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Soaking Effects on the Shear Strength Parameters and Bearing Capacity of Soil

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Abstract

This research includes complete study of the laboratory examinations for soil layers and its engineering properties for certain areas of Baghdad city (Alkadhimya, Alaitaifiya, and Alhurriya). The soil was classified according to USCS and showed the soil is considered as a non homogenous Because of the presence of multiple chemical materials in the soil, some chemical examinations have been done such as sulphate percentage, gypsum content, total soluble salts, in addition to the amount of acidity and alkality (pH) in the soil. In this research the direct shear test was used to obtained to value (cohesion and internal friction angle) for the soil in both natural situation and (24 hour) in water soaked situation. The laboratory tests results showed that these soils have high bearing capacity was varied between (1200 --- 3000) kPa while (760 --- 1000) kPa at soaking state and that the parameters of shear (cohesion and internal friction angle) decrease when soaked in water but the main decrease was in cohesion value. Soaking of soils reduced cohesion by approximately (2-2.5) folds, while the angle of internal friction exhibited marginal reduction

Keywords: Soaking Effects, Cohesion, Friction angle, Bearing Capacity.

تأثيرات الغمر على خواص قوى القص وقابلية التحمل للتربة

الخلاصة

يتضمن هذا البحث دراسة شاملة للفحوص المختبرية لطبقات التربة وخواصها الهندسية لمناطق معينة من مدينة بغداد (الكاظمية ,الحرية والعطيفية) بعد أن تم أخذ عينات من تلك التربة ومن أعماق مختلفة عن طريق حفر الآبار في تلك المناطق من بغداد . وقد صنفت الترب حسب نظام التصنيف الموحد ولجميع الأعماق حيث بينت الدراسة بان التربة تعتبر من الترب غير المتجانسة وبعد ذلك تم إجراء الفحوصات الفيزياوية عليها ونظراً لوجود العديد من المواد الكيميائية في التربة فقد أجريت بعض الفحوصات الكيميائية مثل نسبة الكبريتات ,نسبة الأملاح القابلة للذوبان ,نسبة الجبس ,إضافة إلى مقدار الحامضية والقاعدية في التربة . استخدم في هذا البحث فحص القص المباشر لمعرفة قيم معاملات القص (التماسك وزاوية الاحتكاك الداخلي) للتربة في حالتين الأولى : الحالة الطبيعية والأخرى التربة مغمورة في الماء لمدة (24) ساعة ومقارنة النتائج , وقد بينت نتائج الفحوص المختبرية إن هذه الترب تعتبر ذات قوة تحمل جيدة بعد إن تم حساب قابلية التحمل للترب ولجميع الأعماق . وان معاملات القص تقل عند الغمر في الماء, ولكن النقصان الرئيسي كان في قيم (التماسك) حيث قل بمقدار (2-2.5) مرة , أما قيم وزاوية الاحتكاك الداخلي فإنها قلت ولكن بمقدار طفيف.

List of Symbol :

σ_n : Normal Strength(kPa).

τ_{max} : Maximum Shear Strength(kPa).

ϕ: Angle of Internal Friction (degree).

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Introduction

Usually at the time of the laboratorytesting, the geotechnical engineer and engineering geologist will have located the critical soil layers or subsurface conditions that will have the most impact on the design and construction of the project. The laboratory testing program should be oriented towards the testing of those critical soil layers or subsurface conditions. For many geotechnical projects, it is also important to determine the amount of ground surface movement due to construction of the project. In these cases, laboratory testing should model future expected conditions so that the amount of movement or stability of the ground can be analyzed. Jonathan, (2000).

The shear strength of a soil is a basic geotechnical engineering parameter and is required for the analysis of foundations, earthwork, and slope stability problems. This is because of the nature of soil, which is composed of individual soil particles that slide (i.e., shear past each other) when the soil is loaded. The shear strength of the soil can be determined in the field (e.g., vane shear test) or in the laboratory. Laboratory shear strength tests can generally be divided into two categories:

1. Shear Strength Tests Based on Total Stress. The purpose of these laboratory tests is to obtain the undrained shear strength of the soil or the failure envelope in terms of total stresses (total cohesion (c) and total friction angle (ϕ)). These types of shear strength tests are often referred to as ‘‘undrained’’ shear strength tests.

2. Shear Strength Tests Based on Effective Stress. The purpose of these laboratory tests is to obtain the effective shear strength of the soil based on the failure envelope in terms of effective stress (effective cohesion(c') and effective friction angle(ϕ')) These types of shear strength tests are often referred to as ‘‘drained’’ shear strength tests. The shear strength of the soil can be defined as (Mohr-Coulomb failure law).

The mechanisms that control the shear strength of soil are complex, but in simple terms the shear strength of soils can be divided into two broad categories: granular (nonplastic) soils and cohesive (plastic) soils. Tomlinson, (1996).

Granular soil: These types of soil are non plastic and include gravels, sands, and nonplastic silt such as rock flour. A granular soil develops its shear strength as a result of the frictional and interlocking resistance between the individual soil particles. Granular soils, also known as cohesionless soils, can only be held together by confining pressures and will fall apart when the confining pressure is released (c= 0). The drained shear strength (effective stress analysis) is of most importance for:

Granular soils: The shear strength of granular soils is often measured in the direct shear apparatus, where a soil specimen is subjected to a constant vertical pressure (σ_n) while a horizontal force is applied to the top of the shear box so that the soil specimen is sheared in half along a horizontal shear surface Plate (1). By plotting the vertical pressure (σ_n) versus shear stress at failure (τ_{max}) , the effective friction angle (ϕ) can be obtained. Because the test specifications typically require the direct shear testing of soil in a saturated and drained state, the shear strength of the soil is expressed in terms of the effective friction angle (ϕ) . Tomlinson, (1996).

Granular soils can also be tested in a dry state, and the shear strength of the soil is then expressed in terms of the friction angle (ϕ). In a comparison of the effective friction angle (ϕ) from drained direct shear tests on saturated cohesionless soil and the friction angle (ϕ) from direct shear tests on the same soil in a dry state, it
has been determined that ϕ is only (1° to 2°) lower than ϕ. This slight difference is usually ignored and the friction angle (ϕ) and effective friction angle (ϕ) are typically considered to mean the same thing for granular (nonplastic) soils. (Clough and Davidson, 1977).

Cohesive soil**:** The shear strength of cohesive (plastic) soil, such as silts and clays, is much more complicated than the shear strength of granular soils. Also, in general the shear strength of cohesive (plastic) soils tends to be lower than the shear strength of granular soils. As a result, more shear-induced failures occur in cohesive soils, such as clays, than in granular (nonplastic) soils. Depending on the type of loading condition, either a total stress analysis or an effective stress analysis could be performed for cohesive soil. In general, total stress analysis (c and ϕ) are used for short-term conditions, such as at the end of construction. The total stress parameters, such as the undrained shear strength can be determined from an unconfined compression test or vane test. (Clough and Davidson, 1977).

