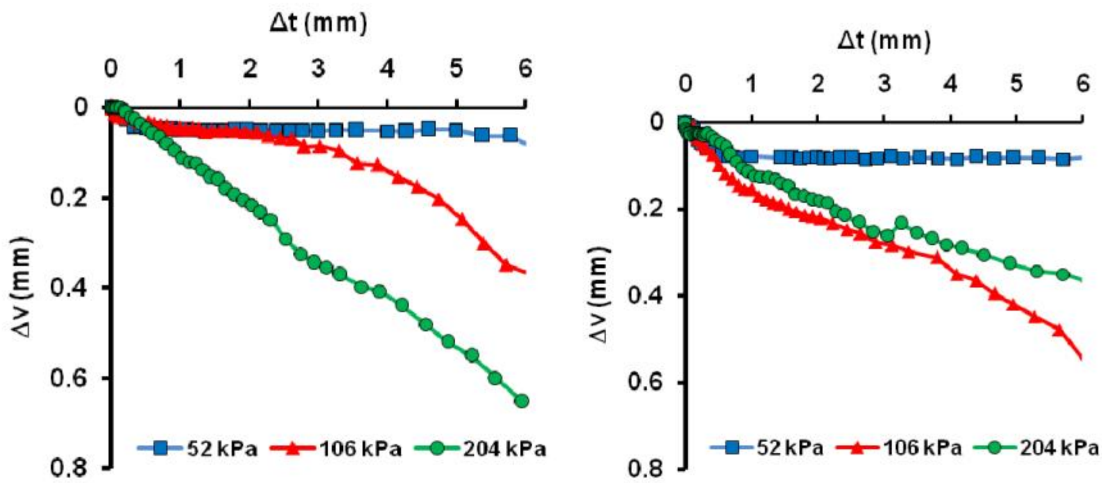
Figure (4) shows the relation between total shear displacement Δt (mm) versus vertical displacement Δv (mm). Figures (4a) and 4bb show the relation for the case of interface between sandy clay soil and smooth concrete and also between sandy clay soil and rough concrete without bentonite mudcake at contact. Figures (4) c and 4d show the same relation but with bentonite at the contact surface. Generally, it can be noticed that as normal stress increases vertical displacement increases Figure (4,a, c and d), however sometimes the results are scattering Figure (4b). Vertical displacement is just compression; there is no transition from compression to tension. Using of bentonite may increase the vertical displacement as will be discussed in sec. 4.2 Figure (4 c, d).



(a)



(b)

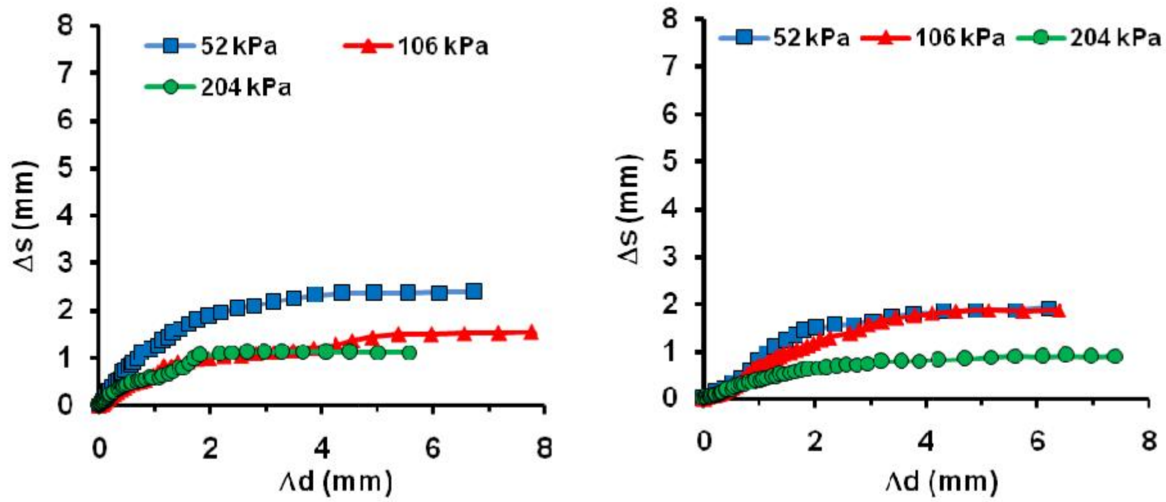


(c) (d)

