Experimental study on the determination of shear strength parameter of bouldery soils using large triaxial calibration chamber

Peregrinus Dhae Siga Taa, Paulus Pramono Rahardjo, A.Aziz Djayaputra

Abstract— In the analysis of slope stability often encountered the condition of certain areas there is a slope mixture of sand soil material, gravel, and dominant boulder. The mixed material is termed in this study as "Bouldery Soils" material. These conditions are complex and heterogeneous materials that are widely used in geotechnical engineering. In practice, the material of the boulder soil mixture, the effect of the boulder particles is particularly neglected in the shear strength analysis. To measure the shear strength parameters (cohesion, c and internal shear angle, φ) on soil material conditions or rock conditions using both direct shear testing and triaxial trials is now common in the laboratory. But to measure the shear strength characteristics of the soil-boulder mixture material (bouldery soils) is still rare. The difference in bouldery soils is the background of this research, followed by the development of calibration chamber as an Unconsolidated-Undrained Triaxial Test (TX-UU). In this research was done on some bouldery soils composition to determine the stress-strain characteristics of bouldery soils and to obtain shear strength parameters according to Mohr-Coulomb criteria.

Keywords: calibration chamber, triaxial test, bouldery soils, complex material, cohesion, internal friction angle, Mohr-Coulomb.

1 Introduction

IN performing a road work on an area that has a hilly topography most civil works cut out the slopes to open road access. So the access road through the hill slopes with soil and rock structure conditions in the area there is a slope mixture of sand soil material, gravel, and dominant boulder. The mixed material is termed in this study as "Bouldery Soils" material. The so-called bouldery soils material is based on the size of the boulder granules used larger than 200 mm and the addition of a percentage of the amount of boulder with a mixture of soil, sand, gravel mixed in the test sample inside the calibration chamber.

Problems with bouldery soils which are complex materials and heterogeneous soils need to be reviewed further the effect of a boulder on the stability of the slope. The shear strength and failure characteristics of bouldery soils are very unclear, often the problem when it does not determine the shear strength parameters carefully for use in geotechnical engineering.

Determination of shear strength parameters on soil material conditions or rock material conditions by using direct shear testing as well as the triaxial test is now commonly performed in the laboratory. But to determine the shear strength characteristics of bouldery soils are still rare. The difference in bouldery soils condition is the background of this study, followed by the development of chamber calibration test by testing methods such as large-triaxial methods in the laboratory measurement.

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Bouldery soils found in the Bukti Salam area of the CIPALI toll road project (Cikopo-Palimanan) are estimated to form in the tertiary period is a very un homogeneous geomaterial that contains a certain percentage of rock blocks [1]. This type of soil consists of boulder blocks of various sizes and high strength, fine-grained and porous soils. Most types of failure mechanisms based on physical or mechanical strength characteristics are controlled by the proportion of the number of rock blocks and their grain distribution. [2] undertook a study of boulder effect on slope stability using the three-dimensional element method. The input parameters use empirical correlation result from the field test. In this research, the investigation of shear strength parameters (cohesion, c and deep shear angle, φ) bouldery soil should be tested in a geotechnical laboratory using calibration chamber using reconstituted samples can be tested by triaxial bouldery soils in the laboratory.

2 Bouldery Soils

The soil is a loose material, the result of weathering of rocks measuring less than 2 mm. While the size of the rocks in nature there are various kinds of gravel size up to the boulder. This soil and rock mixture is said to be a bouldery soils material. Generally, bouldery soils are colluvium soils that originate from volcanic lava mixed with the soil around and then cool and bind the soil material over time. This type of soil consists of many complex materials with variations in shear strength characteristics and material deformation. Strong shear soil bouldery soils and the collapse characteristics of the material cannot be clearly described. In relation to the composition and distribution of highly complicated materials, mechanical characteristics, and deformations different from those of pure soil or rock. Of course, the characteristics of bouldery soils are strongly influenced by geological conditions and the ratio of soil and rock. The mechanical and physical properties of bouldery soils have an important role in the geotechnical stability of the construction associated with the material. Research on the determination of shear strength parameters in new bouldery soils material is limited to triaxial modeling using finite element method as done by [3].