Site Sampling

The soils of this investigation were taken from three sites in Baghdad city located Alkadhumia, Alhuria, Alatafia**,** which were designated as (K, H and A) respectively.

Samples Preparation

Due to lack of water in Baghdad city, most of people had been dig wells for water supply. The samples were taken during the digging process and from different depths four samples were taken from each soil. Each sample from particular depth (d_1, d_2, d_3, d_4) where:

d_1: in depth of (0 — 3) m.
d_2: in depth of (3 — 6) m.
d_3: in depth of (6 — 9) m.
d_4: in depth of (9 — 12) m.

Because of the difficulty of obtaining undisturbed samples for the engineering tests the samples are prepared to satisfy dry unit weight by using the static compaction method. Block samples were obtained for determining the dry density and natural water content. The samples were placed in plastic bags, transformed to the Soil Mechanics Laboratory in National Centre for Construction Laboratories .

Testing Program

Classification tests were performed first including physical and chemical tests. The physical tests includes specific gravity, Atterberg limits, and dry density. The chemical tests carried out on the samples include total soluble salts, pH value, gypsum contain, organic content, and total sulphate content. Two series of the engineering tests were conducted . In first series, the classification and shear strength tests were conducted on the three soils at their natural condition. The second series which include shear strength tests was conducted on the three soils in water soaked condition.

Soil Classification:

The purpose of soil classification is to provide the geotechnical engineer with a way to predict the behaviour of the soil for engineering projects. There are many different soil classification systems in use, and only one of the most commonly used systems will be discussed in this research is Unified Soil Classification System (USCS). Table (1) description of the layers of the soils used at the different depths according to (USCS).

Physical tests

The physical properties of the three soils ((K,H and A) are summarized in tables (2),(3) and (4).The tests were carried out according to the procedures outlined by (Head, 1986).

Characteristics of Compaction

Compaction results for these soils at different depths are shown in Tables (2), (3) and (4). The relationship between the maximum dry unit weight and the optimum moisture content obtained from the standard Proctor compaction test are illustrated in Figure (1). It can be seen that the maximum dry unit weight increases and decreases optimum moisture content as shown in this Figure (1), (ASTM Standards 1979).

Chemical Tests

The results of the chemical properties carried out on the three soils are shown in Tables (5), (6) and (7). The tests were performed according to the specified standards shown in these tables.

Shear Strength Tests:

A series of direct shear tests were carried out to determine the shear strength parameters of natural soil. The tests were carried out according to the procedure proposed by (ASTMD 3080, 1972). The specimen size was (60Χ60Χ20) mm. To predict the shear strength parameters (c,ϕ), two types of tests were conducted on (24) samples which obtained from three soils samples, (12) samples of them are tested in dry state, while the other (12) samples were tested after soaking in water for (3) hours. The summary of the results of direct shear tests conducted on the three soils (K, H and A) for both dry and soak state and for different depth which are (d_1, d_2, d_3 and d_4) is given in Tables (8), (9) and (10). Figures (2), (4), (6), (8),(10) and (12) show the relationship between horizontal displacement and shear stress. It is clear that the stress – strain relationship of dry soils and soaked soils are similar. But one difference is that the peak value of stresses at each normal stress of dry samples is more than the corresponding values of soaked samples. Figures (3), (5),(7),(9),(11) and (13) show the shear stress-normal stress relationship. It can be observed that the cohesion is much more in dry state than in soaked state .On the other hand ,the reduction in the values of angle of internal friction is observed after soaking .This behaviour may be due to bonds destruction in the soil after soaking in water.

The Bearing Capacity Of Soil

Tables (8),(9) and (10) shows all the shear strength parameters for soils under different conditions (soaked and unsoaked) and the bearing capacity of the soils. The bearing capacity theory where used as illustrated in the equation below:

$$\mathbf{q_u = CN_cS_cd_c + qN_qS_qd_q + 1/2B\gamma N_\gamma S_\gamma d_\gamma}$$ (Bowles, (1988)).Where :

q_u: Ultimate Bearing Capacity (kPa).
c: Cohesion Component of Strength, (kPa) .
N_c, N_q, N_γ: Bearing Capacity Factors.
S_c, S_q, S_γ: Shape Factors.
d_c, d_q, d_γ: Depth Factors.
γ: Unit Weight (k N/m^3) .
q: Soil Pressure on Footing.
B: Width of separated square footing (let B =1m).

The tables show the obvious decrease in the bearing capacity in the soaking, state compared to the unsoaked state. Table (11) shows sand and gravel mixtures have a higher effective friction angle than nonplastic silts.

Conclusions:

From the results obtained, the following conclusions are extracted:-

1. Baghdad soil has alkaline nature.
2. Before soaking, the cohesion of Baghdad soil varied between (30---75) kPa .
3. Baghdad soil is half solid to solid and angle of internal friction of soil varied between (32--- 48) deg.
4. Soaking of soils reduced cohesion by approximately (2.5) folds, while the angle of internal friction exhibited marginal reduction
5. The bearing capacity of Baghdad soil varied between (1200 --- 3000) kPa.
6. The bearing capacity of Baghdad soil varied between (760 --- 1000) kPa at soaking state .

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Table (1) Description of the Soils Layers at the Different Depths

Type of Soil / Depth (m)	Alkadhumia	Alhuria	Alatafia
0 — 3	Silty clay with organic material	Sandy clay	Silty clay
3 — 6	Silty clay with gravel	Silty clay with organic material	Sandy clay
6 — 9	Sandy clay	Silty clay with gravel	Silty clay with gravel
9 — 12	Silty fine sand with little clay	Very stiff clay with silt	Sandy clay

Table (2) Physical Properties of the Alkadhumia Soil.

Properties	K_1	K_2	K_3	K_4
Liquid limit (%)	44	38	48	50
Plastic limit (%)	23	24	22	29
Plasticity index (%)	21	14	26	21
Dry unit weight (kN/m^3)	14.4	15.6	14.1	15.32
Optimum moisture content (%)	16	18	17	18
Bulk density (kN/m^3)	19	19.8	18.1	20.95
Specific gravity	2.68	2.68	2.65	2.85

Table (3) Physical Properties of the Alatafia Soil.

Properties	A_1	A_2	A_3	A_4
Liquid limit (%)	35	48	70	62
Plastic limit (%)	30	36	40	33
Plasticity index (%)	5	12	30	29
Dry unit weight (kN/m^3)	16.88	17	17.33	17.7
Optimum moisture content (%)	18	17	18.5	18
Bulk density (kN/m^3)	19.6	20.4	18.6	18.9
Specific gravity	2.63	2.61	2.7	2.83

Table (4) Physical Properties of the Alhuria Soil.

