Study Shear Strength Characteristics of Gypseous Sandy Soil Using Additives

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ABSTRACT

The present study investigated the possibility of enhancing collapsible gypseous soil of Al-Qarma site (with relatively high gypsum content around 50%), which is located in Al-Anbar Governorate, using kaolinite and bentonite as additives. The essential idea is concentrated in mixing these additives with natural soil using different percentages (5, 10, 15 and 20% by soil dry weight) to investigate soil shear strength enhancement. The effect of such additives on soil shear strength parameters, cohesion (C) and angle of internal friction (Φ), and their behavior were studied using direct shear test. The results showed that shear strength parameters of soil sometimes increased and then decreased with increasing additives. Generally, higher shear strength parameters have been obtained from bentonite mixed soil than that of kaolinite mixed soil for the same percentages of additives. It was concluded that bentonite was much more effective in increasing C and reducing Φ than kaolinite. While, kaolinite was much more effective in reducing C than bentonite. It was also concluded that gypseous soil shear strength is improved using such additives (with only 5% kaolinite or with only 20% bentonite) which provide cohesion strength to the soil mass and also acts as a binder agent material.

Keywords: Gypseous soil; Kaolinite; Bentonite; Additives, Shear strength

دراسة خصائص مقاومة القص للتربة الرملية الجبسية باستخدام مضافات

الخلاصة

تبحث الدراسة الحالية في امكانية تحسين التربة الجبسية الانهيارية لموقع الكرمة (ذات المحتوى الجبسي العالي نسبيا بحدود ٥٠%), الواقع ضمن محافظة الأنبار, باستخدام الكاؤلينايت والبنتونايت كمضافات. ان الفكرة الأساسية تتركز بخلط هذه المضافات مع التربة الطبيعية وبنسب مئوية مختلفة (٥ , ١٠ , ١٥ و ٢٠ % من وزن التربة الجاف) من أجل البحث في تحسين مقاومة القص. تم دراسة تأثير هذه المضافات على معاملات مقاومة القص, قوة التماسك (C) وزاوية الاحتكاك الداخلي (Φ), وسلوك التربة باستخدام فحص القص غير المباشر. أظهرت النتائج ان معاملات مقاومة القص للتربة تزداد أحيانا ومن ثم تتناقص مع زيادة

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المضافات. عموما، تم الحصول على أعلى معاملات مقاومة القص للتربة المخلوطة مع البنتونايت من تلك المخلوطة مع الكاؤلينايت ولنفس النسب من المواد المضافة. استنتج أن البنتونايت كان أكثر فعالية بكثير في زيادة C وتقليل Φ من الكاؤلينايت. في حين، كان الكاؤلينايت أكثر فعالية في تقليل C من البنتونايت. وخلصت الدراسة أيضا إلى أن مقاومة القص للتربة الجبسية تم تحسينها باستخدام مثل هذه المضافات (بنسبة ٥% كاؤلينايت فقط أو ٢٠% بنتونايت فقط) حيث أدت الى زيادة قوة التماس بالاضافة الى عملها كمادة رابطة.

INTRODUCTION

Gypseous soils are soils containing gypsum as cementing agent, may be affected considerably when subjected to changes in water content. The presence of gypsum in soil affects its engineering properties and behavior in a degree, which is greatly dependent on amount of gypsum present in the soil. This influence depends mainly on the amount and type of gypsum present in the soil. The question is about the appreciable amount of gypsum that causes a serious change in the soil properties. The presence of gypsum in soil alters its behavior, in other words, there is a large influence of gypsum on the physical and mechanical properties of soil. Gypseous soils are characterized by decreasing strength upon wetting and increasing primary and secondary compression in addition to the dissolution in continuously seeping water. Under these circumstances, underground canals and cavities are formed [1]. In general, gypseous soils are reliable for construction under dry and even under short term flow, but become problematic, collapsible and undergo large settlement under long term flooding with water [2]. Water will cause dissolution of gypsum within the soil mass which leads to one or a combination of the processes which are collapsibility, consolidation and leaching processes. The combination of these processes will cause the soil to settle considerably when loading is applied. In general, the settlement of gypseous soils is mainly due to the dissolution of the cementing gypsum which is a companied by the collapse of the soil structure especially in sandy gypseous soils [3]. Even capillary water may sometimes be sufficient to cause the collapse of the soil structure in gypseous sandy soils [4, 5].

Gypseous soil is distributed in many locations in Iraq and it constitutes 7.3 to 10 percent of the total world gypseous area and it forms 11 to more than 20 % of the area of Iraq [6]. And as the engineering properties of such soil will be changed when it is wetted and it leads to failure which causes danger on the structure built on. Besides, the evaluation of shear strength is necessary in most soil stability problems. For these reasons, it needs to study its properties and find the way to treat it which is the main objective of this article. For the importance of shear strength properties of the soil, the effect of the additives was also studied.

EXPERIMENTAL WORK

In this study, a disturbed sample was taken from Al-Qarma site, which is located in the east of Al-Falluja city in Al-Anbar Governorate about 50 km west of Baghdad, was studied. The gypsum content of soil is found to be 50% using hydration method of Al-Mufty and Nashat (2000) [7]. Classification, physical and chemical tests were performed according to the standard procedures. The grain size distribution using wet sieving was conducted according to BS 1377 [8]. The grain size distribution curve of the soil sample is classified as poorly graded sand (SP) according to Unified Soil Classification System (USCS) Figure (1). Thus, the soil has no consistency limits (liquid and plastic limits). The specific gravity was determined according to BS 1377 [9], but kerosene is used instead of water to avoid the dissolving of gypsum in water [8]. The unit weight and water content were determined according to BS 1377 [8]. Two chemical tests were carried out on the natural soil, these tests include: gypsum content using hydration method of Al-Mufty and Nashat [7] and sulphate content (SO_3) according to BS: 1377 test No. 1 [9]. All results of chemical and physical properties of the tested soil are summarized in Table 1. For direct shear test, ASTM D 3080 [10] Standard test method under unconsolidated undrained condition was used.

The primary clay minerals used as additives were the commercial bentonite and kaolinite, obtained from a commercial company, used as representatives for non- and low-swelling clays respectively. Kaolinite possesses low plasticity and cohesion, low compressibility and limited surface activity. Bentonite (Na-montmorillonite) with its thin particles exhibits very high specific surface (50–800 m^2/g), combined with high plasticity and cohesion. The high shrink/swell potential of bentonite makes soils containing this mineral extremely compressible [11, 12]. Kaolinite and bentonite were used for the above reasons which make them suitable candidate for additives, since the present study was also concerned with the effect of clay content on the geotechnical properties of soil mixtures.

To improve this soil, many trials were carried out on the soil by adding the additives represented by bentonite and kaolinite. Natural collapsible soil with commercial pure bentonite and kaolinite in different proportions (5, 10, 15 and 20% by dry soil weight) were used to obtain mixed soil samples. In this study, four different mixtures for each additive were prepared with the above percents added to the natural soil. These samples were selected for carrying out the tests of specific gravity, Atterberg limits and shear tests.

DIRECT SHEAR SPECIMENS' PREPARATION AND TESTING

After mixing the soil with the required amount of additives, with proportions 5, 10, 15 and 20 % by weight, the predetermined weight of the mix which gives the required dry density was compacted in a mould of (6x6x2) cm in dimensions using a static compaction. Specimens were withdrawn immediately from the mould and subjected to curing at a room temperature of 25±3ºC for 12 days. A direct shear apparatus was used to determine the shear strength parameters of the soil. The direct shear test of the natural and mixed samples under unconsolidated undrained conditions was conducted with various normal loads of 27, 55 and 111 kPa according to ASTM D 3080- Standard test method [10], so that the cohesion and angle of internal friction were obtained.