In reality in the field, there is a mixture of soil and boulder material larger than gravel, so in this study is categorized as material "Bouldery Soils". In various publications about the mixture of rock and soil materials, the evaluation of the shear strength of the soil and rock mixture has been done by several researchers and gives different definitions. [4] classified rock masses by weathering into three levels: soil, rock, soil and rock according to the grain composition. [5] and [6] express the strength and deformation properties of mélange and characterization of engineering mélanges by estimating volumetric proportions in complex mélanges and similar blocks using stereological methods, the soil-rock mixture is defined as "Block in Matrix Soil" which shortened to Bimrokcs. Geologic words to describe mélanges and olistostromes that include, fault rocks, weathered rocks and mixed materials in other embedded complex geologies in a weak matrix.

[7] Study on the shear strength of soil–rock mixture by large scale direct shear test. [8] obtains aggregate soil-rock mixture strength characteristics under complex environments by conducting a series of large-scale direct shear tests based on orthogonal design. [9] defined soil particle and rock matrix as Soil-Rock Mixture (SRM) and also examined the shear strength and failure characteristics in SRM, using numerical tri-axial compression test. From the numerical test results indicate that the rock in SRM has a strong influence on shear strength parameters, stress field distribution and SRM form of failure. The SRM stress-strain curve obtained from the numerical tri-axial compression test is actually different from the pure soil or rock curve. In the SRM stress-strain curve, there is a large difference in power parameters between rock and soil. The cohesion of SRM is almost five times larger than the soil, although the internal friction angle in SRM remains almost constant. The effect of gravel on SRM cohesion is greater than that of the internal friction angle. And obtained a comprehensive SRM shear strength parameter for slope areas in southwestern China using engineering analogy method, direct shear test by conducting the large-scale direct shear test and test SRM numerically. [10] Large-scale Triaxial Testing and Numerical Modeling of Rounded and Angular Rockfill Material.

3 Calibration Chambers

The history of a large calibration chamber began in 1969 in the Materials Research Division, Country Roads Board (CRB) (now called VIC ROUDS), Melbourne, Victoria, Australia. The idea of using a calibration chamber is followed by many in the belief that there is a great need to learn the performance of something learned with a full-scale test that can be done in the laboratory. It will then be able to accurately measure and or control the properties of soil, stress, and strain [11]. Calibration chambers are used in research so far with differences in a number of ways, including dimensions; stiffness and loading conditions in the lateral, upper and lower direction; sample deposition procedure; ability to handle saturated samples; and control of boundary conditions.

The use of chambers calibration has proven to be a valuable tool in the development of correlations. This chamber has an advantage over field test conditions under boundary conditions during penetration (stress and strain) can be controlled and accurately measured. Also, accurate density determination eliminates an important element of uncertainty in developing correlation with soil parameters. Large-diameter stress sels used for geotechnical investigations [12]. Characteristics of some calibration chamber ever used in various studies can be seen in Table 1.

TABLE 1.
Principal Calibration Chambers used in geotechnical investigations Adapted from Peterson '1986).

Test Cell Owner/Location	Specimen Diameter (m)	Specimen Height (m)	Boundary Conditions		
			Radial	Bottom	Top
Country Roads Bureau, Australia	0.76	0.91	Flexible	Cushion	Rigid
University of Florida, USA	1.2	1.2	Flexible	Cushion	Rigid
Monash University, Australia	1.2	1.8	Flexible	Cushion	Rigid
Norwegian Geotechnical Institute	1.20	1.50	Flexible	Cushion	Rigid
ENEL-CRIS, Milano, Italy	1.20	1.50	Flexible	Cushion	Rigid
ISMES, Bergamo, Italy	1.20	1.50	Flexible	Cushion	Rigid
University of California, Berkeley, USA	0.76	0.80	Flexible	Cushion	Rigid
University of Texas at Austin, USA	cube 2.1x2.1x2.1m		All flexible		
University of Houston, USA	0.76	2.54	Flexible	Cushion	Cushion
North Carolina State University, USA	0.94	1.00	Flexible	Rigid	Rigid
Luisiana State University, USA	0.55	0.80	Flexible	Flexible	Rigid
Golder Associates, Calgary, Canada	1.40	1.00	Flexible	Rigid	Cushion
Virginia Polytechnic Institute and State University, USA	1.5	1.5	Flexible	Rigid	Rigid
University of Grenoble, France	1.2	1.5	Flexible	Cushion	Cushion
Oxford University, UK	0.90	1.10	Flexible	Cushion	Rigid
University of Tokyo, Japan	0.90	1.10	Flexible	Rigid	Rigid
University of Clarkson, USA	0.51	0.76	Flexible	Rigid	Rigid

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University of Sheffield, UK	0.79	1.00	Flexible	Rigid	Flexible
Cornell University, USA	2.1	2.9	Flexible	Rigid	Rigid

4 Shear Strength

The shear strength of the soil is the soil resistance to the existence of shear failure resulting from a movement between the surface of the soil particles. The shear strength indicates the ability of the soil to withstand the soil shear forces. The shear strength of a soil mass is the internal resistance of the soil per unit area to the failure or shift along the sliding plane in the soil in question. Knowledge of shear strength is needed to analyze and solve problems related to soil bearing capacity, soil stress on retaining walls and slope stability.

