Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 6, Issue 10, October -2019

FABRICATION AND CALIBRATION OF LARGE SCALE DIRECT SHEAR TEST APPARATUS

Muhammad Shafi [1], Beenish Jehan[2], Irshad Ahmad[3], Abdullah[4]

[1]*Department of Civil Engineering, University of Engineering and Technology, Peshawar, Pakistan,*

Abstract — *This research is focused on the Design, Fabrication and Calibration of large scale Direct Shear and Pullout apparatus to find the shear strength parameters of the soil with large particles under constant normal load. With this apparatus experiments on fine (loose & dense state), medium (loose & dense state), and coarse (loose & dense state) sand and also crush aggregate were conducted under different normal loads of 12.7 KN (1.27 ton), 25.4 KN (2.54 ton) and 38.1KN (3.81 ton). To check the performance of apparatus testing were also done with standard direct shear test apparatus under the same conditions. As the tests were carried out under different loading conditions without any problem occur in the equipment assembly hence it was concluded that the equipment design governs. Furthermore it was observed that there is reasonable difference in the test values of large scale and small scale tests so it was concluded that the large scale direct shear equipment is calibrated.*

Keywords*-fine, medium and coarse sand soil; relative density test; small scale direct shear test; large scale direct shear test*

1. INTRODUCTION

Standard direct shear test apparatus has been used with particles size up to 2mm while large size particles has been excreted which counteract with site conditions result in less shear strength value. To examine the impact of large size particles there is a need to design and fabricated a LSDS test apparatus. This research is conducted to design, fabricate and calibrate a LSDS and pullout apparatus. Shear strength of soil is very important because most soil failure involves shear type failure. Shear strength of soil is expressed in term of cohesion and friction angle and the same depends on particle size. Shear strength of soil is the main component used in the design most soil related structures etc.

Direct shear test is commonly used to determine the shear strength of soil. For foundation engineering one must have adequate knowledge about the shear strength of soil. Soil can be divided into two main categories; (1) Cohesion-less soil (2) Cohesive soils.

The fundamental parameters for soil are influenced by, overburden pressure, density, gravel content, its size, and shape. In this study, the effects of the same on the shear strength are investigated in LSDS apparatus design and fabricated.

As soil with small size particles has been tested in direct shear test and the large particles are excreted, which contradict the actual conditions, where a mixture of small, medium and large particles exists. The large size particles are excreted due to the limited size of shear box.

In view of the above it is necessary to design a large size direct shear test equipment for testing of the soil with large particle sizes, in order to get results that most resembles the actual conditions at site.

@IJAERD-2019, All rights Reserved

2. Literature Review

A. General

This head includes literature review of shear strength of granular soils and different type of large scale direct shear instruments used in different researches throughout the world. Different types of large scale direct shear instruments are studied having different type of large scale direct shear boxes using difference soil as testing material. In this chapter all the aspect of the large scale direct shear instruments are discussed. Research Work of numerous researchers on coarse and granular soil is also discussed.

B. Direct Shear Test

Shear Strength of a mass is the resistance of the mass to deformation of the particle sliding and crushing. It is like tensile or compressive strength of material. Shear strength is generally measured in the term of two soil parameters i) the Cohesion or inter particle bonding and ii) angle of internal friction which is the resistance of particles to slide. It can be expressed in equation form as

$$s = c + \sigma \tan\phi$$

Where “s” is the total shear stress, “c” is cohesion, “σ” is normal or overburden stress and “ϕ” is the angle of internal friction

Using *effective* strength parameters it can be written as,

$$s = c' + \sigma' \tan\phi'$$

where s = shear strength, kPa, ksf, etc.

c' = cohesion

σ= normal stress on shear plane (either total σ or effective σ'),kPa, ksf, etc.

$\sigma' = \sigma - u$ = effective normal stress

ϕ = angle of internal friction

The strength parameters are often used as constants, but they are dependent on the type of laboratory test, previous stress history, and current state of material (Joseph E. Bowles, 1997).

In this test procedure the testing specimen is kept in a box which is called shear box made of metal. This box is usually square or circular in its cross section. It splits at mid height horizontally. There is a small gap between them to avoid friction among the two halves. In case of fully or partially saturated specimen, porous plates are put below and on top of the specimen for the drainage of sample during testing. A loading plate is placed on top of the specimen and a vertical force (N) known as normal load is applied on it. A lateral load is gradually applied in horizontal direction which moves to shear the specimen inside the box. The Shear Force ((T) measured with the help of gauge fixed to the box. Compression of the sample is also measured for recording settlement of the specimen. Figure-1 below shows general form of direct shear instrument.

.

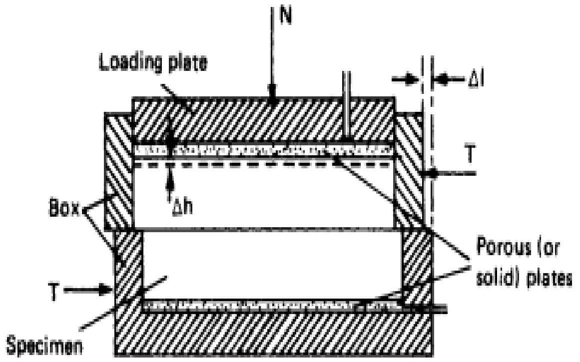


Figure –2.1: General form of direct shear equipment

@IJAERD-2019, All rights Reserved

A soil specimen is tested in shear box under different vertical forces. The value of shear stress at failure for a specimen is plotted on graph against the normal stress. Minimum three tests on a specimen under three normal loadings are required. From the graph best fit line, the values of both parameters can be determined. This test procedure has several advantages as well as disadvantages. Main advantage of this test is its simplicity and least time of testing. Main disadvantage of this apparatus is that during testing the pore pressure cannot be controlled and the specimen is sheared along a predetermined plane which may vary than actual shear plane (Craig, 2004).

C. Different types of direct shear tests

There are two main classes of the direct shear test.