RESULTS AND DISCUSSION

Shear strength characteristics of soil before and after treatment with kaolinite and bentonite additives using different percentages were studied by conducting direct shear test at three normal stresses (27, 55 and 111 kPa). For the importance of shear strength properties of the soil, the effect of such additives on soil behavior also was studied. Figures 2 to 10 show the plots obtained from direct shear test represented by the vertical displacement versus the horizontal displacement as shown in Figures (a); the shear stress versus horizontal displacement from which the maximum shear stress is obtained for a specific normal stress as shown in

Figures (b); and shear stress versus normal stress from which shear strength parameter are obtained as shown in Figures (c). While, Table (2) summarizes the results of both untreated and treated gypseous soil in shear.

The typical results of direct shear test of natural (untreated) soil are shown in Figure (2). It is found that the shear strength parameters of normal soil are of relatively low cohesion of 16 kPa and high internal friction angle of about 50.5° Table (2) and Figure (2). Besides, it can be observed that the maximum shear strength increases with the increase in normal stress. This may be due to the values of angle of internal friction (Φ) and cohesion (C) generated by the cementation action of gypsum and fine particles of soil.

Figures (3) to 6 and Table 2 represent the results of direct shear tests carried out on treated soil with kaolinite as an additive in different percentages (5, 10. 15 and 20%).It is found that the cohesion value (C) abruptly increases when 5% kaolinite additive is added, and then it dramatically decreases with increasing its addition (10 to 20%) to be nearly constant. The highly increase in cohesion at 5% kaolinite addition is resulted in sharp reduction in angle of internal friction (Φ). It is well noticed the negative effect of kaolinite addition in cohesion except for the addition of 5 % which gives the highest cohesion of about 28 kPa with an increase of about 75% of the untreated soil, which is about three times that of bentonite mixed soil of the same proportion. The increase in kaolinite addition resulted in a decrease in cohesion value to 4.0 kPa at 10% with a reduction percent of 25% of the natural soil. Moreover, the addition of kaolinite has significantly reduced the internal friction angle (Φ) to about 43° at 5% with reduction percent of 15% of its natural soil. With increasing kaolinite addition (10 to 20%), the angle of internal friction (Φ) is increased again to be nearly constant but with reduction percent of about 10% of its natural soil. This is attributed to the kaolinite additive filling the voids between soil particles and reducing the inter particle friction of soil specimen. Generally, it can be said the reduction in cohesion with the increase in kaolinite proportion above 5% leads to reduce the shear strength and this reduction occurs due to decrease in frictional forces between particles besides the softening and breaking bonds between soil mass. Thus, kaolinite was much more effective in reducing C than Φ. It can be said that with increasing kaolinite, cohesion decreases as kaolinite possesses low plasticity and cohesion, low compressibility and limited surface activity [12, 13].

On the other hand, results of direct shear test conducted on soil under testing with bentonite as additive in different percentages (5, 10, 15, and 20%) are shown in Figures 7 to 10 and summarized in Table 2. In general, the addition of bentonite with the same percentages have significantly increased the cohesion and decreasing the internal friction angle of the soil mixture. It can be observed that the shear strength slightly decreases with increasing bentonite additive (at 5% and 10%) with the lowest value of 10 kPa at 5% addition. The reduction in shear strength is due the reduction in cohesion (C) by about 38 % and 16% of the untreated soil respectively. With increasing bentonite addition (15 to 20%), shear strength increases as a result of increasing cohesion. Highest cohesion values of 16.5 and 18.5 kPa are found with bentonite addition of 15% and 20 %. The increase percent, of 3 to 16% respectively, is due to providing optimum bonding between soil particles. Moreover, the increase in bentonite proportion resulted in reduction of the internal friction angle to about 42° at 15% with a reduction percent of 17% of the untreated soil except for 5% that gives a slightly higher value but very close to that of the natural soil. This behavior could be attributed to the high cohesion of the this clay material particles that covers the loss in cohesion of soil due to the dissolved gypsum bond and slightly decreases of angle of internal friction (Φ). Thus, bentonite was much more effective in increasing C and reducing Φ (or more effective in reducing Φ than C. It can be said that with increasing bentonite, cohesion increases as it possesses fine particles and exhibits very high specific surface, highly compressible, combined with high plasticity and cohesion [12, 13].

Thus, it can be concluded that bentonite was much more effective in increasing C and reducing Φ than kaolinite. The magnitude of decrease in the frictional strength was greater when the additive was bentonite and lower when it was kaolinite. While, kaolinite was much more effective in reducing C than bentonite. Finally it can be said that the above behaviors have been justified with findings reported by Al-Abdullah et al. (2000) [14]; Al-Neami (2000) [15] and Al-Obaydi (2003) [16].

CONCLUSIONS

Conclusions can be drawn as follows:

1. For kaolinite mixed soil samples, the cohesion and internal friction angle values were found to vary between 4 - 28 kPa and 43°- 45.5° respectively. Kaolinite was much more effective in reducing C than Φ.
2. For bentonite mixed soil samples, the cohesion and internal friction angle values were found to vary between 10-18.5 kPa and 42°- 48° respectively. Bentonite was much more effective in increasing C than Φ. Highest cohesion of 18.5 kPa was found with bentonite addition of 20 % with an increase percent of 16% of the untreated soil.
3. It is found that the additions of low proportion of kaolinite (with only 5%) or high proportion of bentonite (with only 20%) to sandy gypseous soil improve its shear strength.
4. Generally, higher cohesion values have been obtained from bentonite mixed soil samples than that of kaolinite mixed soil. Thus, kaolinite was much more effective in reducing C than bentonite.
5. It was found that mixing clay additives to normal soil generally caused a decrease in the frictional strength; however, the magnitude of this decrease was greater when the additive was bentonite and lower when it was kaolinite. Thus, bentonite was much more effective in reducing Φ than kaolinite.

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Table (1) Results of physical and chemical properties tests for natural soil.

Physical and chemical property	Value
Specific gravity	2.47
Liquid limit %	NP
Plastic limit %	NP
Plasticity index %	NP
Maximum unit weight (kN/m^3)	16.2
Field unit weight (kN/m^3)	١٤,٢٦
Optimum moisture content	١٢,٦
Gravel (≥4.75mm.) %	11.0
Sand (4.75mm to 0.075mm)%	89.0
Silt and clay (≤0.075mm.) %	-
١٠*D* , mm	٠,١٧
٣٠*D* , mm	٠,٢٣
٦٠*D* , mm	1.0
Coefficient of uniformity, $_uC$	٥,٨
Coefficient of curvature, C_c	٠,٣٣٩
Soil classification (USCS)	*SP*
SO_3	23.8
Gypsum content %	50.0

Table (2) Results of direct shear tests.