The failure of the soil is generally distinguished according to the behavior of the soil when applying a load, ie the soil that behaves strain-softening and the soil that behaves strain-hardening. The failure in soil that behaves strain-softening is determined at the point of "peak" or the maximum voltage value of the soil stress-strain curve, ie a turning point where the voltage drop starts to occur in line with the increase in strain. Clays that are overconsolidated clays and dense sands generally have strain-softening properties or behaviors. In soils with strain-hardening behavior, the soil stress-strain curve does not have a peak point so that the determination of the point of collapse is generally done by taking a certain allowable strain value. Clay soil that normally consolidated clays and loose sands have strain-hardening behavior.

[13] Mohr (1900) gives the theory of the collapse of a material that the material will collapse if the combination of the shear stress and the normal stress acting on the collapse reaches a certain value, where the shear stress in the collapse plane of collapse (τ_f) is a function of the normal voltage in the field of collapse when collapse is reached (σ_f) expressed as:

$$\tau_{ff} = f(\sigma_{ff}) \qquad (1)$$

Coulomb (1776) conducted an experiment to obtain a shear resistance value of the soil and found that there was a shear strength component. The stress-dependent component is referred to as the angle of internal friction given the symbol φ and the shear force component independent of the stress is the cohesion given the symbol c. The shear strength equation given by Coulomb is a straight-line equation which expresses the shear strength in the total stress condition and is expressed as follows:

$$\tau_f = c + \sigma \cdot \tan \varphi \qquad (2)$$

where c and φ are the shear strength parameters referred to as the cohesion intercept and the angle of shearing resistance, respectively.

The combination of Mohr's failure criteria (1) and Coulomb's shear strength equations (2) gives Mohr-Coulomb's shear strength equations expressed as follows:

$$\tau_{ff} = c + \sigma_{ff} \cdot \tan \varphi \qquad (3)$$

5 Experimental Program

The measurement of shear strength parameter of bouldery soils using Calibration Chamber in Laboratory, the experiment was conducted on a mixture of sand soil material, gravel without boulder and mixture of sand, gravel and boulder soil with a composition of boulder content.

a) Soils and boulder used in this study are mixed materials of soil and boulder taken from the location of the Cikopo-Palimanan toll road, West Java. The boulder used is angular to sub-angular obtained from explosives and excavations using heavy equipment.
b) The material of sand, gravel, and boulder used as a mixture material in boulder soils, derived from the results of grain size analysis. The mixed soil is taken from the sieve size # 3/4 ", # 1/2", # 3/8 ", and fine aggregate No.4, No.10, No.20, No.40, No.80, No.120, No.200, and Pan This mixture of sand and gravel, as a fixed material (independent), is varied by the amount and weight of the boulder added to the composition of the bouldery soils mixture.
c) Development of Calibration Chamber
Calibration chamber designed and developed at UNPAR, which is intended for soil bouldery soils with house soil samples with a diameter of 0.6 m and height of 0.6 m (Fig.1). Chamber with rigid walls with independent pressure control from the external chamber, which allows complex boundary conditions to be applied. Lateral and vertical pressures, as well as strain conditions, can be applied independently.
The testing system with a calibration chamber instrument is applied as in the Large Triaxial Unconsolidated-Undrained (TX-UU) test kit on bouldery soils material.

Fig.1. View and detail calibration chamber in geotechnical laboratory of Parahyangan Catholic University, Bandung.