Properties	H_1	H_2	H_3	H_4
Liquid limit (%)	39	41	35	57
Plastic limit (%)	27	31	29	38
Plasticity index (%)	12	10	6	19
Dry unit weight (kN/m^3)	14.6	14.2	16.7	17.32
Optimum moisture content (%)	16	18	17	19
Bulk density (kN/m^3)	18.6	18.9	19.3	21.2
Specific gravity	2.51	2.62	2.42	2.7

Table (5) Chemical Properties of the Alkadhumia Soil.

Properties	**K_1**	**K_2**	**K_3**	**K_4**	Standards
Total Soluble Salts (T.S.S)	18	16.33	9.48	2.61	Earth manual E8 (1975)
Total Sulphates Content SO_3 (%)	6.45	5.33	3.55	1.76	B.S (1377-1975)
pH	8.6	8.1	7.6	8	B.S(1377-1975)
Organic Content (%)	3.93	1.03	0.86	0	B.S (1377-1975)
Gypsum Content (%)	8.2	6.11	3.89	1.55	Improvement soil-saline and Al-Kali soil

Table (6) Chemical Properties of the Alhuria Soil.

Properties	H_1	H_2	H_3	H_4	Standards
Total Soluble Salts (T.S.S)	27	21.63	9.48	2.61	Earth manual E8(1975)
Total Sulphates Content SO_3 (%)	6.8	5.3	1.55	0.34	B.S (1377-1975)
pH	8.2	8.1	7.6	8	B.S (1377-1975)
Organic Content (%)	0.72	1.03	0.86	0	B.S (1377-1975)
Gypsum Content (%)	9.4	5.69	2.21	0.67	Improvement soil-saline and Al-Kali soil

Table (7) Chemical Properties of the Alatafia Soil.

Properties	A_1	A_2	A_3	A_4	Standards
Total Soluble Salts (T.S.S)	20.15	15.33	9.48	2.61	Earth manual E8 (1975)
Total Sulphates Content SO_3 (%)	8.7	6.78	1.55	0.34	B.S (1377-1975)
pH	7.9	8.1	7.6	8	B.S (1377-1975)
Organic Content (%)	0.84	1.03	0.86	0	B.S (1377-1975)
Gypsum Content (%)	10. 6	8.22	2.21	0.67	Improvement soil-saline and Al-Kali soil

Table (8) Summary of the Variation of Cohesion and Angle of Internal Friction and the Bearing Capacity of Soaked and Unsoaked by the Direct Shear Test of Alkadhumia Soil.

Type of Test		Unsoaked				Soaked			
Type of Soil	σ_n kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa
K_1	55	66	38	34.87	1443	41	18	29.15	765
	110	106				76			
	165	155				110			
K_2	55	95	42	44	1654	63	20	39.9	1003
	110	146				111			
	165	202				158			
K_3	55	77	36	32	1223	58	18	31	798
	110	105				93			
	165	141				117			
K_4	55	73	31	38.66	1188	53	12	34.65	675
	110	114				82			
	165	163				126			

Table (9) Summary of the Variation of Cohesion and Angle of Internal Friction and the Bearing Capacity of Soaked and Unsoaked By the Direct Shear Test of Alhuria Soil.

Type of Test		Unsoaked				Soaked			
Type of Soil	σ_n kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa
H_1	55	58	36	36.7	1498	44	21	29.67	786
	110	118				78			
	165	159				115			
H_2	55	68	42	37.5	1509	53	24	32.5	899
	110	123				101			
	165	169				131			
H_3	55	75	48	42.66	1812	62	26	36.7	1067
	110	139				97			
	165	202				149			
H_4	55	116	75	47.5	2876	69	38	40	1510
	110	178				127			
	165	255				177			

Table (10) Summary of the Variation of Cohesion and Angle of Internal Friction and the Bearing Capacity of Soaked and Unsoaked by the Direct Shear Test of Alatafia Soil.

Type of Test		Unsoaked				Soaked			
Type of Soil	σ_n kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa	τ_{max} kPa	c kPa	ϕ deg	B.C kPa
A_1	55	80	46	43	1785	43	27	36.25	987
	110	139				101			
	165	199				148			
A_2	55	73	43	41	1709	39	20	37.37	804
	110	131				99			
	165	186				146			
A_3	55	77	48	40	1896	41	22	38.45	854
	110	136				106			
	165	190				153			
A_4	55	69	39	38.23	1543	54	19	36.5	786
	110	113				89			
	165	168				141			

Table (11) Typical Effective Friction Angles (ϕ) for Different Cohesionless Soils (Hough, 1994)

Soil types	Effective friction angles(ϕ) at peak strength		
	Loose	Medium	Dense
Silt (nonplastic)	26 to 30	28 to 32	30 to 34
Uniform fine to medium sand	26 to 30	30 to 34	32 to 36
Well-graded sand	30 to 34	34 to 40	38to 46
Sand and gravel mixtures	32 to 36	36 to 42	40 to 48

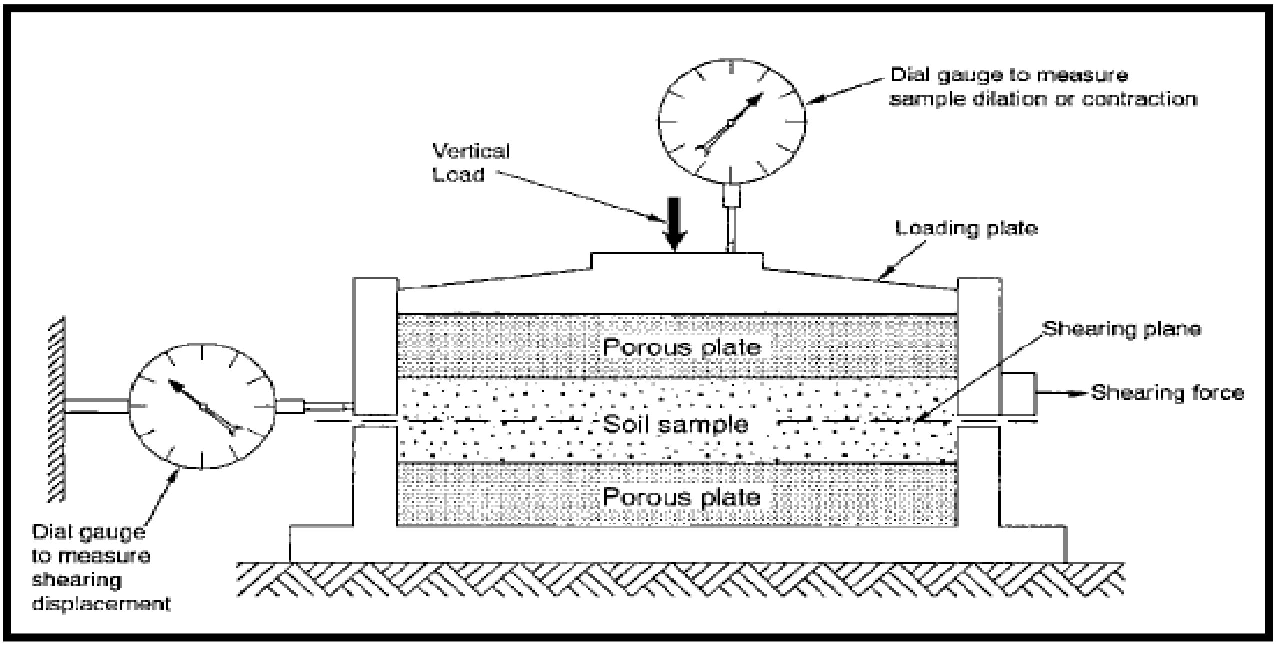


Plate (1) Direct Shear apparatus.