Soil Additive	Soil Property		Soil Additive	Soil Property	
Kaolinite	C (kPa)	**Φ** (Deg.)	Bentonite	C (kPa)	**Φ** (Deg.)
0 %	16	50.5	0 %	16	50.5
5 %	28	43.0	5 %	10	48
١0 %	4	45.5	١0 %	13.5	46.5
١٥ %	5	45.5	١٥ %	16.5	42
٢0 %	5	45	٢0 %	18.5	45

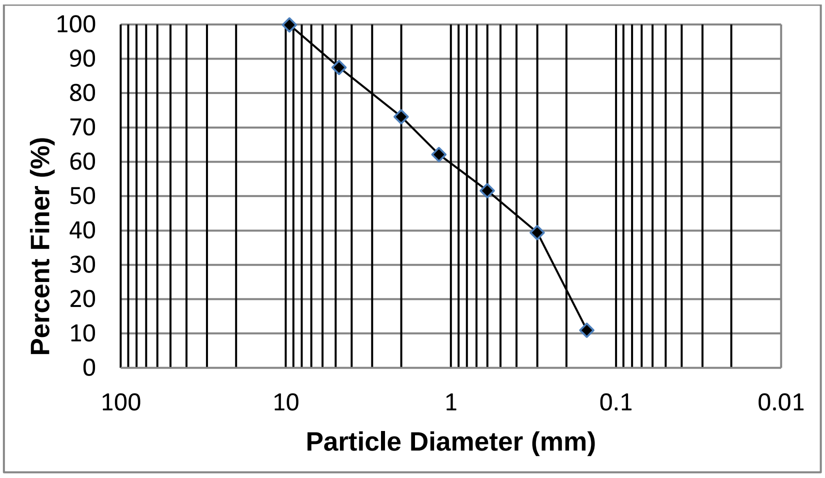
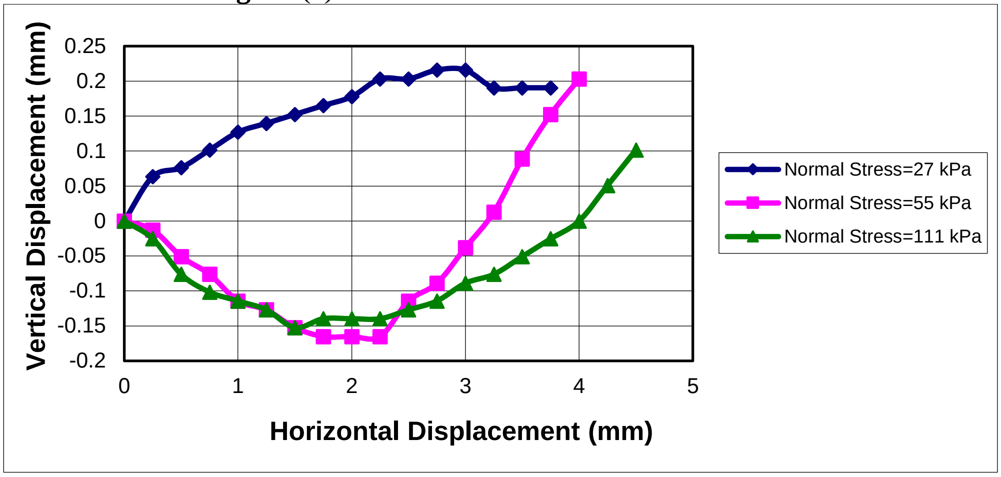
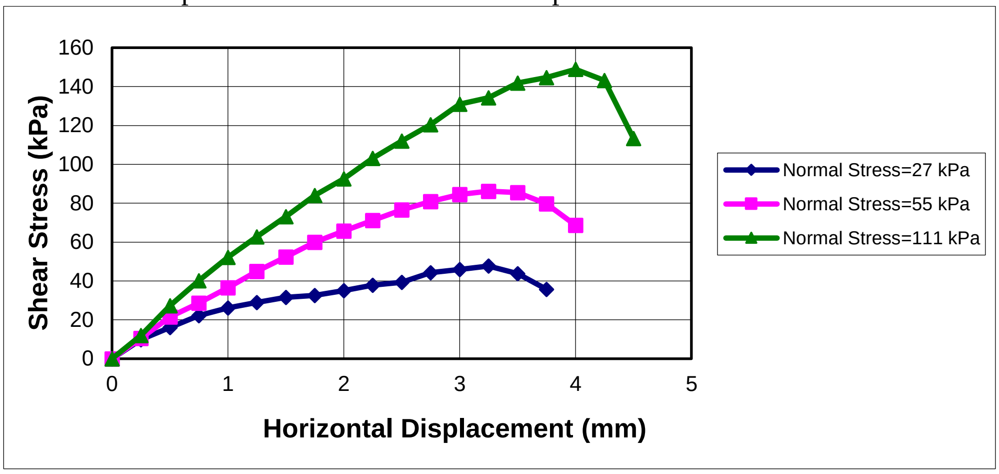


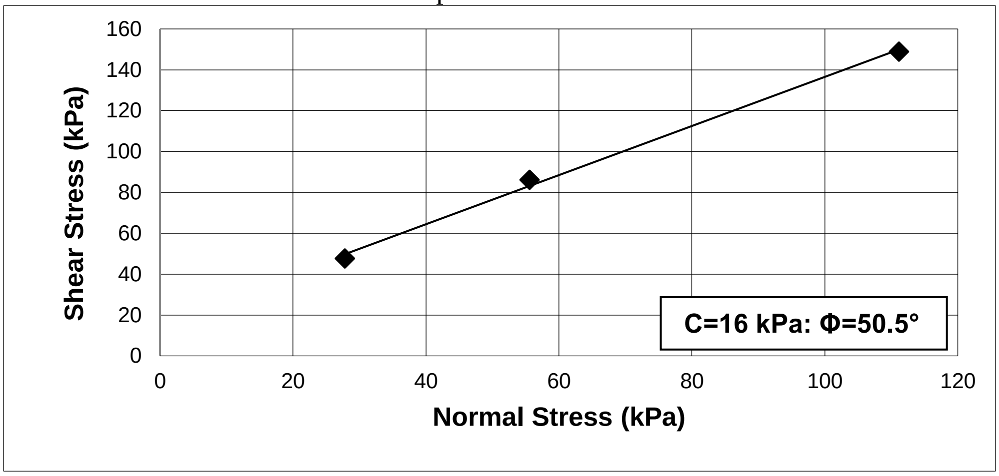
Figure (1)Grain size distribution of natural soil.



a. Vertical displacement versus horizontal displacement

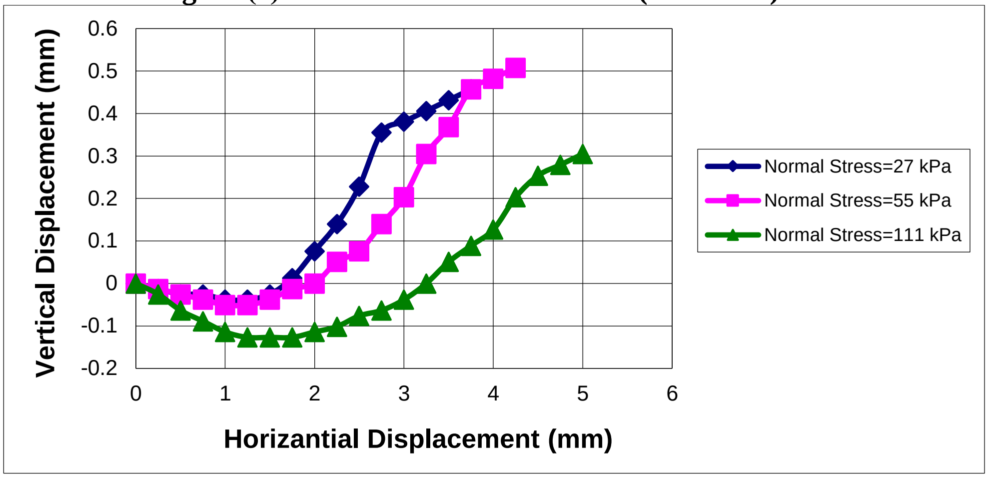


b. Shear stress versus horizontal displacement



c. Shear stress versus normal stress

Figure (2)Direct shear test for natural (untreated) soil.