- **Constant Normal Load**

In this test the normal load under consolidated drained conditions remain constant during the testing process. The specimen is sheared near the shear plane at controlled rate. The shear stress and displacement are not uniformly distributed within the specimen. The presence of coarse grained particles may affect the results. In order to represent the field conditions, the test conditions in laboratory, should be selected and maintained during testing. To ensure drainage of specimen, test must be performed at slow shearing rate. Usually, three or more tests are performed on specimens from one soil sample; each soil sample is tested under a different normal loading, to determine the effects upon shear resistance and displacement of sample. Test results are plotted to draw Mohr strength envelope and determination of cohesion and angle of internal friction. (ASTM, D 3080-90, 2011). An apparatus used for the determination of shear strength under constant normal load is shown in Figure-2.

Figure 2.2: Direct shear test equipment

@IJAERD-2019, All rights Reserved

- **Constant Normal Stiffness**

The vertical load varies and the variation in load is due to the following reasons.

- When the test sample dilates.
- When the sample consolidate.

D. Large Scale Direct Shear Instrument

Large scale direct shear instrument is a device that is used to determine the interface shear strength of soil-soil, concrete-soil, soil-geomembrans interfaces and soil with large particle size like gravels. The working principle of the large scale direct shear instrument is the same as that of the standard direct shear instrument. But in large scale direct shear instrument apparatus the shear box size is relatively larger than the standard size direct shear box as specified by (ASTM, D 3080-90 , 2011).

Different types of large scale direct shear instruments are used in many different researches throughout the world. A variety of shear box sizes are used in these research works. The dimensions of the shear box are controlled by the ASTM Specifications, which mainly depend on the soil maximum particle size to be tested and the type of the soil to be tested. Large scale direct shear instrument is a modified form of standard direct shear instrument. Due to large size of the direct shear box, large capacity loading devices are required for the application of the normal load and the lateral shearing loading on the sample during the test process.

Shallenberger (1996) developed a large scale direct shear instrument for the determination of interface shear strength of two interfaces. The device is capable of handling interfaces as large as 28 by 16 inches. In this device the upper half shear box is movable and the lower box is fixed with respect to the upper box. He pointed out that end effects in large scale direct shear instrument are negligible as compare to the conventional direct shear instrument. He further stated that maximum displacement in large scale direct shear test allow the exact determination of the interface residual shear strength.

The sample preparation in the large scale apparatus is difficult and time consuming which is the main disadvantage of the test. Also high capacity loading devices are required for this apparatus.

E. Influence of maximum particle size on the shear strength of the soil

In order to find the effect of particle size on the shear strength of the soil, Kim (2014) performed tests in Large Scale Direct Shear box using three types of granular soil. He used geo-grid reinforcement in the research and concluded that Shear Strength of soil increases with increase of particle size. The effect of use of geo-grid was also prominent and the interface friction angle was smaller but the shear strength was more than non-reinforced soil. Large scale direct shear testing machine used in his research is shown in Figure-2.3, while the material used in his research is shown in Figure-2.4.

@IJAERD-2019, All rights Reserved


Figure – 2.3: Different types of soil samples

Figure–2.4: Large scale equipment used by Kim et al. (2004)

F. Different type of large scale equipment utilized by researcher in the research study

Throughout the world many researchers uses large scale direct shear instrument in their research work for the determination of the shear strength of the soil, soil structure interface and soil-geo-membrane interfaces. Below are some of the research works done by different researchers.

Yarmahmoudi (2014) in his research work designed and fabricated large scale direct shear apparatus of direct shear box of size 400 mm x 400 mm. This fabricated large scale direct shear apparatus is shown in Figure-2.5. He conducted large scale direct shear testing on Almond gravel materials and found satisfactory results of this apparatus

Figure –2.5: LSDS Equipment by Yarmahmoudi A. et al.

Rao (2009) in research work on shear strength of rocks conducted laboratory test on planer rock joints. He used conventional direct shear test apparatus in which during shearing the normal load was kept constant, However, shearing of non-planar rock joint dilation was restricted by the surrounding rock mass and shearing does not

@IJAERD-2019, All rights Reserved

take place under Constant Normal Load (CNL) but rather under variable normal load where stiffness is constant called Constant Normal Stiffness (CNS) boundary condition. In this research work a servo controlled large scale direct shear apparatus consist of two steel box i.e. upper shear box and lower shear box was used. The apparatus is shown in the Figure-2.6.

Figure – 2.6: LSDS Instrument

Sun (2010) conducted tests for the determination of shear strength of sandstone that had to be used in the filling of walkway for the crane .He tested the rock fill in a small (100mm x100mm) as well as medium scale direct shear boxes (500mm x 500 mm) and quantified the effect of particle size, specimen size, density and normal stresses on the shear strength and concluded that shear strength increases when relative density increases.

Figure – 2.7: Visual aspect of LSDS Equipment

@IJAERD-2019, All rights Reserved

G. Overview of studies of the different researcher on shear behavior

Considering the studies on the effects of gradation, Rico et al. (1977), Marsal (1965) and Marachi et al. (1972) reported increase in strength with broader gradation in contrast to Leslie (1963) and Susan (1999), who have reported decrease in strength with broader gradation.

Scalping method is a process used for the determination of shear strength of soil having larger particles. In this method the maximum size of the specimen is restricted to the maximum size of particles that can be tested in the apparatus. The oversized particles are removed and test is performed on the finer part of soil. Parallel gradation is another method in which the soil is sieved and test is performed on finer fraction in the laboratory and a parallel curve of gradation is used for the original soil. In both these methods a fraction of material remains ignored and its property can affect the strength of soil thus the test results are compromised which may lead to under designed or over designed structure.

Fragaszy et al (1992) gave the idea of near field density and the far field density while working on granular soil tested through large scale triaxial tests. They investigated the effect of large scale particles on the density of sand.

Yagiz, Vallejo and Kukoshu et al (2001) conducted research on the sand gravel mixtures and concluded that shear strength of sand gravel mixture increases by increase of gravel concentration. Simoni and Houlsby (2006) conducted research on coarse grained soil and developed a correlation between the mechanical parameters and its finer fractions.

Pakbaz et al (2012) conducted research on the effect of clay content in a sandy soil. They conducted test in direct shear box with various percentage of clay content with in the sandy clay mixture. They concluded that the increase of clay within the mixture decrease the shear strength

Kim et al (2014) studied the effect of particle size on shear strength and concluded that the shear strength increase with the increase of particle size. The test results are shown in the graphical form in Figure-2.8 and Figure-2.9.