Figure (4). Relation of vertical displacement (Δv) versus total displacement (Δt). (a: Sandy clay soil-smooth surface concrete) (b: Sandy clay soil-rough surface concrete; c: Sandy clay soil-smooth surface concrete with bentonite (mudcake) at contact; d: Sandy clay soil-rough surface concrete with bentonite (mudcake) at contact).

4.3 Sliding-deformation results

Relations between deformation displacement and sliding displacement are shown in Figure (5). Figure (5a) shows the result for the case of sandy clay and smooth concrete. At low normal stress 52 kPa the substantial displacement is the sliding displacement, while for normal stress 106 kPa, 204 kPa the deformation displacement is the substantial. Generally, the deformation displacement is the substantial one Figure (5b, c, d). Effect depicted in figures depends on normal stress intensity.



(a) **(b)**

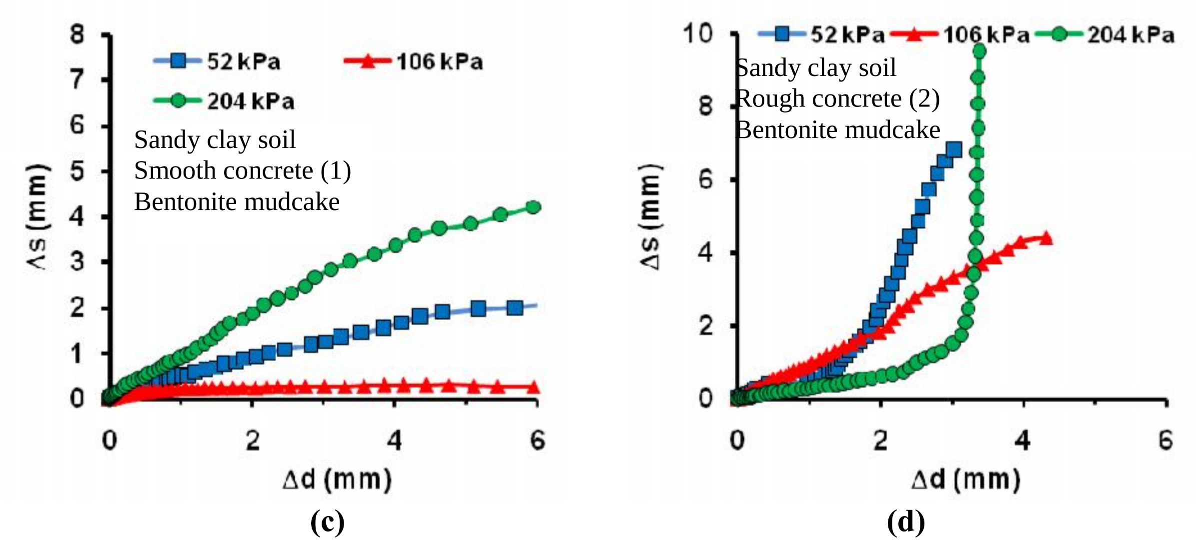


Figure (5). Relation of deformation displacement (Δd) versus sliding displacement (Δs). (a: Sandy clay soil-smooth surface concrete) (b: Sandy clay soil-rough surface concrete; c: Sandy clay soil-smooth surface concrete with bentonite (mudcake) at contact; d: Sandy clay soil-rough surface concrete with bentonite (mudcake) at contact).