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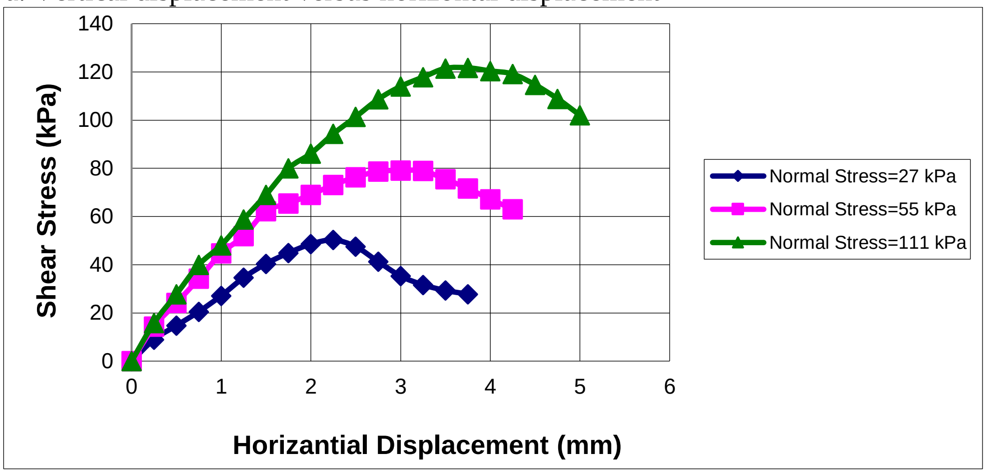

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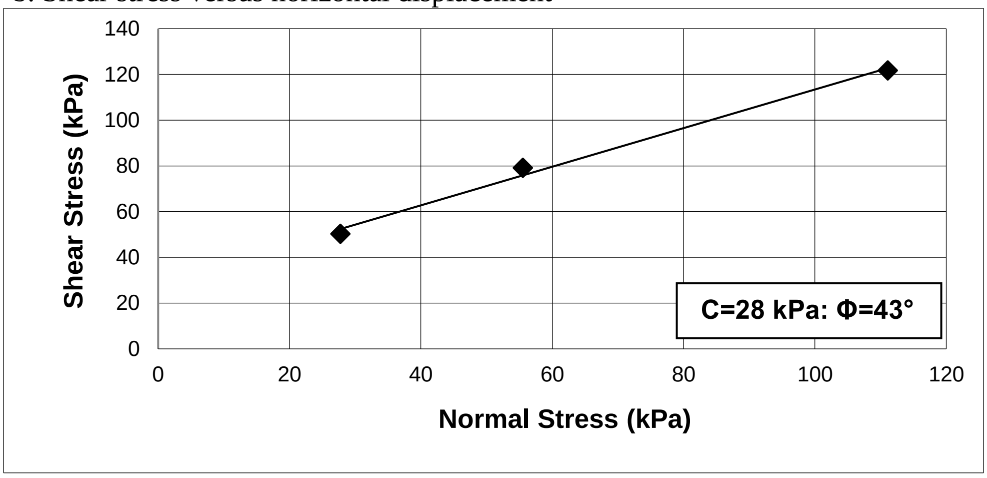
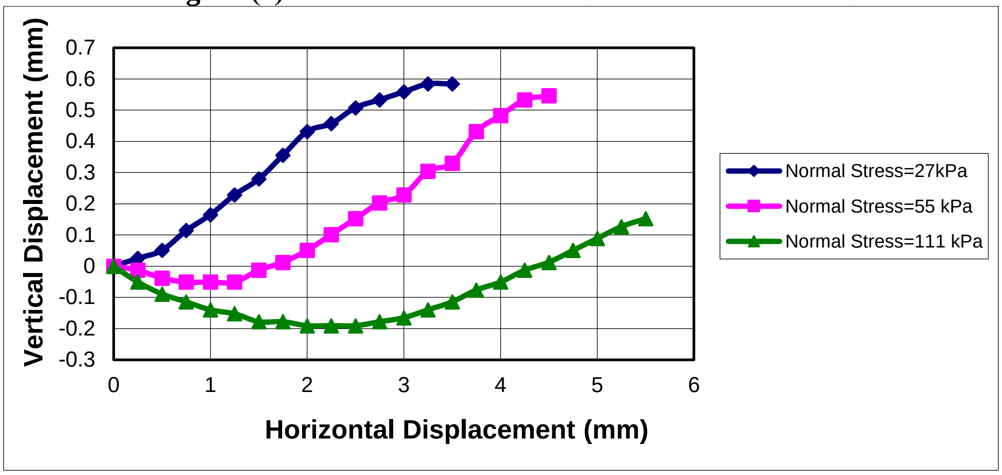


c. Shear stress versus normal stress

Figure (3)Direct shear test for 5 % kaolinite mixed soil.



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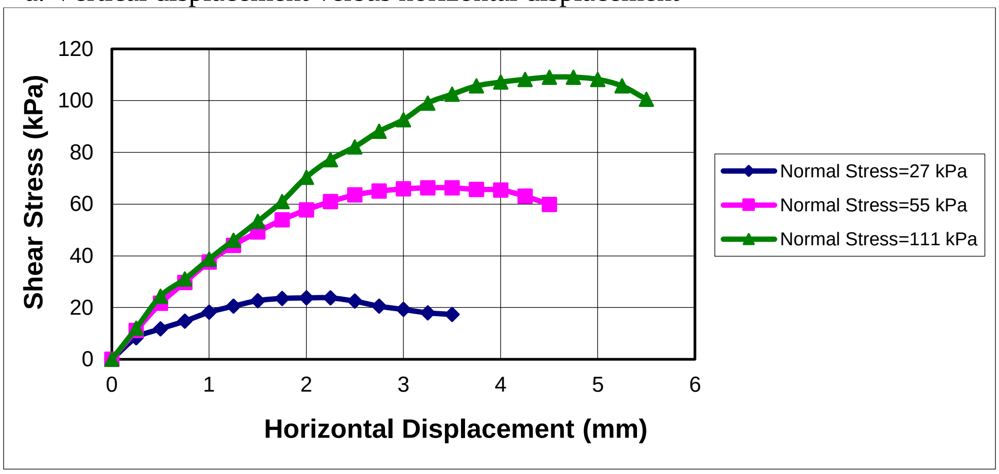