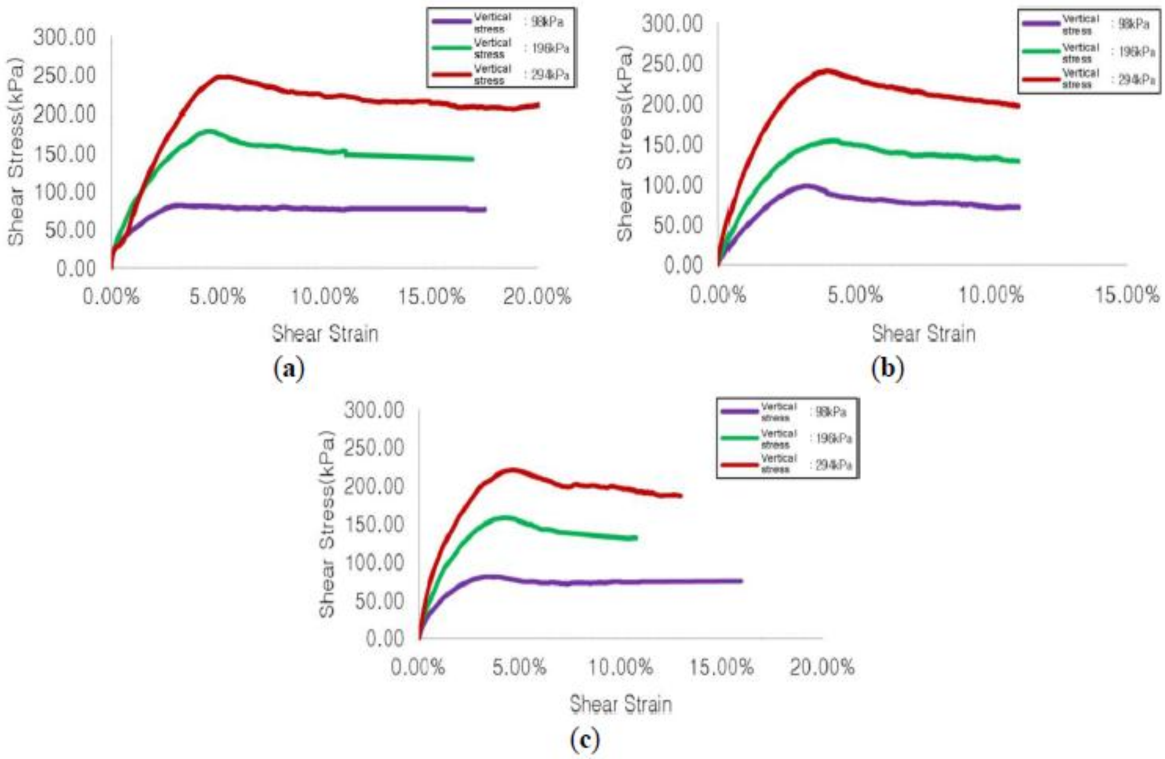


Figure –2.8: Shear Strength Versus Shear strain

@IJAERD-2019, All rights Reserved

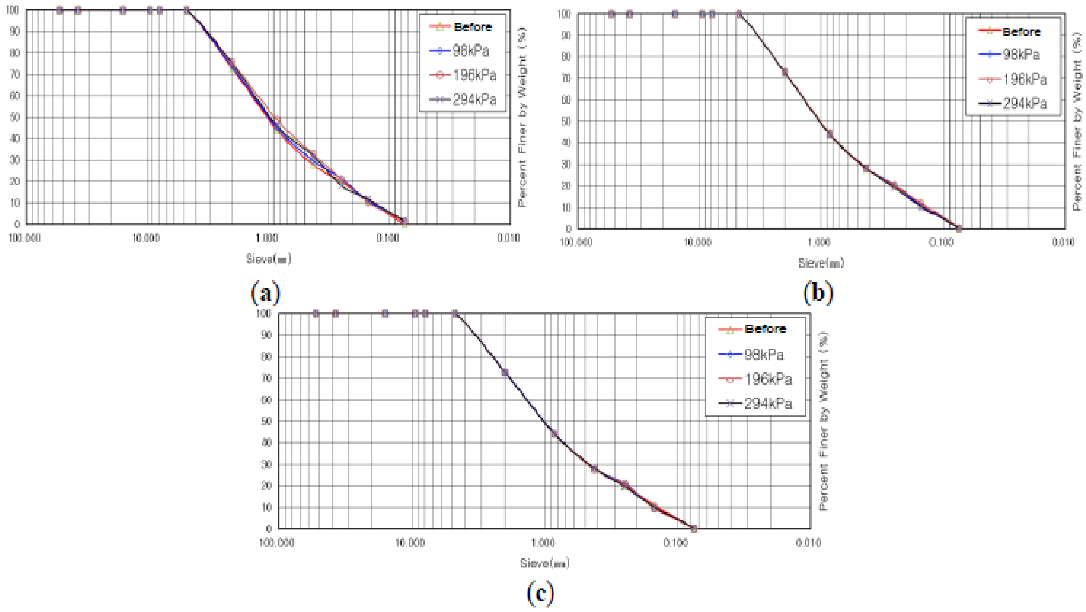


Figure – 2.9: Sieve analyses before and after testing

Alias et al (2015) conducted research on sandy soil of different particle sizes and tested the soil both in small as well as large scale apparatus. These tests were performed under the similar loading conditions and the results were concluded. The results show that the increase in particle size increased both peak and residual shear strength. The result of shear stress versus normal stress is shown in the graphical form in Figure-2.10 while the peak and residual shear strength is shown in Figure-2.11.