5- Discussion

The main goal of the present research is to explain the effect of bentonite mudcake on the different relations such as shear stress-shear displacement relations, vertical displacement-shear displacement relations and shear strength relations.

5.1 Shear strength relations

The stress-displacement relations do not show clear peak point Figure (3). Peak point almost appear when the test is carried out on dense sand interfaced with rough surface, see for instance the results of tests conducted between dense sand and steel plate and also between dense sand and concrete [12]. It customarily occurs when applied stresses change sample volume from compression to expansion. Maximum shear stress was mapped against normal stress in order to establish the strength line. Table (2) shows the parameters of adhesion and angle of friction (C, δ) that were obtained from linear curve fitting of the strength line between maximum shear stress and normal stress. The first row in Table (2) represents the parameters for the interface between sandy clay and five types of concrete without bentonite at contact and row two shows the parameters (C, δ) for the case of interface between sandy clay and concrete with bentonite mudcake at contact. The average values for adhesion and angle of friction are shown also in Table (2). Results in Table (2) showed that bentonite decreases the adhesion from 12.9 kPa to 0.4 kPa and in contrast increases angle of friction from 13 to 20.2.

Table (2). Angle of friction and adhesion for sandy clay-concrete interface and Sandy clay-concrete-bentonite-interface.

	Smooth(1)		Rough(2)		Rough(3)		Rough(4)		Rough(5)			
Parameters	C	δ	C	δ	C	δ	C	δ	C	δ	C^{av}	δ^{av}
Sandy clay-concrete-Interface	4.5	14.2°	14.1	13.1°	15.0	13.0°	16.6	13.4°	14.1	11.5°	12.9	13.0°
Sandy clay-bentonite-concrete-Interface	0.0	19.8°	0.0	19.1°	0.0	20.9°	1.8	20.6°	0.0	20.7°	0.4	20.2°

The strength relation is represented by the following equation:

$$\tau = c + \sigma_n \tan \delta \qquad (1)$$

τ_{max} symbolizes the equation of ultimate strength, c is the adhesion, δ is the angle of friction. Average of parameters Table(2) were used in Eq. 1 to calculate the average maximum shear strength for three normal stresses (52, 106, and 204 kPa), The average strength for the case of interface between sandy clay and concrete without bentonite is τ^{av}=122 kPa and for that with bentonite mudcake at contact is τ^{av}=134. The increase in strength is about 10%. At low normal stress the effect of adhesion (c) is sensible, however as normal stress increases the adhesion has an insensible effect compared to the effect of angle of friction. For instance, at normal stress 52 kPa, applying equation 1 on the two average parameters (C^{av}, δ^{av}) Table (2), gives τ = 25 kPa for test without bentonite and τ = 20 kPa for test with bentonite. It can be seen that using bentonite decreases the strength about 20% at normal stress 52 kPa. At normal stress 204 kPa, τ = 60 kPa for test without bentonite and τ = 75 kPa for test with bentonite. Here using bentonite increases the strength about 25% at normal stress 204 kPa. At normal stress 106 kPa the increase is about 5%. Taking the average for the increase and decrease in strength, result of averaging show using bentonite increase the strength by 10%.

5.2 Vertical displacement-shear displacement- relations

Generally, the vertical displacement (Δv) increases as bentonite is used. At smooth surface there is no increase Table (3), Δv equals to 0.6 mm. Average value (Δv^{av})for the test without bentonite was 0.47 mm while it increases to 0.55 mm for the test with bentonite mudcake (Figure 6a,b). Vertical displacement increases by 17%, however the increase in vertical displacement for bentonite layer is not the same and can be determined through this section. Vertical strain equals to vertical displacement divided the original height of the soil sample $\varepsilon_v = \Delta v / h$, which is equal to 0.047. When we use bentonite layer of 1.5 mm, the thickness of soil sample will be 8.5mm (Figure 6 c,d). The vertical displacement in the soil sample will be $\Delta v_{8.5mm} = 8.5 \times \varepsilon_v$ which is equal to 0.400 mm. Therefore, the vertical displacement in the bentonite layer will be equal to 0.55-0.4 =0.15 mm where 0.55 mm is the vertical displacement in the soil sample plus bentonite layer. Vertical strain in bentonite is equal to 0.15/1.5 which is equal to 0.1. Strain in bentonite equal to 0.1/0.045=2.2 times the strain in sandy clay sample. Thus we can conclude that compressibility of bentonite layer is greater two times than the compressibility of sandy clay.