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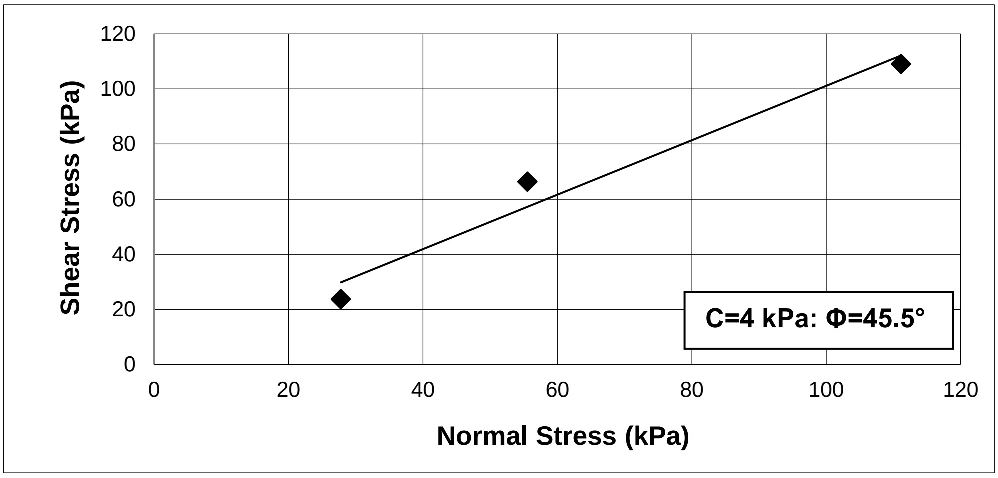
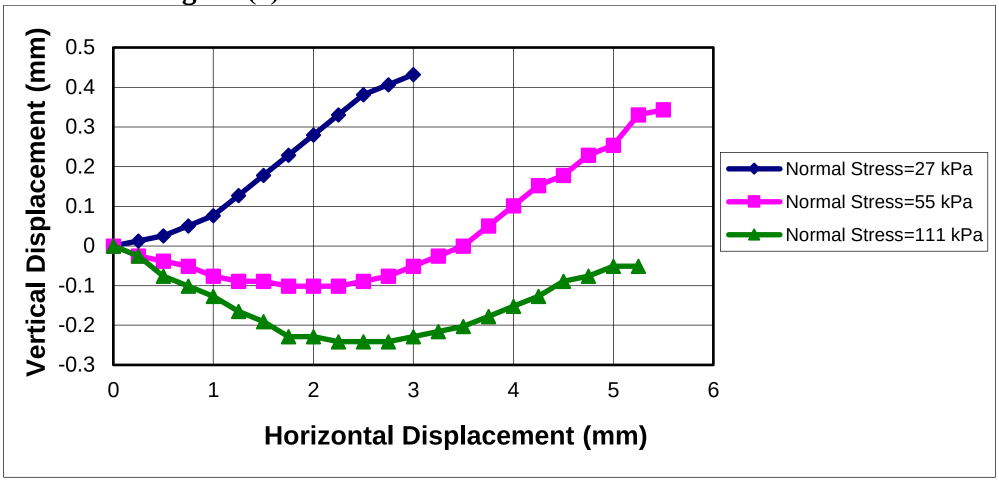


c. Shear stress versus normal stress

Figure (4)Direct shear test for 10 % kaolinite mixed soil.



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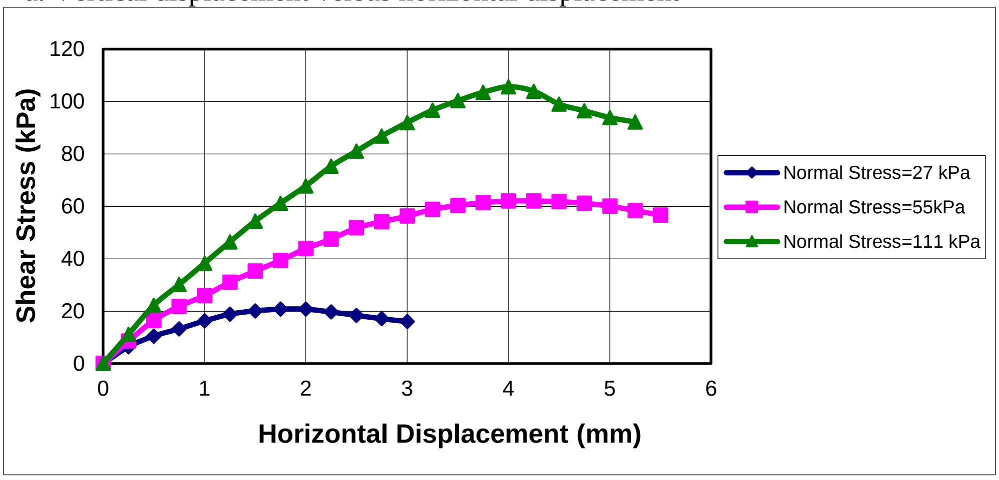

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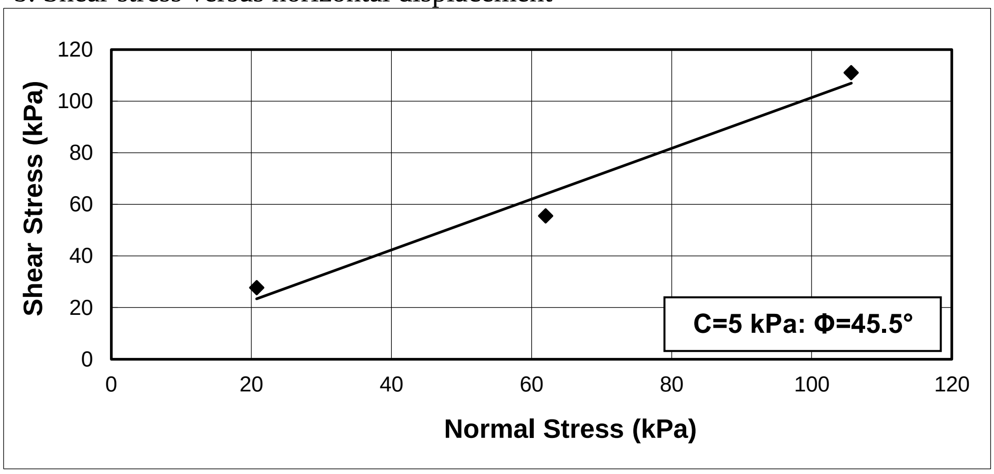
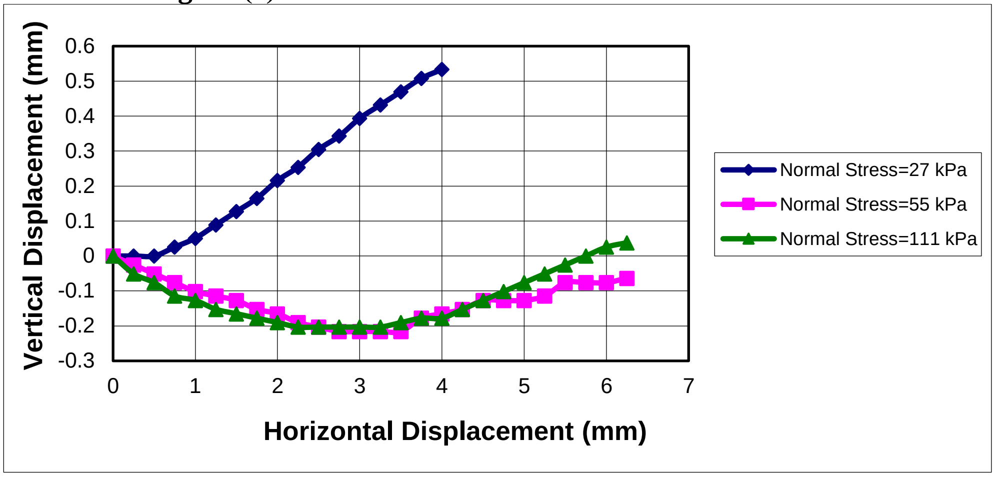


c. Shear stress versus normal stress

Figure (5)Direct shear test for 15 % kaolinite mixed soil.