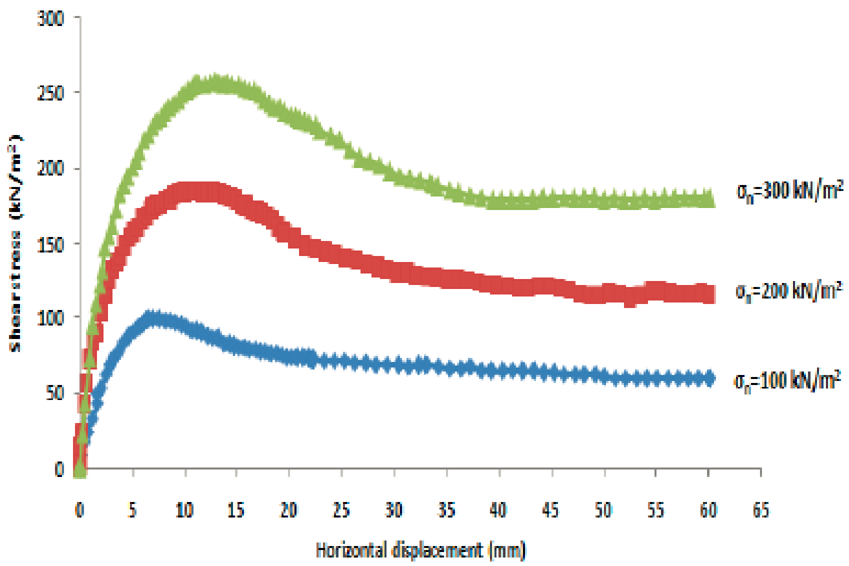
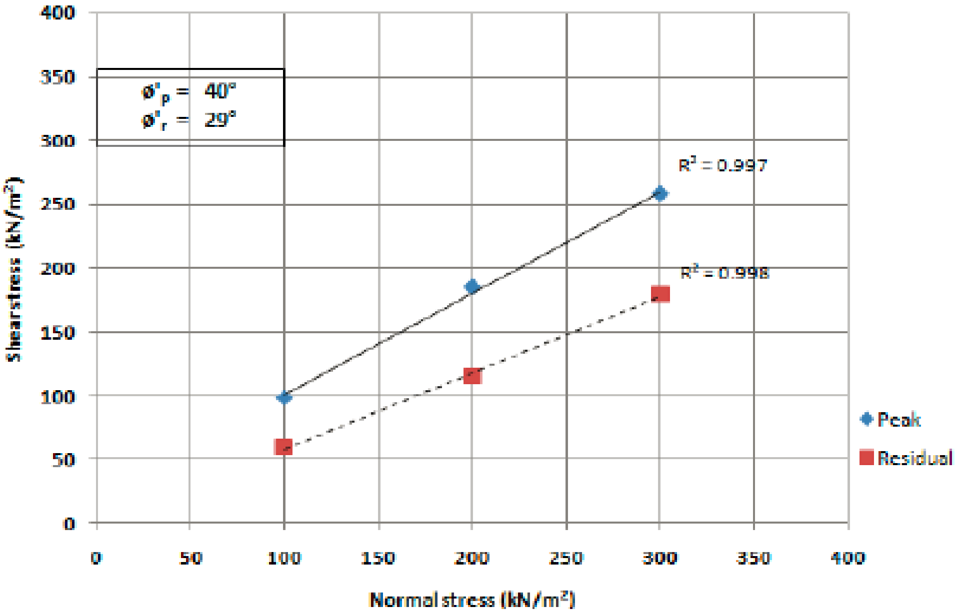


Figure –2.10: Shear Strength versus Shear strain



F

Figure-2.11: Shear stress versus Normal stress

Hamidi et al (2009) conducted research in laboratory and investigated the effect of gravel content on sand. They performed test in large scale direct shear apparatus under dry conditions. They concluded that shear strength of the soil increased with increase of gravel content in soil. It was observed that gravel content has a more pronounced effect on shear strength than the relative density. In Figure-2.12 gradation curve of the material used in the test is shown. In Figure-2.13 variation of shear strength with deformation is shown.

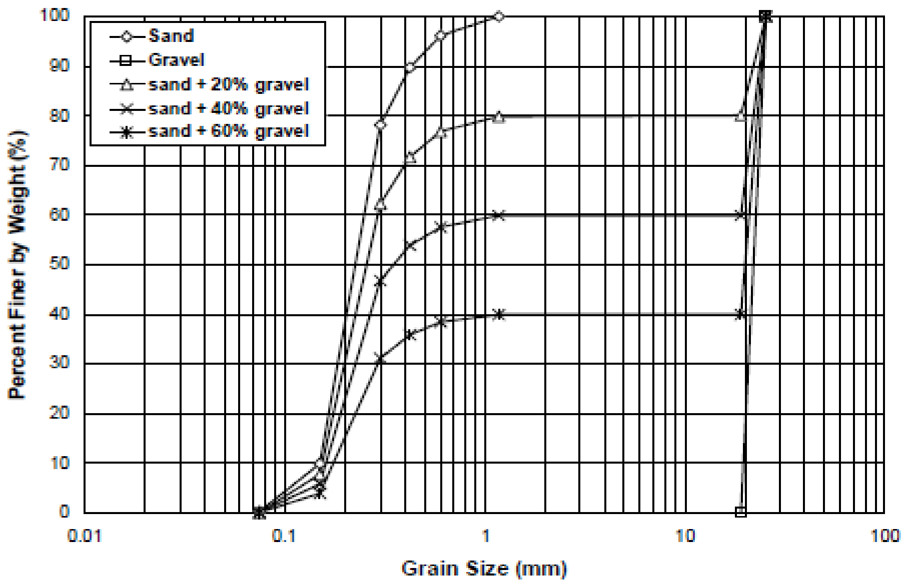


Figure – 2.12 Sieve analyses of different samples with varying concentration of gravel

@IJAERD-2019, All rights Reserved

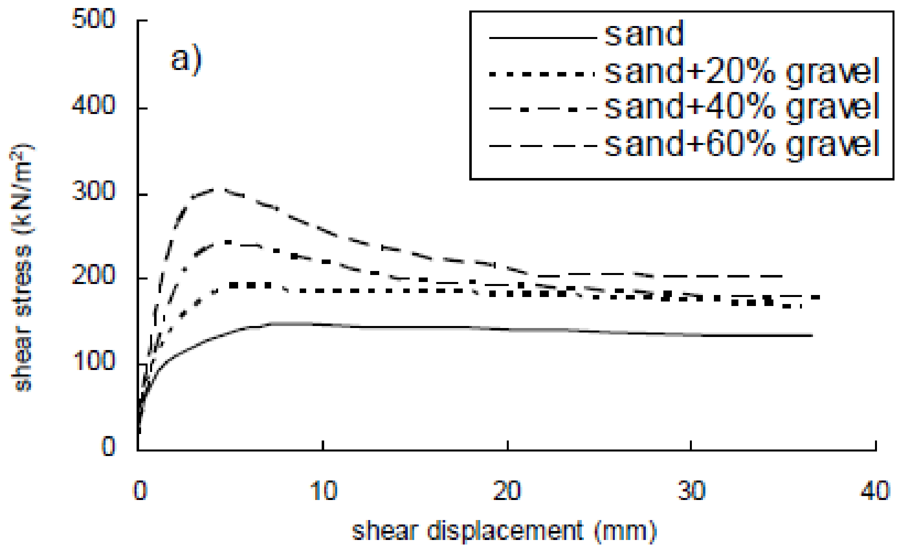


Figure –2.13: Shears stress versus shear strain

Seminsky (2013) studied the effect of oversized particles in soil mixture. The Guth relation was verified both experimentally and numerically. For sand gravel mixture large direct shear test apparatus was used while for numerical analysis the Discrete Element Method (DEM) was used. The results indicated that the shear strength of sand gravel mixture increased with the concentration of large particles in the mixture. Data of a test regarding shear and horizontal displacement is shown in Figure-2.14