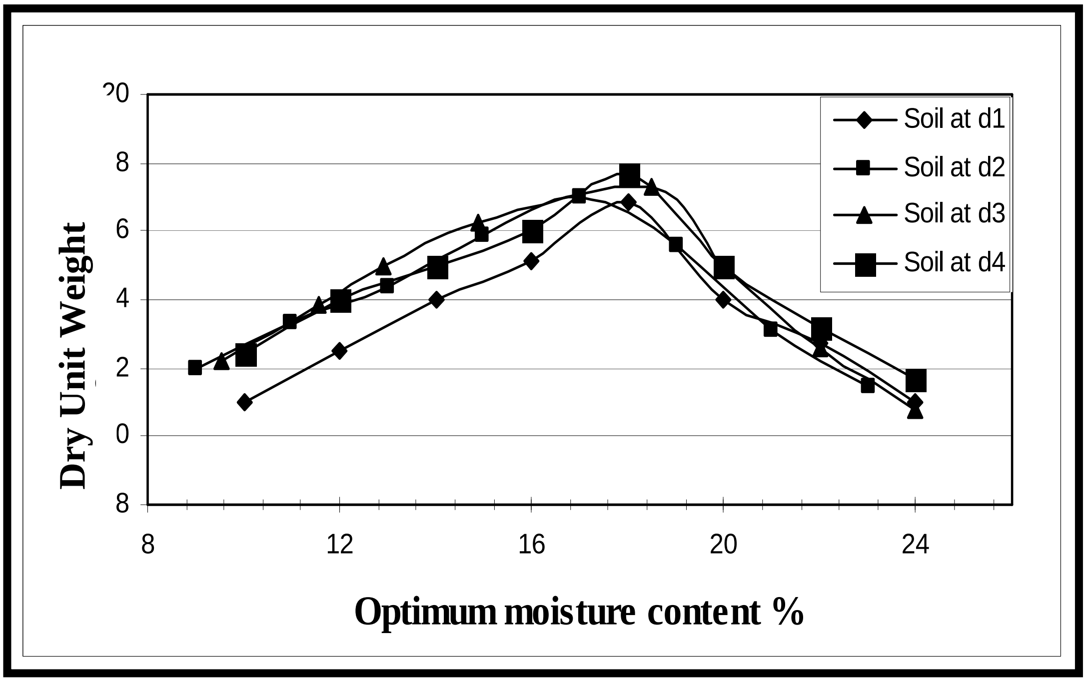
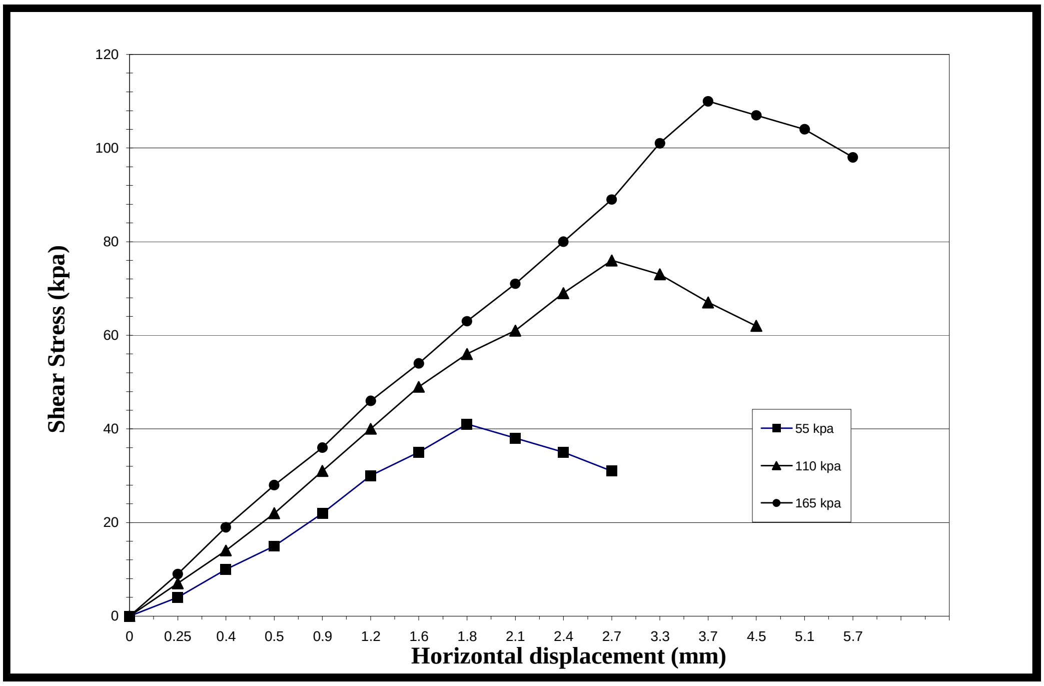