Table (3). Average maximum vertical displacement.

Concrete Shape	Δv (mm), (1)	Δv (mm), (2)	Δv (mm),(3)	Δv (mm),(4)	Δv (mm),(5)	Δv^{av} (mm)
Sandy clay-concrete	0.6	0.49	0.45	0.25	0.58	0.47
Sandy clay-bentonite-concrete	0.6	0.76	0.51	0.24	0.62	0.55

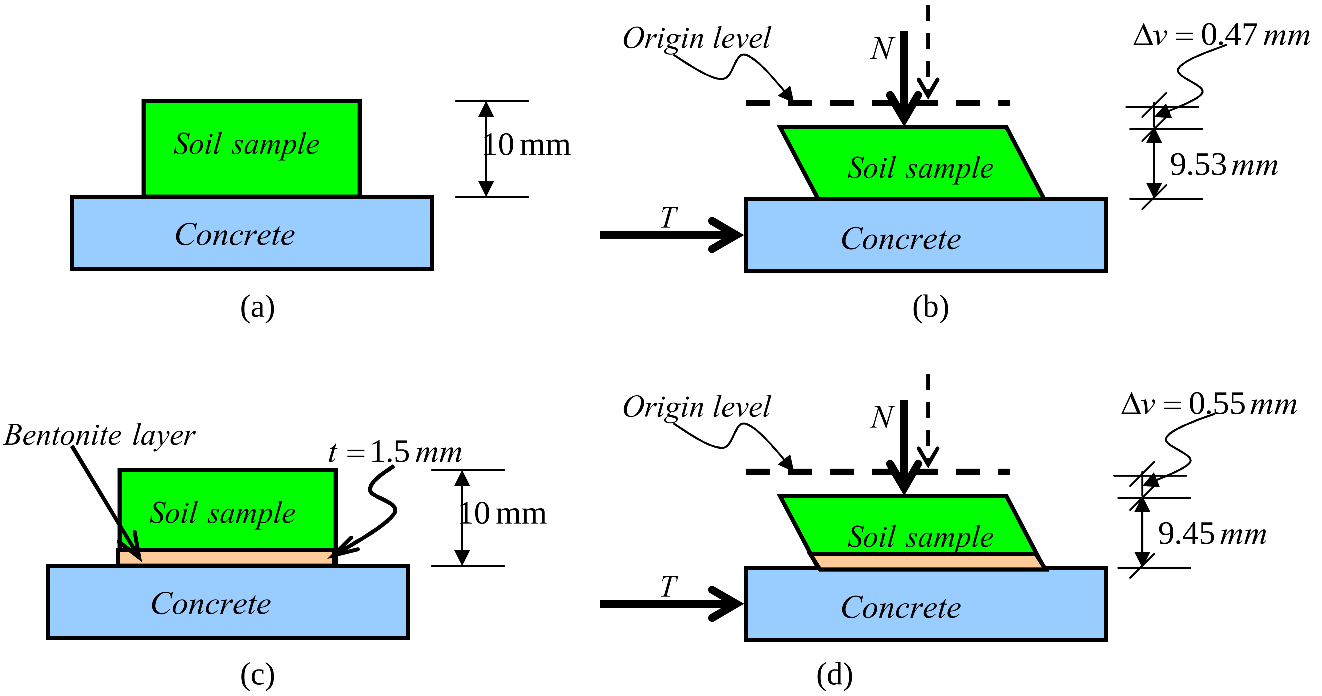


Figure (6). Schematic view show the vertical displacement for test with/without bentonite, before/after the test.