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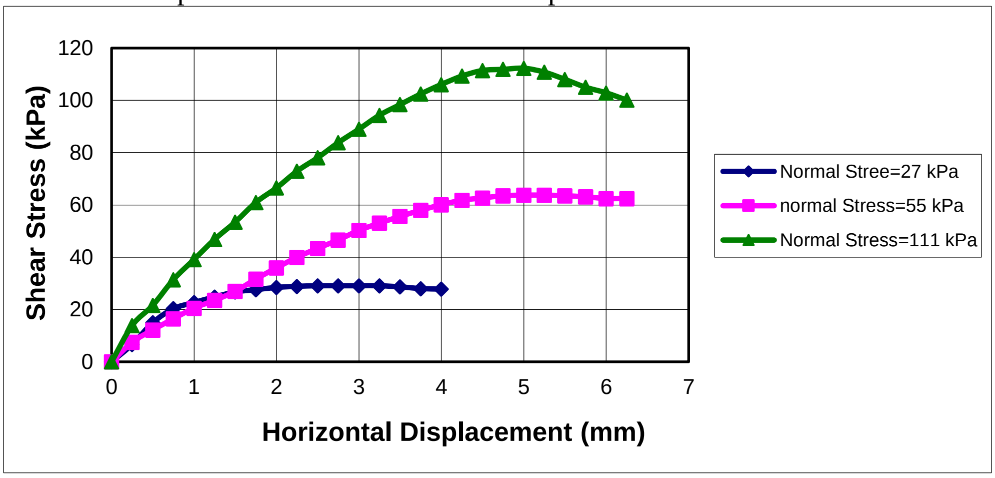

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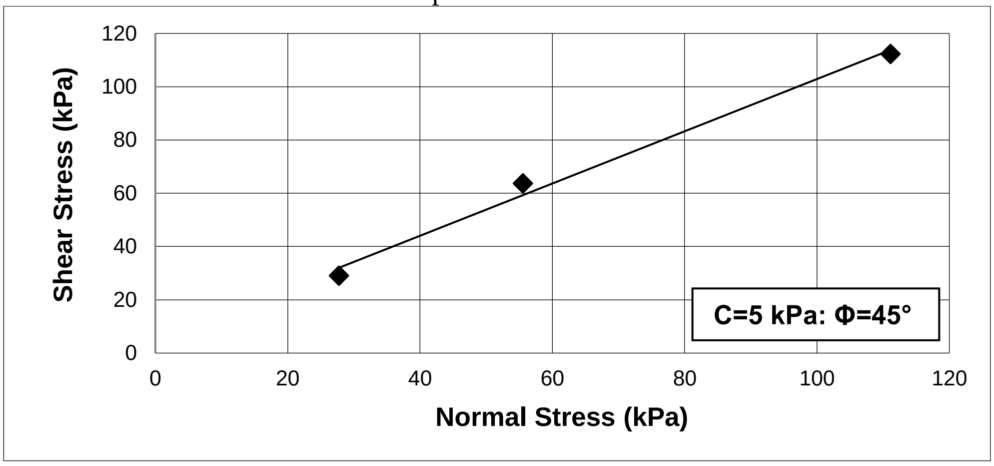
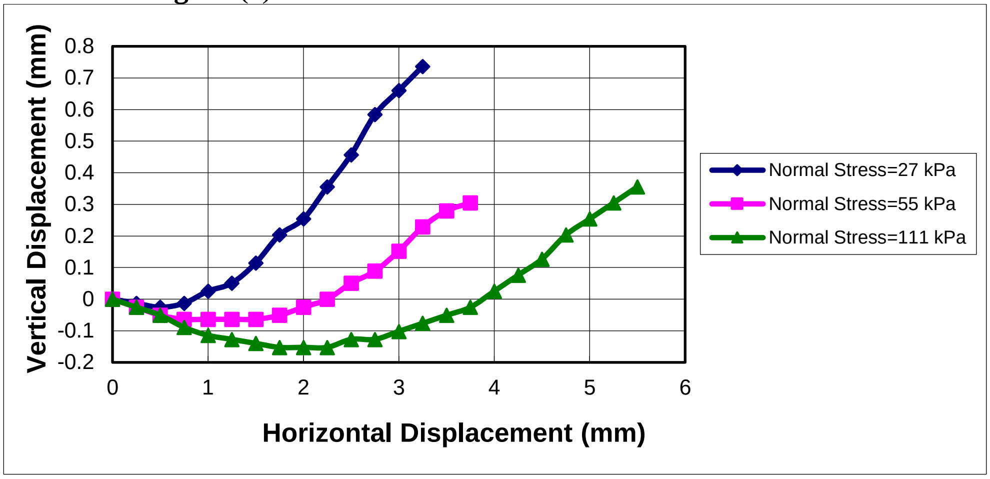


c. Shear stress versus normal stress

Figure (6)Direct shear test for 20 % kaolinite mixed soil.



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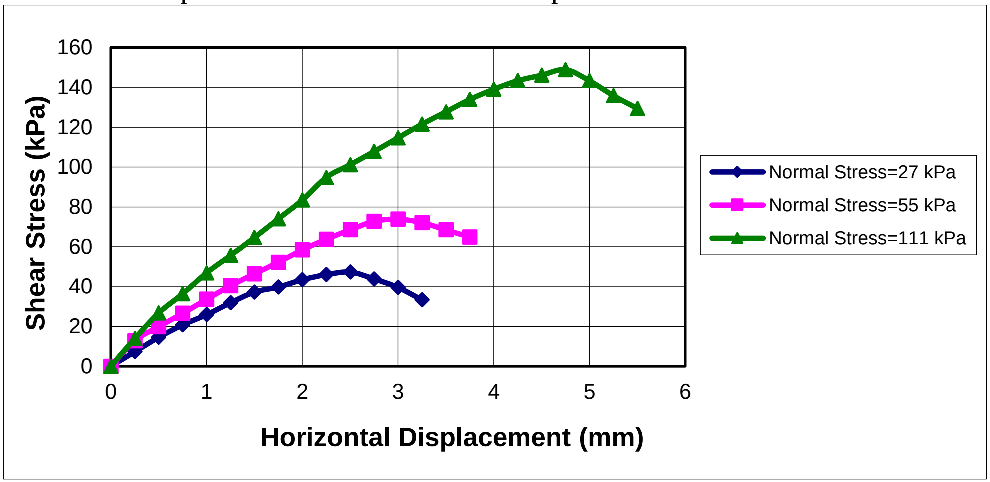