In general, the calibration chamber test instrument developed has the following main parts:

a) Triaxial cells and supporting equipment
b) The system of confining pressure
c) Axial load system

d) Axial deformation measurement system

A large-scale triaxial test scheme with a calibration chamber test instrument developed in the form of axial pressure suppression system (σ_1) from below using a hydraulic electric pump and a tensioning stress system (σ_3) using air pressure from an air compressor. While the axial deformation measurement system is installed Linear Variable Differential Transducer (LVDT) sensor. To study the effect of soil without boulder and soil-boulder mix with boulder content composition on shear strength parameter value, triaxial multi-stage unconsolidated undrained test using chamber calibration tool. Using the boulder composition method used is 0% (without boulder), and with a mixture of 10%, 20%, 30%, 40%, 50% and 60% boulder soils by applying a cell pressure (σ_3) of 0,4 kg/cm², 0.8 kg/cm² and 1.6 kg/cm².

6 TESTING PROSEDUR

The triaxial test steps on the chamber calibration tool are as follows:

1) The calibration chamber tool is prepared first.
2) Sampling mixture of sand and boulder soil material from Bukit Salam, then separated boulder and sand. Further testing the water content in the laboratory and continued by grain size analysis test with the sieve arrangement of the aggregate coarse that is; # 3 ", # 2", # 11/2 ", # 1", # 3/4", # 1/2", # 3/8 ", and fine aggregate No.4, No.10, No.20 , No.40, No.80, No.120, No.200, and Pan. The fine aggregate soil and the coarse aggregate are separated in each container according to the size of the sieve. After the sieve analysis is done, the fine aggregate soil of the sand is re-mixed with the coarse aggregate by means of mixer in order to obtain a mixture of bouldery soils which are like all of the sampling conditions. The size of the smallest used boulder blocks is 3" to the largest boulder size from 200 to 250 mm and the rock is angular to subangular.
3) In the early stages of testing performed a test on the composition of 0% (without boulder). Before the sample is inserted into the chamber, install the former sample in a chamber calibration apparatus so that when the sandy soil is uniformly distributed and the sample stays upright.
4) The soil is weighed first to determine its weight according to the weight of the plan to ensure the density of the sand soil in the chamber on each layer is equal. The process of entering the sand soil is done step by step then flattened and compacted.
5) If tested with a mixture of boulders, the boulder position in the chamber for the Triaxial Test Act on the sample "Bouldery Soils" boulder placement in the calibration chamber is done by arranging. (if tested without a boulder, step (5) is not done).
6) After the height of the sample has reached 60 cm, then close the sample using the sample cover on the surface of the soil. Then control it with water pass.
7) Remove the former sample when the sample is filled in with the plan and the sample cover is mounted and blend with the rubber membrane. The former sample is removed so as not to disrupt horizontal directional movement.
8) Close the chamber tightly and firmly by tightening the bolts so that air pressure is not lost. After that the cell pressure is applied by using an air compressor device according to the planned cell pressure.
9) To observe the displacement of the sample vertically then a Linear Variable Differential Transducer (LVDT) sensor is installed on the bottom cover port of the sample from the inside of the chamber. LVDT is connected by cable to digital display and reads to 0.01 mm accuracy then set to zero. Before the first test is done calibration tool that is by matching data readings on the digital display with data readings on digital dial gauge calibrated. This is done to obtain data accuracy at displacement measurements.
10) At the beginning of the first test carried out the application of loading (loading) by giving vertical pressure using electric hydraulics pump with a capacity of 30 tons. At the time of loading pressure speed of 1 mm / minute. The stopwatch is turned on simultaneously in order to know the speed of the given pressure. Note the displacement of LVDT (dial gauge) on any pressure application with a strain controlled system.
11) For subsequent observations, ie observation during pressure reduction (unloading) by reducing pressure on the electric hydraulic pump and read the displacement on LVDT.

7 REZULTS AND DISCUSSION

7.1 Regional Geological Condition of the Study

A review of Bouldery Soils material on the slope stability project at Bukit Salam (Cipali Toll Road Project 202 + 075) is part of the Cikopo - Palimanan (Cipali) toll road mega project.The toll road elevation is planned to reach 50 m below the existing elevation of Bukit Salam. This condition is assumed to be a conservative condition in which the most effective soil stress conditions can harm the slope conditions. With limited land, the slope of the slope is limited so as not to be too sloped so that the width of the toll road plan can be achieved.

Based on field observations on slope and field morphology conditions and geological studies are generally dominated by sedimentation materials from the eruption of Mount Ciremai and sedimentation from local materials. The eruption material undergoes a chemical process so that it blends with the original soil layer into a mixed material composed of soil and boulder. So the state of the study area material is said to be bouldery soils which describe the condition of the soil laminated with the rock matrix. Material bouldery soils in Bukit Salam area, CIPALI toll road, West Java, show in Fig.2 and geological stratification are show in Fig.3.