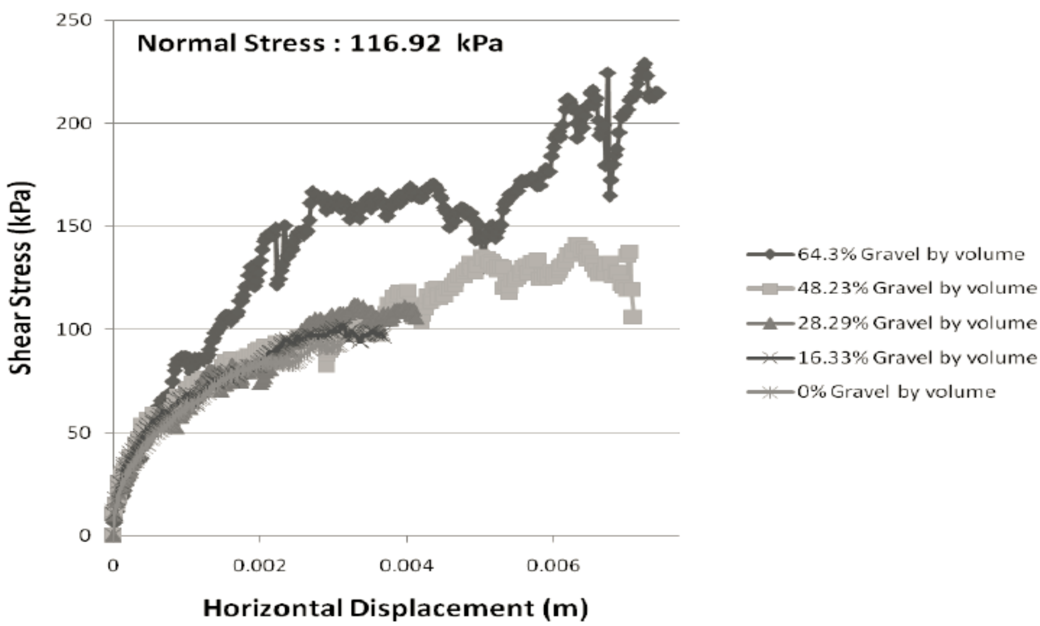


Figure –2.14: Shear stress versus shear strain

From the above studies it has been observed that the influence of the size of particle on the shear strength is predominant while in some cases they are opposing such statement. There is need to design and fabricate a LSDST apparatus to determine the influence of large size particles on shear strength.

@IJAERD-2019, All rights Reserved

In this research thesis design, fabrication and calibration of the LSDST apparatus has been has been discussed and presented. For calibration purpose the same sand has been tested in both LSDST instrument and SSDST instrument under the same loading.

3. Material for Testing

Sand with the following sizes and schemes have been used in the research work.

Large scale direct test on the following sand samples:

a. Fine Sand (.06mm to .2mm)
   - Loose
   - Dense

b. Medium Sand (.2mm to .6mm)
   - Loose
   - Dense

c. Coarse Sand (.6mm to 2mm)
   - Loose
   - Dense

A. Large Scale Direct Shear Testing

As we have to compare results of Large scale direct shear tests with Small scale direct shear tests for calibration, so using the density of sand for both testing equipment's, the weight of each sand sample for both loose and dense state has been calculated.

S.No	Description	Density (gm/cc)	Sample Weight for Small Scale DST
	Fine sand (Loose)	1.41	319.4 Kg
	Fine sand (Dense)	1.48	335 Kg
	Medium sand (Loose)	1.53	346.5 Kg
	Medium sand (Dense)	1.56	353 Kg
	Coarse sand (Loose)	1.58	357.9
	Coarse sand (Dense)	1.675	379.4 Kg

Table-3.1: Density and Weight of the samples

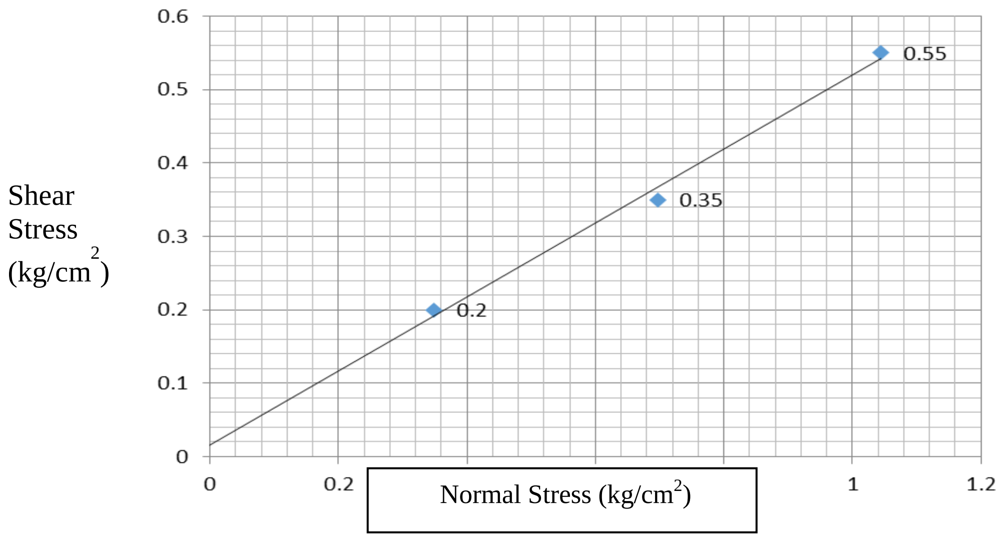
Using the above weights the large scale direct shear tests for each case has been conducted and test results are listed below in Table-3.2.