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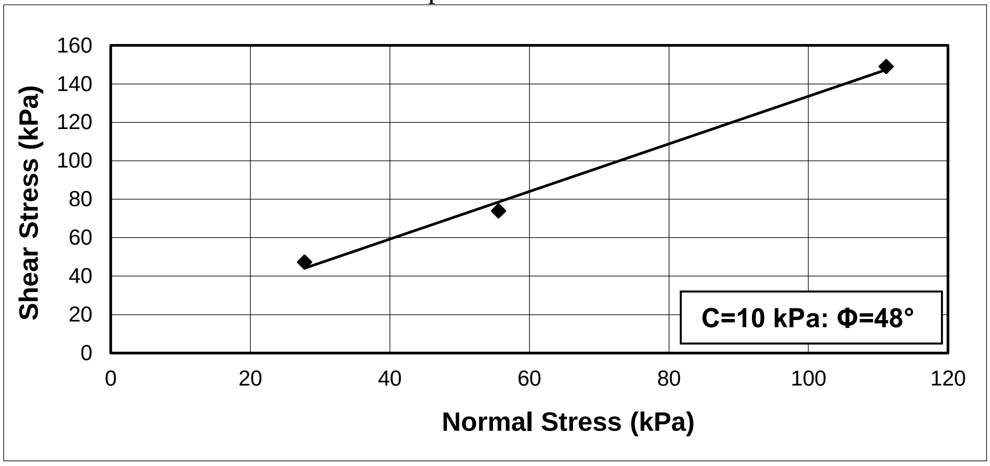
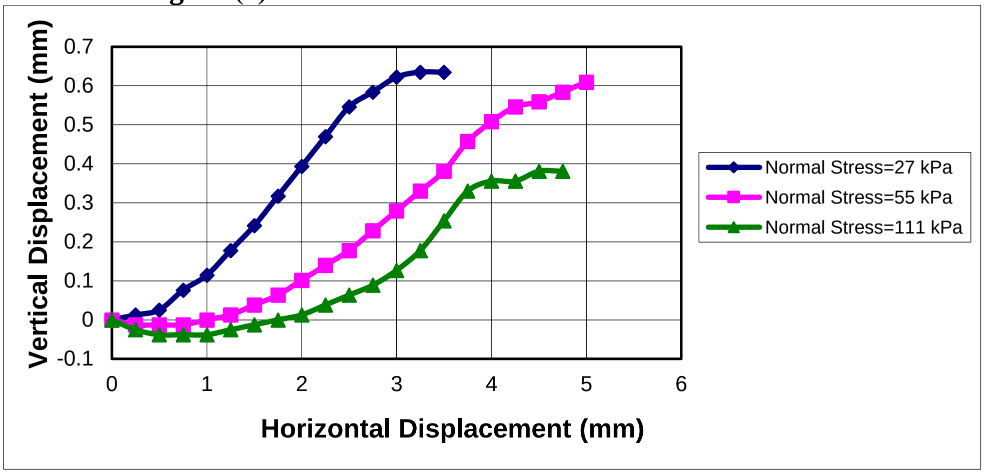


c. Shear stress versus normal stress

Figure (7)Direct shear test for 5 % bentonite mixed soil.



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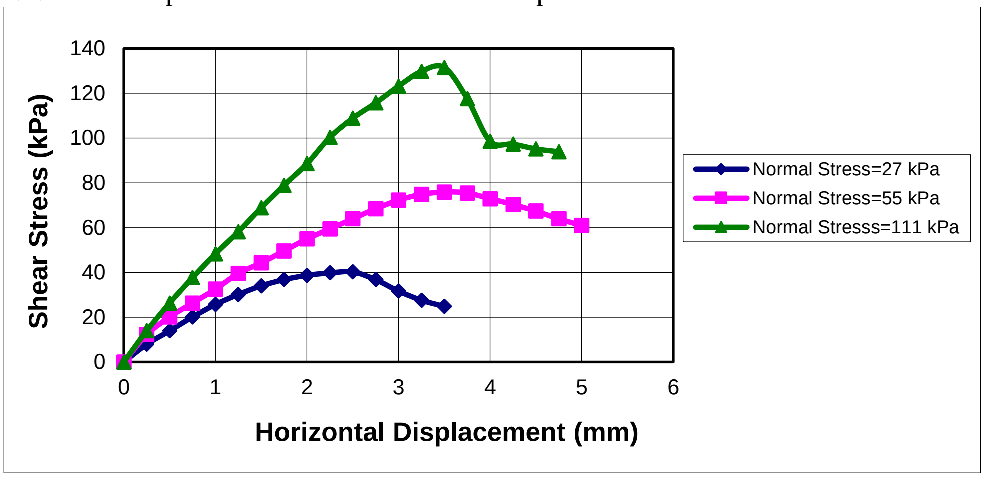
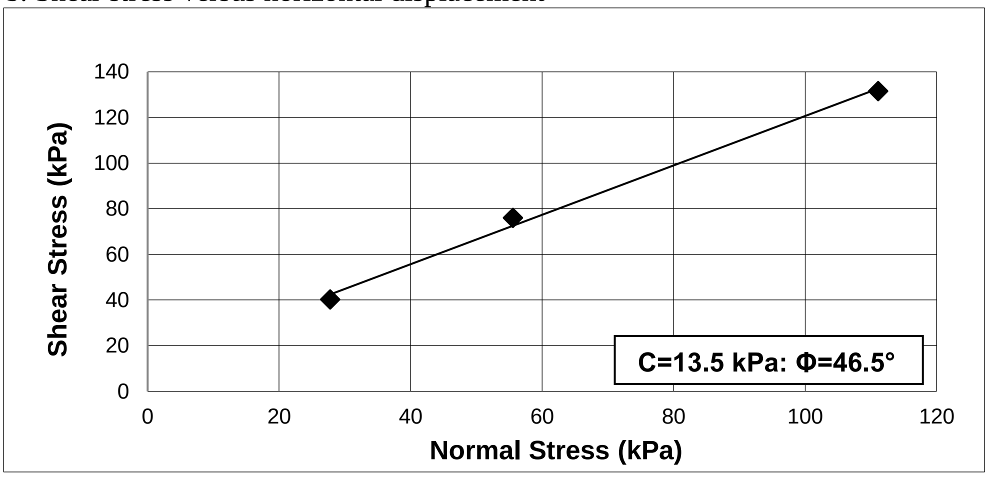
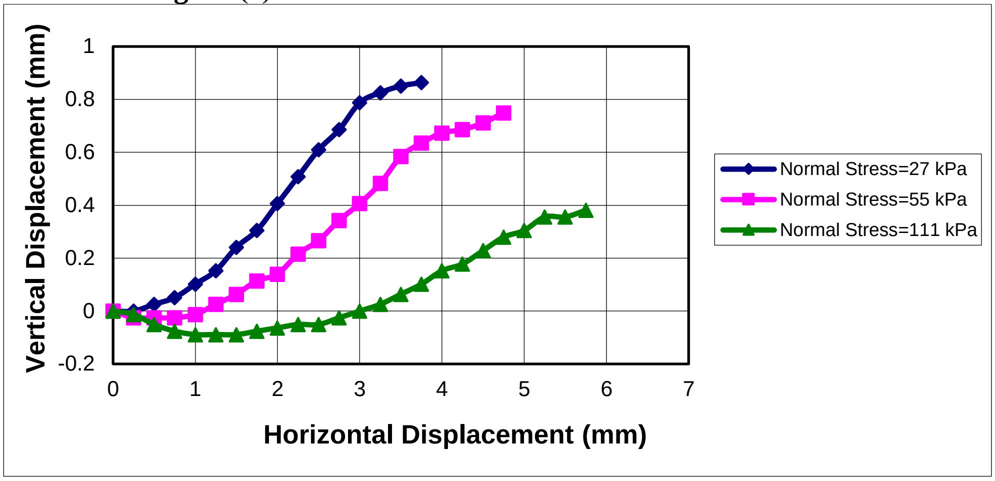