Figure (1) Dry Unit Weight with Optimum Moisture Content for AlatafiaSoil



.Figure (2) Direct Shear Test for Soaked Alkadhumia Soil at d_1

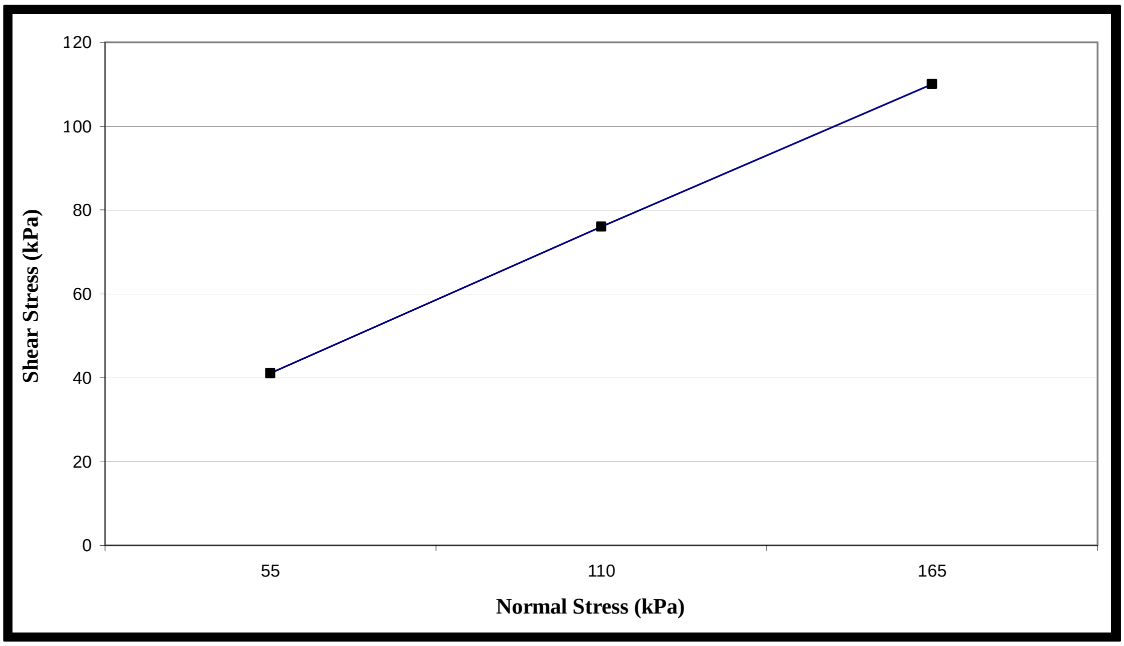


Figure (3) Shear Stress-Normal Stress Relationship **for Soaked Alkadhumia Soil at d_1.**

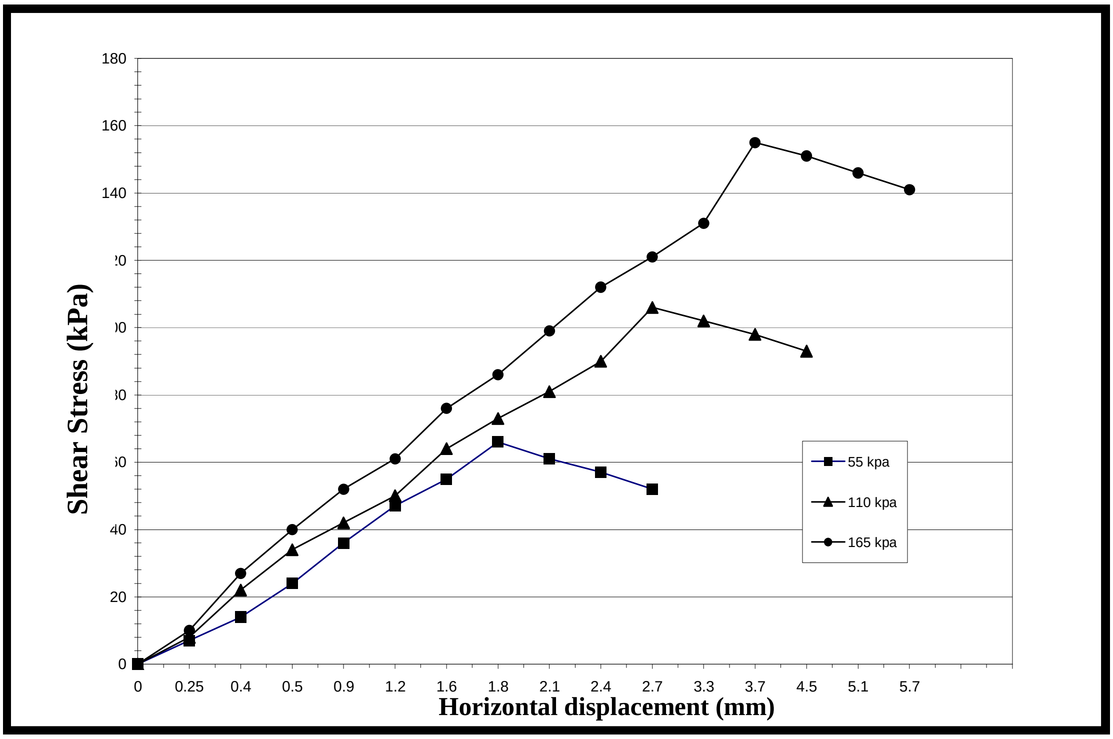


Figure (4) Direct Shear Test for Unsoaked Alkadhumia Soil at $d_{1.}$

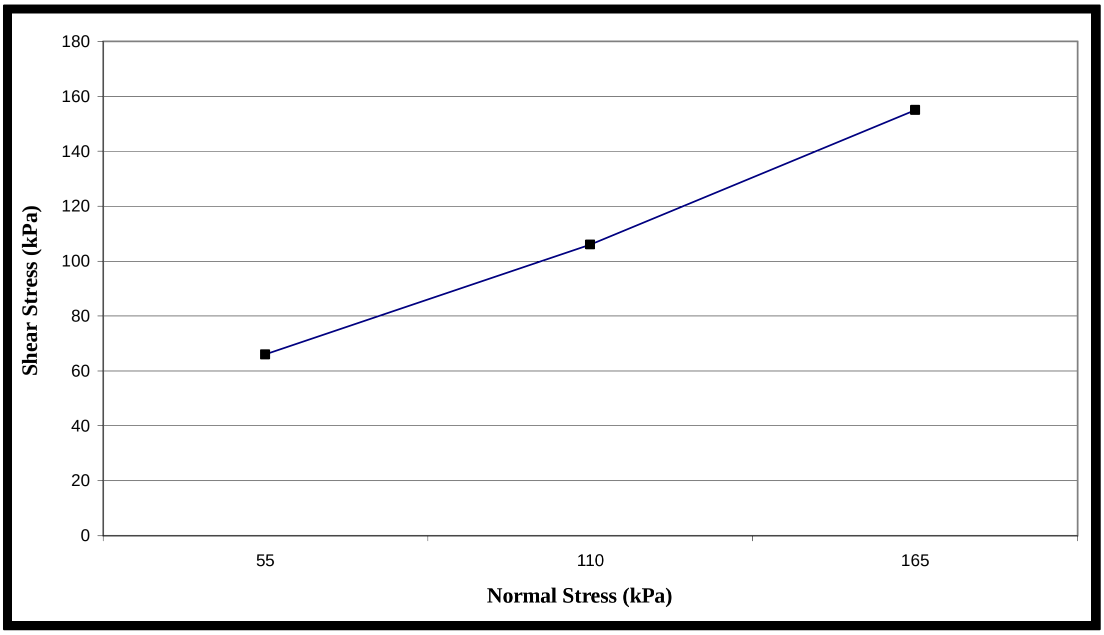


Figure (5) Shear Stress-Normal Stress Relationship for Unsoaked Alkadhumia Soil at $d_{1.}$