S.no	Description	**Φ**	**c = 0.00 kg/cm^2**	Density(g/cm^3)
1	Fine sand loose	26.65	.00	1.41
2	Fine sand dense	31.5	0.01	1.48
3	Medium sand loose	26.1	.02	1.53
4	Medium sand dense	29.24	0.01	1.56
5	Coarse sand loose	27.6	0.0.02	1.58
6	Coarse sand dense	31.38	0.03	1.67

Table-3.2: Shear Strength Parameters and Density of the samples

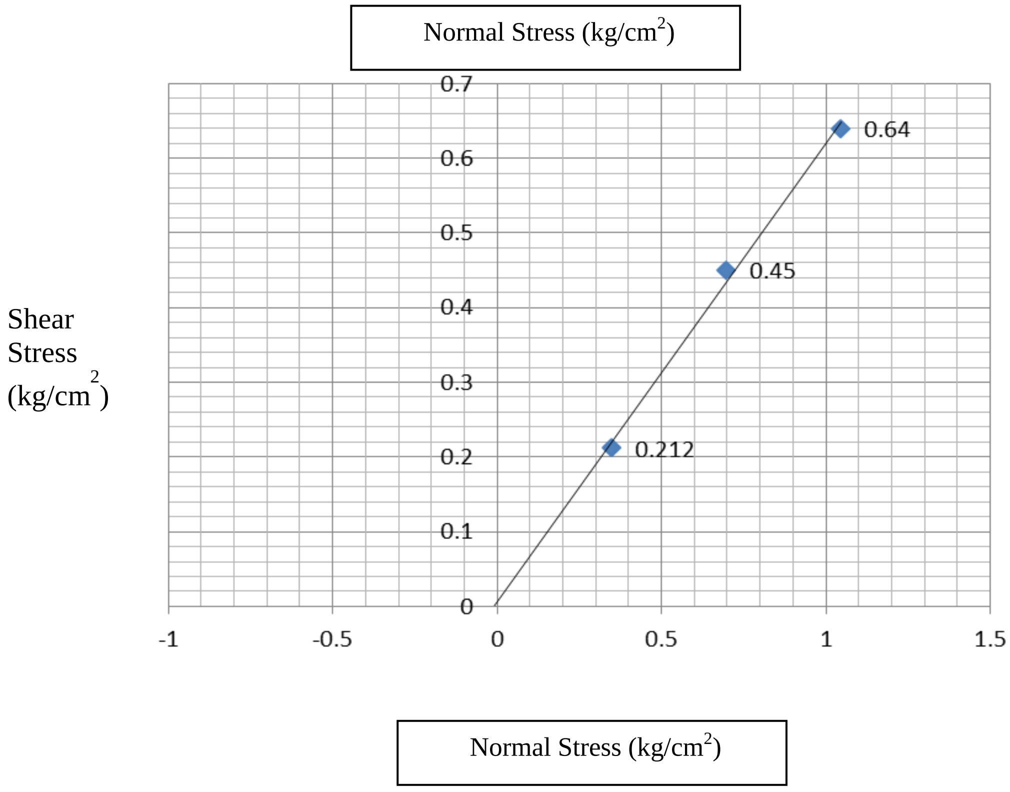
B. Graphical representation of the test results

Results of all the testing is hereby presented.



Friction angle Φ = 26.65

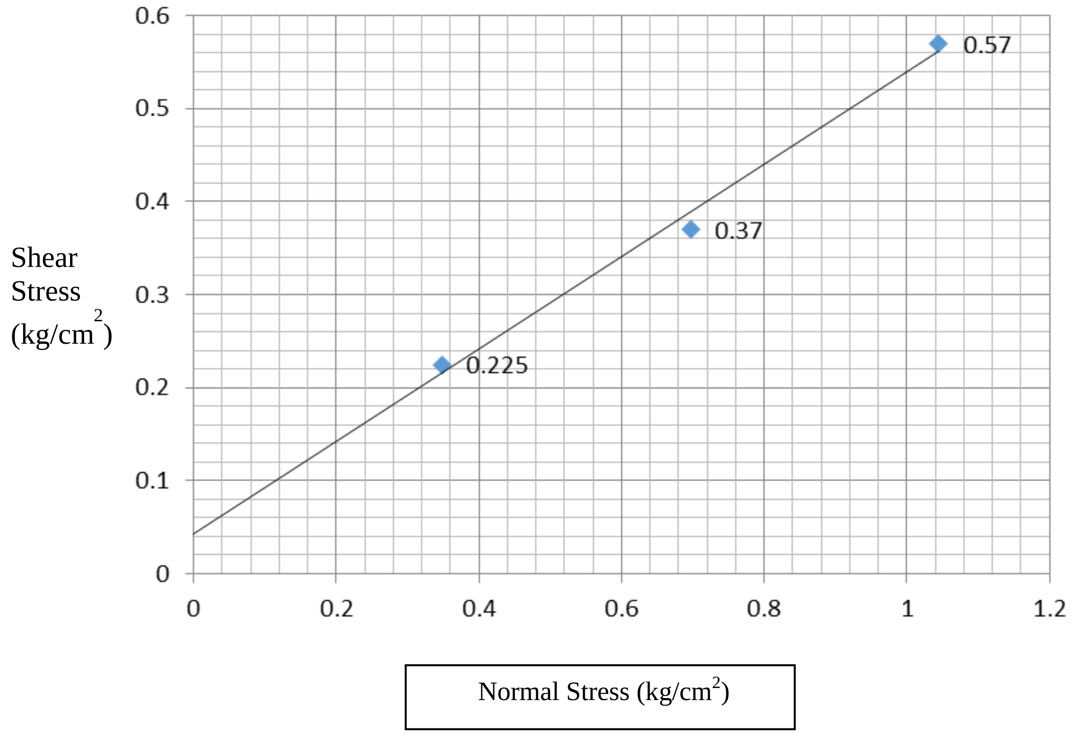
Figure-3.1: Shear stress verses normal stress for fine sand in loose state