5.3 Sliding –deformation relations

Sliding of the sample depends on two parameters the adhesion and the friction. Using the relations between sliding displacement and deformation displacement (Figure 5) can show that the maximum value of sliding is different as concrete surface and normal stress are changed. We suggested the following equation to calculate sliding ratio $R_s = \Delta_s/\Delta_t$. Table 4 shows the average of sliding ratio. Using of bentonite increases the sliding ratio from 0.25 to 0.36. Figure (7) shows schematic view for the sliding for the test with and without bentonite.

Using of bentonite increases the sliding by percentage of 44%. Increasing of sliding refers to weakness in the contact between soil and concrete, however it is worthless to say that it will reduce the strength. The resistance then will be moved to the body of sample. If the sliding ratio less than 0.5 that means sliding failure was indicated. Most surly the parameters of adhesion and friction are different at each point in the sample body, however it is impossible now to calculate the parameters at each point. With the aid of sliding ratio we can indicate how much shear stresses cause sliding and deformation. We can get the adhesion and angle of friction at sliding by multiplying the total adhesion and angle of friction by the sliding ratio.

Table (4). Sliding ratio for sandy clay-concrete interface and sandy clay-bentonite-concrete-interface.

Concrete Shape	R_S (1)	R_S (2)	R_S (3)	R_S (4)	R_S (5)	R_S
Sandy clay-concrete	0.19	0.38	0.25	0.17	0.27	0.25
Sandy clay-bentonite-concrete	0.24	0.65	0.35	0.17	0.38	0.36

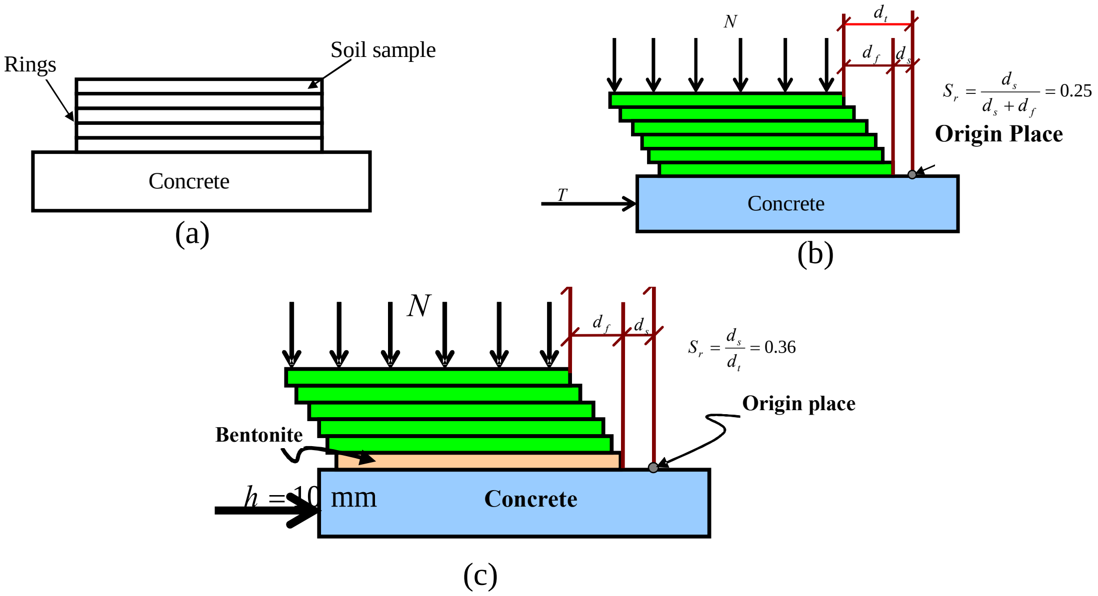


Figure (7). (a) schematic view show the sample rings and concrete before performing the test (b) Average sliding ratio after applying normal and shear force for test between sandy clay and concrete without bentonite (c) Average sliding ratio after applying normal and shear force for test between sandy clay and concrete without bentonite.