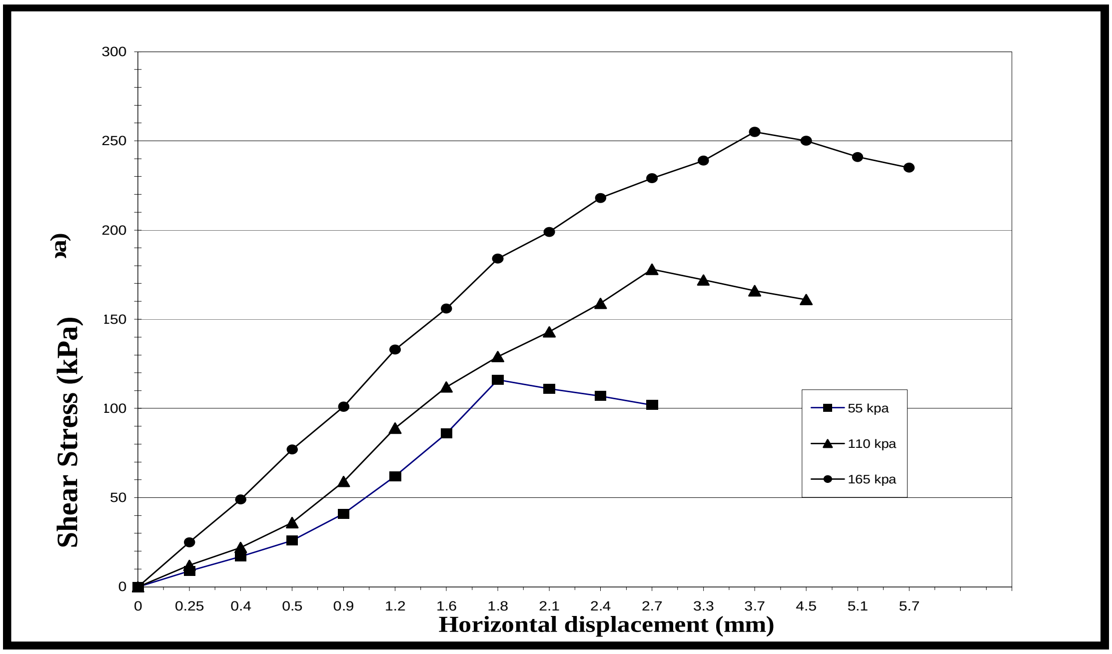


Figure (6) Direct Shear Test for Unsoaked Alhuria Soil at d_4

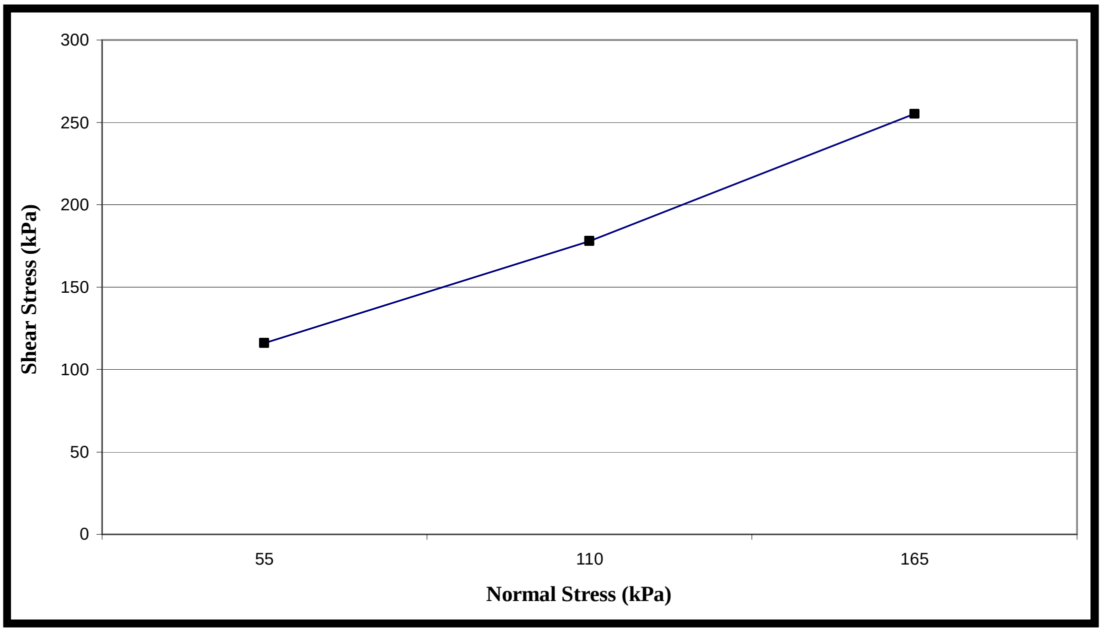


Figure (7) Shear Stress-Normal Stress Relationship for Unsoaked Alhuria Soil at d_4.