Friction angle Φ = 31.5

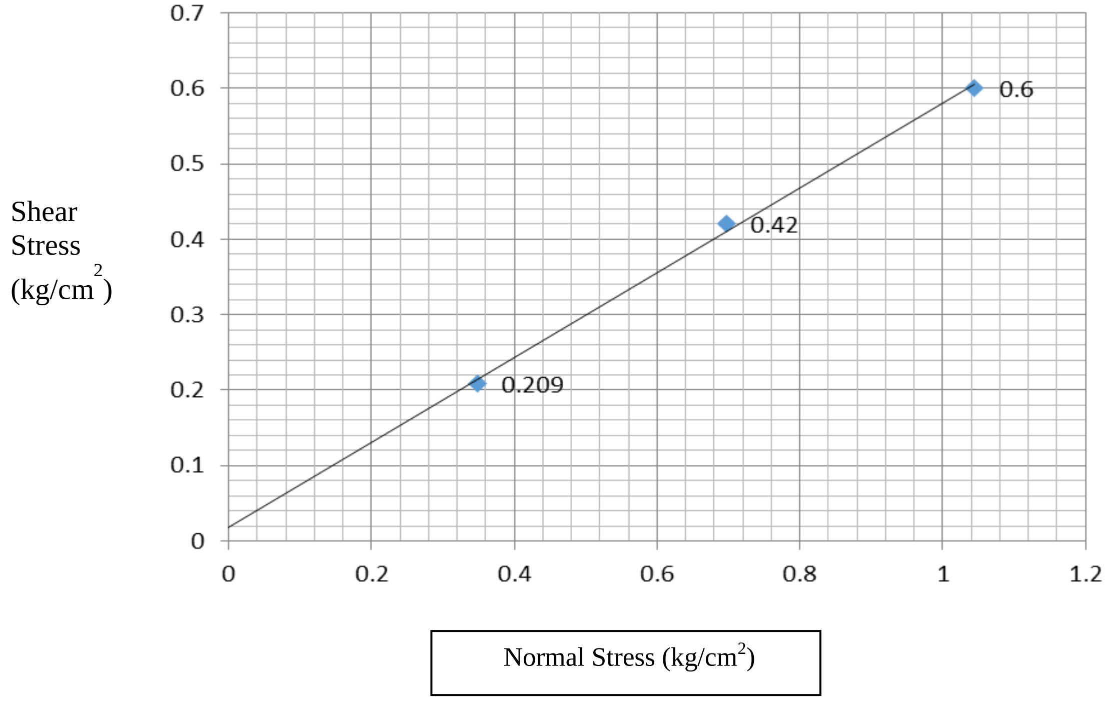
Figure-3.2: Shear stress verses normal stress for fine sand in dense state

@IJAERD-2019, All rights Reserved



Friction angle Φ = 26.1

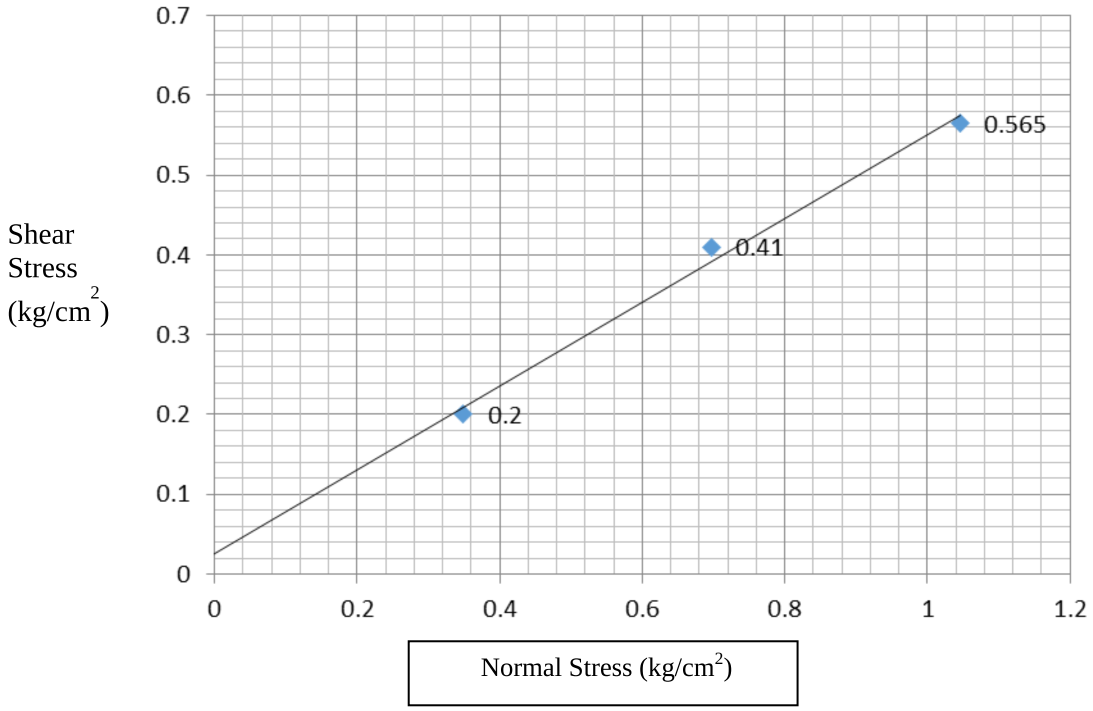
Figure-3.3: Shear stress verses normal stress for medium sand in loose state