b. Shear stress versus horizontal displacement

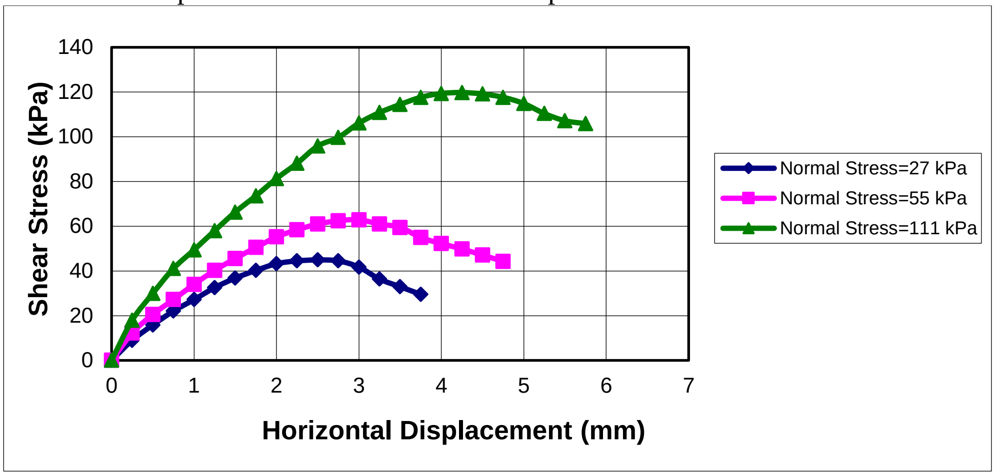


c. Shear stress versus normal stress

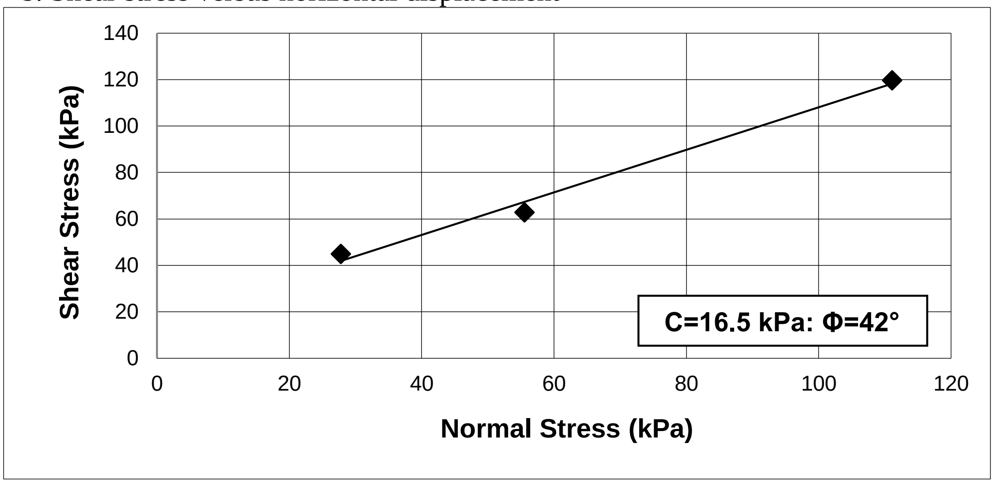
Figure (8)Direct shear test for 10 % bentonite mixed soil.



a. Vertical displacement versus horizontal displacement

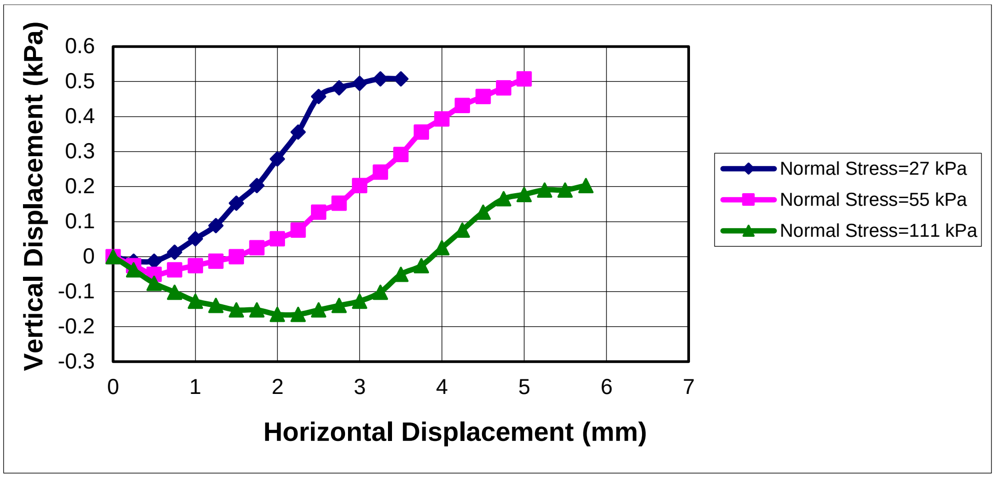


b. Shear stress versus horizontal displacement

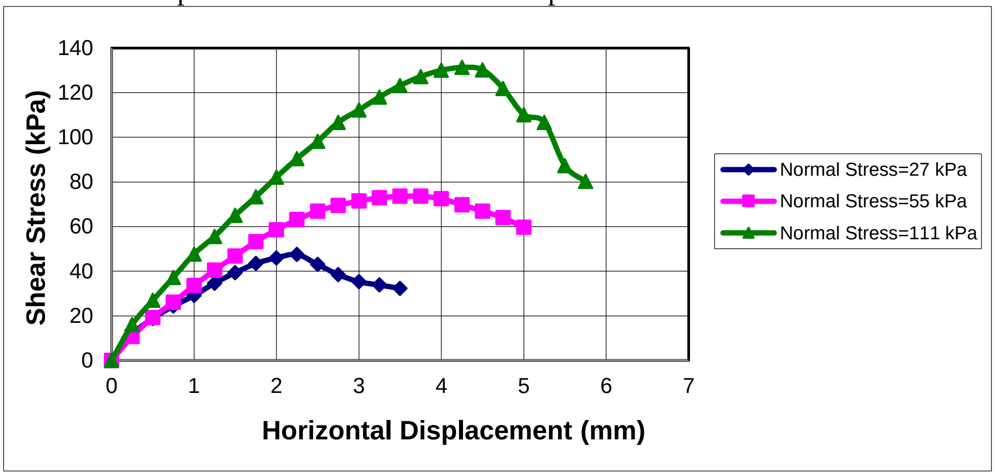


c. Shear stress versus normal stress

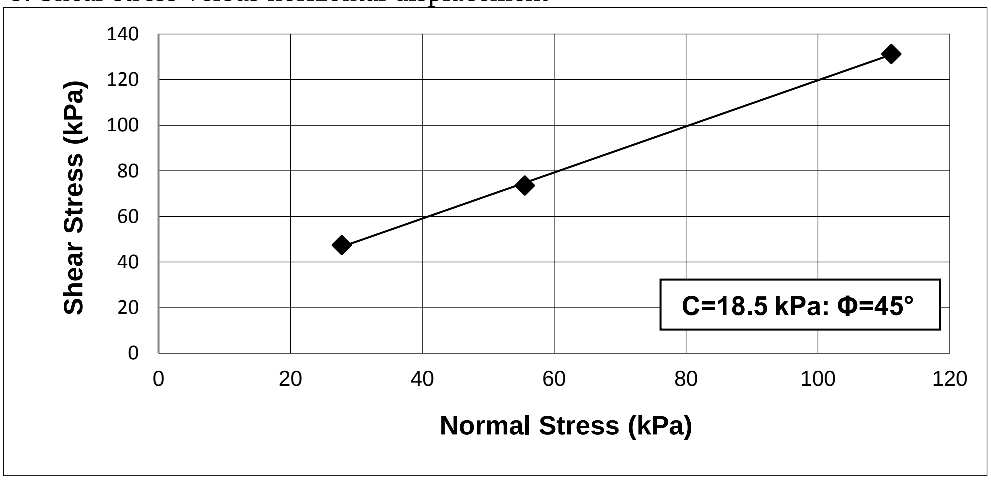
Figure (9) Direct shear test for 15 % bentonite mixed soil.



a. Vertical displacement versus horizontal displacement



b. Shear stress versus horizontal displacement



c. Shear stress versus normal stress

Figure(10) Direct shear test for 20 % bentonite mixed soil.