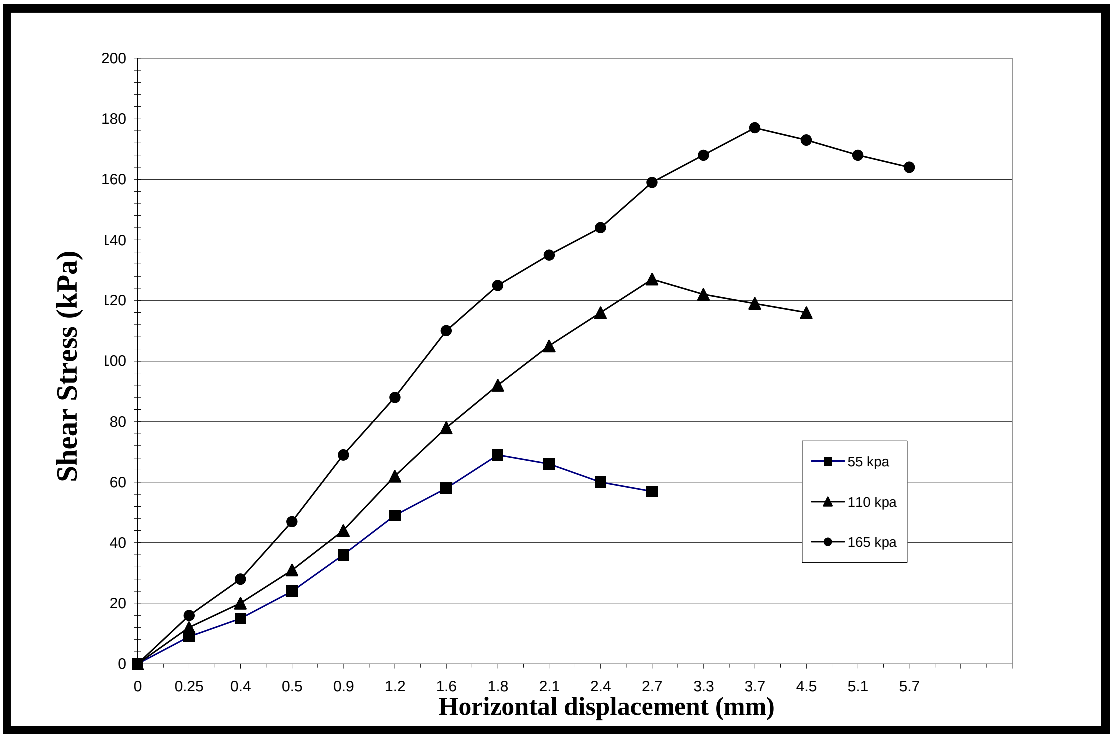


Figure (8) Direct Shear Test for Soaked Alhuria Soil at d_4

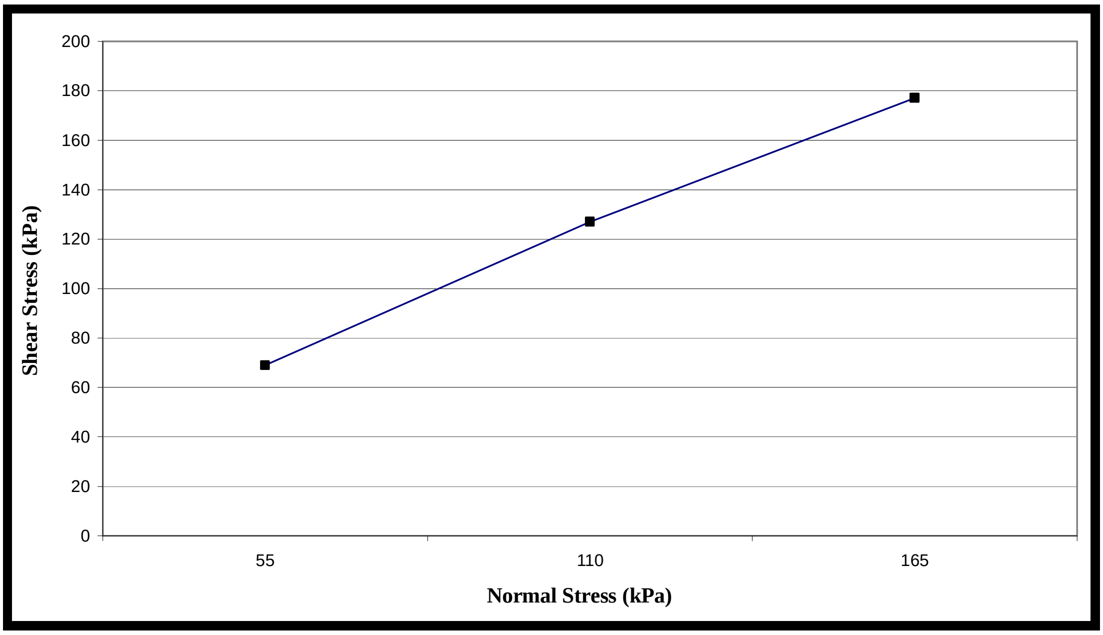


Figure (9) Shear Stress-Normal Stress Relationship for Soaked Alhuria Soil at d_4.

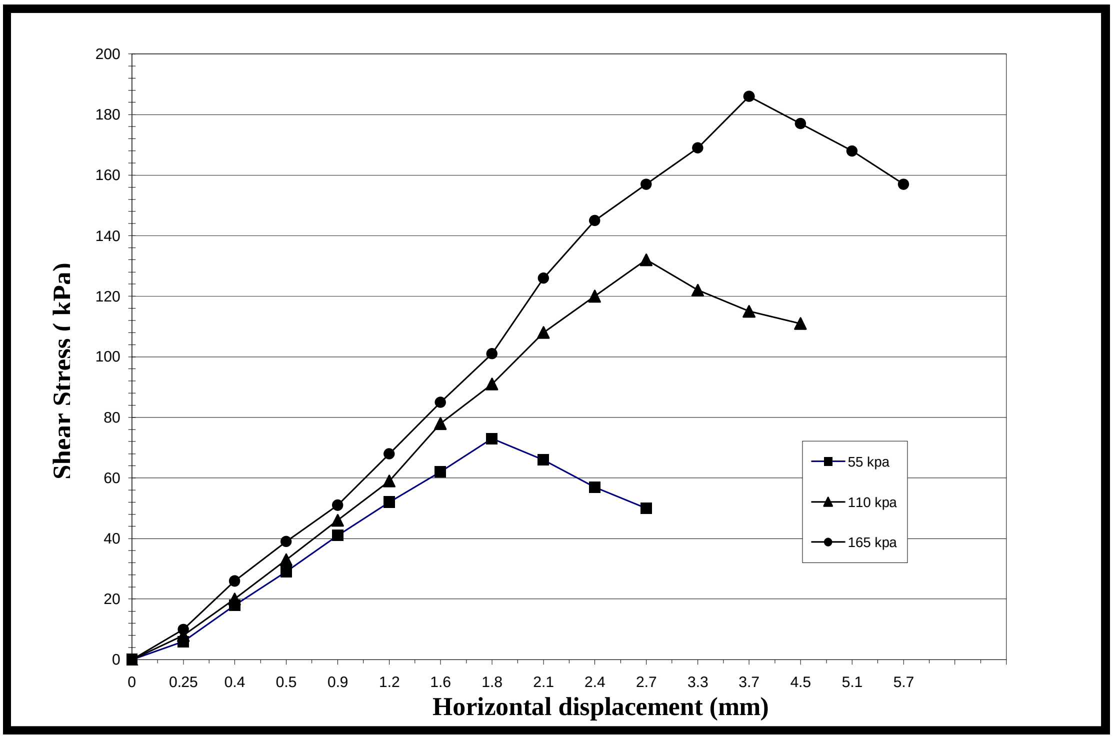


Figure (10) Direct Shear Test for Unsoaked Alatafia Soil at d_2.