Friction angle Φ = 29.24

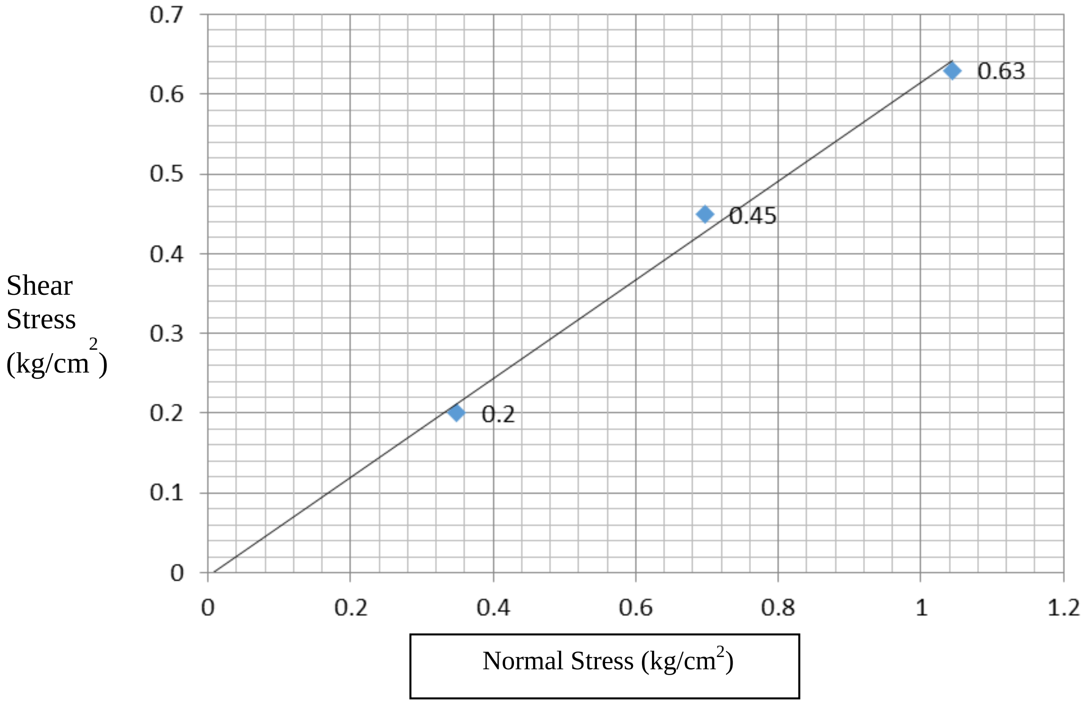
Figure-3.4: Shear stress verses normal stress for medium sand in dense state

@IJAERD-2019, All rights Reserved



Friction angle Φ = 27.6

Figure-3.5: Shear stress verses normal stress for coarse sand in loose state



Friction angle Φ = 31.6

Figure-3.6: Shear stress verses normal stress for coarse sand in dense state

@IJAERD-2019, All rights Reserved

S. No	Description	Φ (Large scale testing)	Φ (Small scale testing)
1	Fine sand loose	26.65°	26.1°
2	Fine sand dense	31.5°	30.1°
3	Medium sand loose	26.1°	26.5°
4	Medium sand dense	29.24°	31°
5	Coarse sand loose	27.6°	30.11°
6	Coarse sand dense	31.60°	31.25°

Table-3.3: Friction angle from direct shear test

4. Conclusions and recommendations

Large scale direct shear tests under different normal loads were performed to check that equipment is working properly and also to compare the results with small scale testing for calibration of the equipment.

Conclusions are as under:

- As the shear box size and the particle size increases the strength parameters also increases.
- In few tests the friction is slightly decreased with the increase in equipment scale.
- As the soil sample varies from fine to coarse the sample density increases which also affect the strength parameters.
- Considerable affect has been observed sand sample in dense state.
- Slow shearing rate result in more reliable test values.
- It was concluded from tests carried out under different loading conditions that the equipment assembly has the capacity to bear the design load.

Recommendations:

- Tests should be carried out in saturated condition as well to find the difference between dry and saturated condition.
- Testing with different percentages of crush aggregate mixed with sand may be tested to determine the effect of crush aggregate on the shear strength of soil sample.
- Computerized system shall be used for the application of lateral load so as to achieve a control shearing of the soil sample.
- Hydraulic system for removing of the shear boxes shall be included for smooth and quick replacement/compaction of the soil sample.

@IJAERD-2019, All rights Reserved

REFERENCES

[1] American Society for Testing Materials (1990). Standard test methods for direct shear test of soils under-consolidated drained condition, D-3080-90, ASTM and Philadelphia.

[2] Alias R., et al (2015) "Particle Size Effect on Shear Strength of Granular Materials in Direct Shear Test" International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering Vol: 8, No: 11, 2014.

[3] Yarmahmoudi A. "Design and Construction of Direct Shear Apparatus in Large Scale" Indian Journal of Fundamental and Applied Life Sciences, 2014 Vol. 4 (S4), pp. 1890-1897.

[4] Amir Hamidi et al (2009) "Effect of Particle Crushing on Shear Strength and Dilation Characteristics of Sand-Gravel Mixtures" International Journal of Civil Engineerng. Vol. 7, No. 1, pp 61-71.

[6] Bishop, A.W and Donald, I.B; (1961) "The experimental study of partly saturated soil in the triaxial apparatus" Proceedings of the 5th International Conference on Soil Mechanics and Foundation Engineering, Paris, pp. 13-21.

[7] Craig, R. (2004). Craig's Soil Mechanics. London: Spoon Press Taylor & Francis Group.

Carter, L. H. (March 1987). A Constant Normal Stiffness Direct Shear Device for Static and Cyclic Loading. Geotechnical Testing Journal, GTJODJ, Vol. 10, No. 1, 3-12.

[8] Fragaszy, R.J. et al (1992). "Modeling strength of sandy gravel." Journal Geotechnical Engineering Division, ASCE, 118(6), 920-935.

[9] Jewell, R.A. (1988) "Direct Shear test on Sand" Soil Mechanics Report No. 082/88.

Kim, D. and Sungwoo, H. (2014) "Effects of Particle Size on the Shear Behavior of Coarse Grained Soils Reinforced with Geogrid". Materials 2014,7, 963-979.

[10] Kokusho, T. and Harra T. et al (2004) "Un-drained strength of gravelly soils with different particle gradations"13th World Conference on Earthquake Engineering Vancouver, B.C., Canada August 1-6, 2004, Paper No. 144.

[11] Daehyeon Kim and Sungwoo Ha. "Effect of Particle Size on the Shear Behavior of Coarse Grained Soil Reinforced withGeogrid" Department of Civil Engineering, College of Engineering, Chosun University, 375 Seosuk-Dong, Dong-gu, Gwangju 501-759, Korea; E-Mail: gilryong@nate.com.

[12] Pakbaz M.S and Moqaddam A.S (2012) "Effect of Sand Gradation on The Behavior of Sand-Clay Mixtures" International Journal of GEOMATE, Sept., 2012, Vol. 3, No. 1 (Sl. No. 5), pp. 325-331.

[13] Leanna Seminsky (2013) "The Shear Strength of Granular Materials with Dispersed and Non-dispersed Oversized Particles" M.Sc thesis Pittsburgh University.