Bentonite has dual effect on the interface. It represents the interface layer and the place of stress concentration. The upper face of bentonite contact with sandy clay which may work as an enhancement material. The bentonite fill the voids between particles of sandy clay sample at contact. The lower face of bentonite contacts with concrete, which may decrease the interlocking between bentonite and concrete. Because the layer of bentonite is weak, it may reduce the strength to sliding. Therefore, we can say that sliding increased from 0.25 for the test without bentonite to 0.36 for the test with bentonite at contact. The increase in sliding is about 44%. Increase in sliding means the body of sample undergo little applied force at first, but after increasing of the applied force, sliding increases, bentonite mudcake fills the voids between asperities of concrete surface making a high resistance against applied shear stress Figure (8), the body of sample begun to undergoes the load and deformation increases until failure. Therefore the shear strength increases as normal stress increase since bentonite will improve the sandy clay soil at the contact between sandy clay and bentonite and also makes the bentonite slurry fill the voids between asperities of concrete.

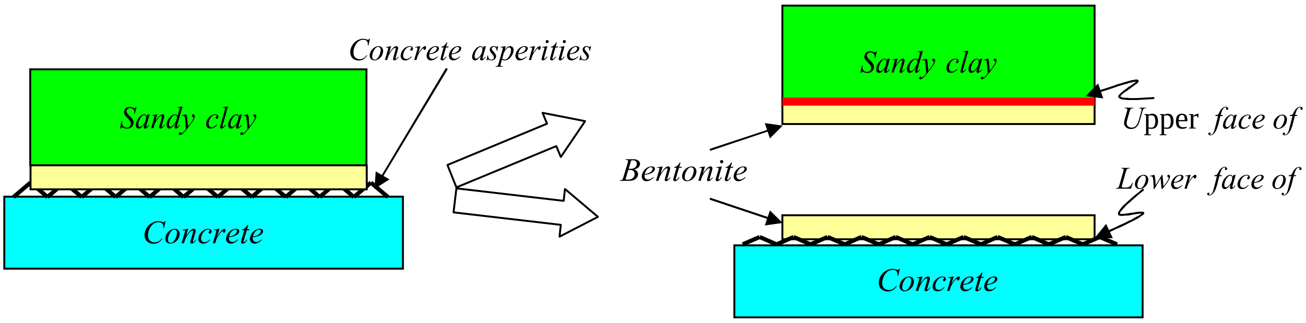


Figure (8). (a) schematic view show the dual effect of bentonite mudcake.

6. Conclusions

In this research simple shear test was used to investigate the effect of bentonite mudcake between sandy clay and concrete and described the relations of shear stress-displacement, vertical displacement-shear displacement relations. Laboratory tests were conducted on interface between sandy clay soil and five specimens of concrete, one has smooth surface and four have different rough surfaces. Tests were conducted with and without bentonite at contact of sandy clay and concrete. The paper presented the following findings. (1) The bentonite mudcake increased the strength by 10% since it fills the voids between soil particles trying to enhance the soil at contact. (2) Using bentonite indicated an increase in vertical displacement by 17% when testing conducted with bentonite at contact more than that without bentonite (3) Using bentonite increased the sliding between sandy clay and concrete by about 44%. (4) bentonite mudcake has dual effect on the interaction between soil and concrete; the upper face of bentonite interacts with sandy clay and the lower face interacts with the concrete. The contributions increase the understanding of the effect of bentonite mudcake and also describing the constitutive relations of sandy clay-bentonite-concrete-interface .

Acknowledgement

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8. Notations

List of symbols

Δ_s = *sliding displacement*

Δ_c = *concrete displacement*

Δ_l = *lower ring displacement*

Δ_u = *upper ring displacement*

Δ_t = *total displacement*

Δ_d = *deformation displacement*