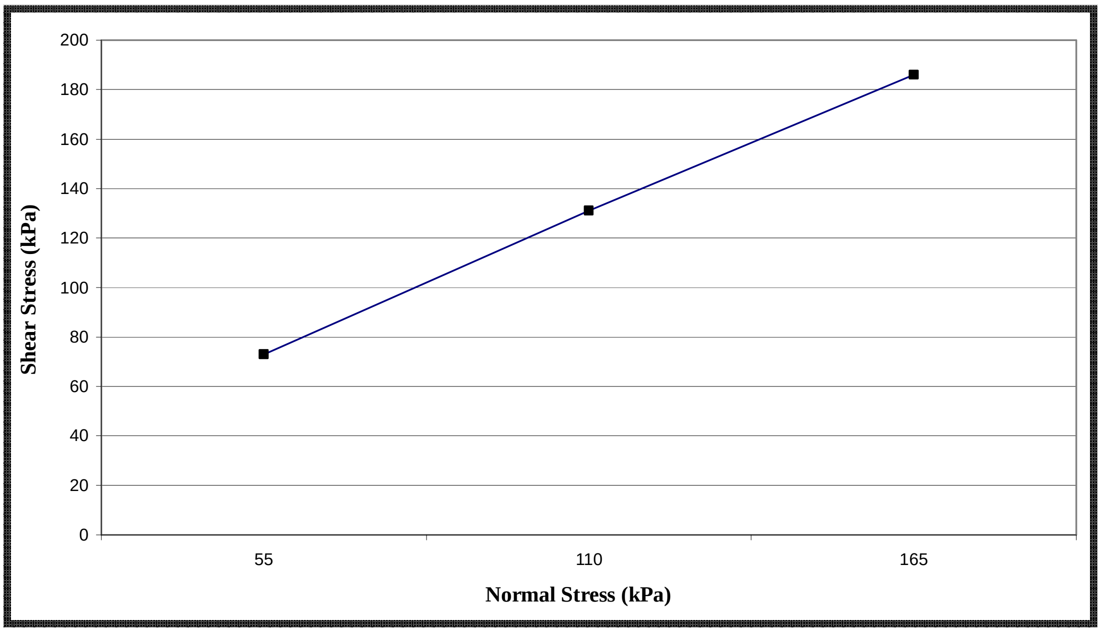


Figure (11) Shear Stress-Normal Stress Relationship for Unsoaked Alatafia Soil at d_2.

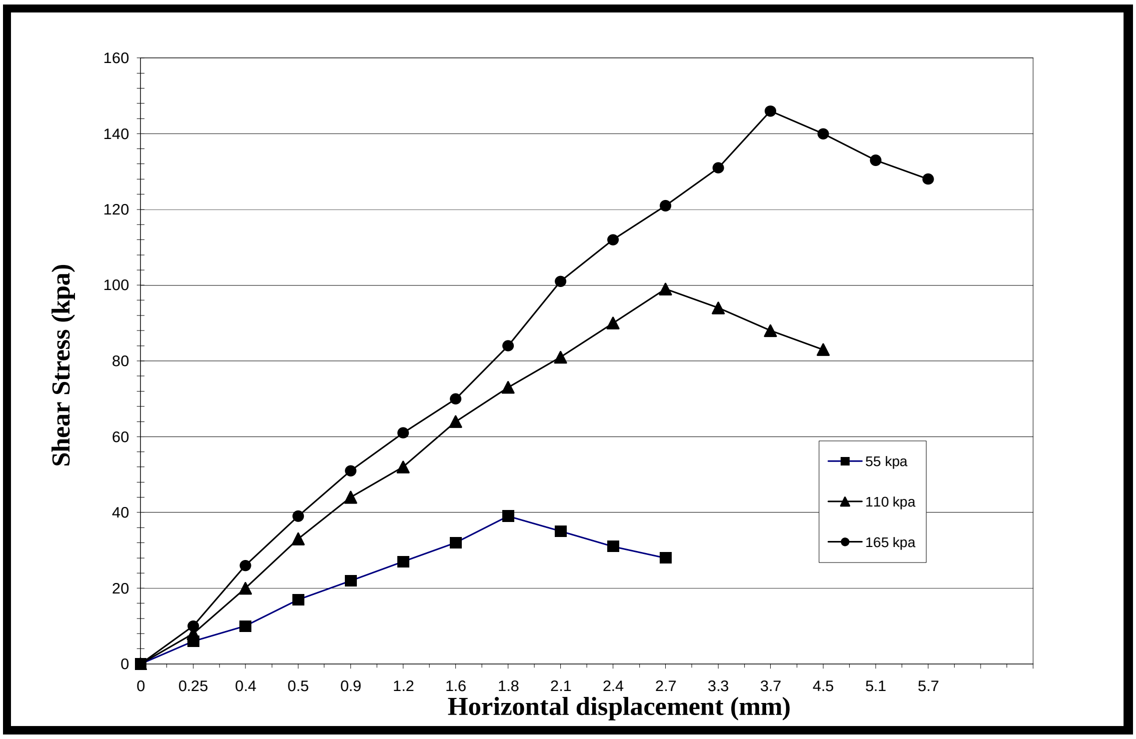


Figure (12) Direct Shear Test for Soaked Alatafia Soil at d_2.

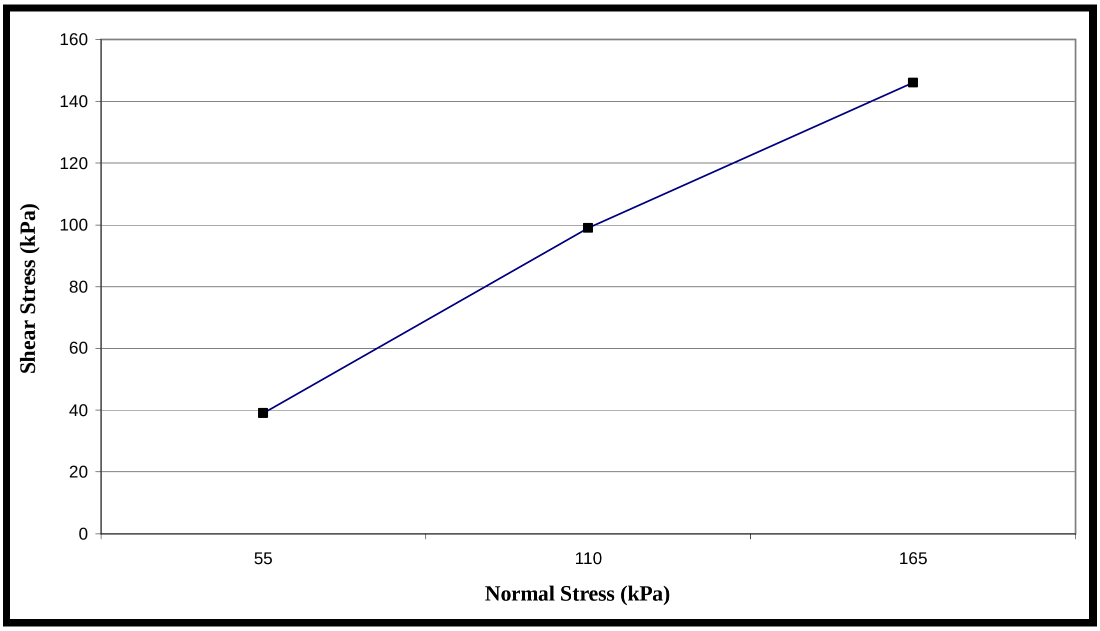


Figure (13) Shear Stress-Normal Stress Relationship for Soaked Alatafia Soil at d_2.