Fig. 2. Material bouldery soils in Bukit Salam area

Soil and geological stratification are shown in Fig.3.

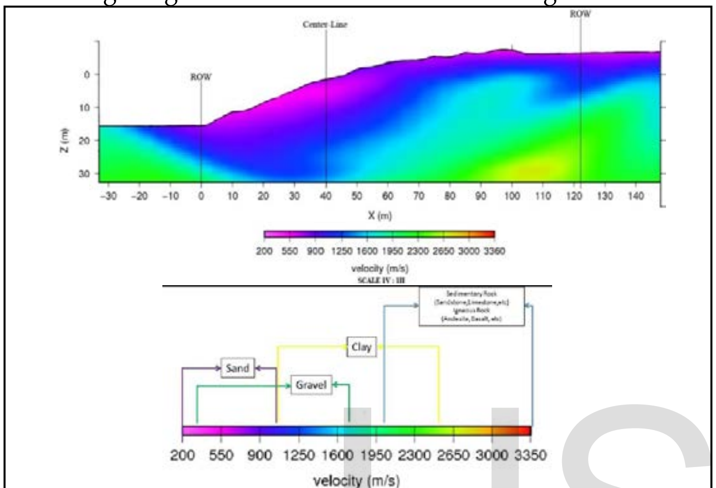

Fig. 3. Cross section STA.202+075 Based on the Earthquake Survey.

Geoseismic results indicate that the stratification of the Bukit Salam area is dominated by the sandy layer of pebbles in the upper area (blue and pink). The next layer is a layer of clay mixed with sedimentary rocks which are generally formed from a material deposit.

7.2 Analysis of soil size distribution used in triaxial testing

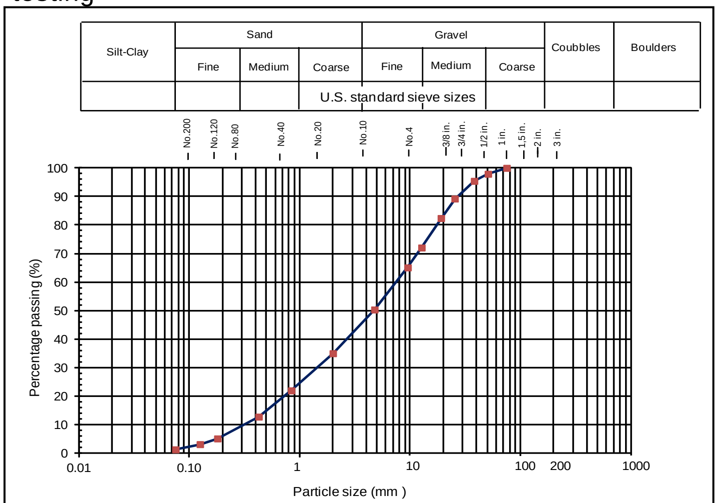

Fig. 4. The results of the distribution of grain size of the sandy soil before added boulder.

Fig. 4. shows the analysis of soil size distribution used in triaxial testing is gravel 35.05%, sands 61.81% and fine friction (Silt, Clay) 3.13%. The slope and general shape of the distribution curve are illustrated by the coefficient of uniformity, Cu = 5.69 and the coefficient of gradation, Cc = 2.97. From the above results obtained the dominant grain size distribution is the size of aggregate sand and gravel. Based on the soil classification way of USCS the soil at the study site belongs to the classification of well-graded soil as it has a grading coefficient of 1 <Cc <3 with Cu> 4. The aggregate that has been sieved is mixed again using mixer agitator to be used as a test sample mixed with the boulder in bouldery soils material.

7.3. Large-Scale Triaxial Test Material Bouldery Soils Using Calibration Chamber

To determine the shear strength parameters (cohesion, c and inner shear angle, φ) bouldery soils using calibration chamber in the laboratory by studying the effect of "boulder content" composition on the value of shear strength parameters. Triaxial test using calibration chamber with boulder composition used is 0% (without boulder), and with mixture of soil material with 10%, 20%, 30%, 40%, 50% and 60% boulder with apply cell pressure (σ_3) of 0.4 kg/cm², 0.8 kg/cm² and 1.6 kg/cm². The final test results are presented in the form of graphs of stress and strain relationships as well as the normal and shear stresses of the Mohr diagram as shown in Fig. 5. to Fig. 10. below;

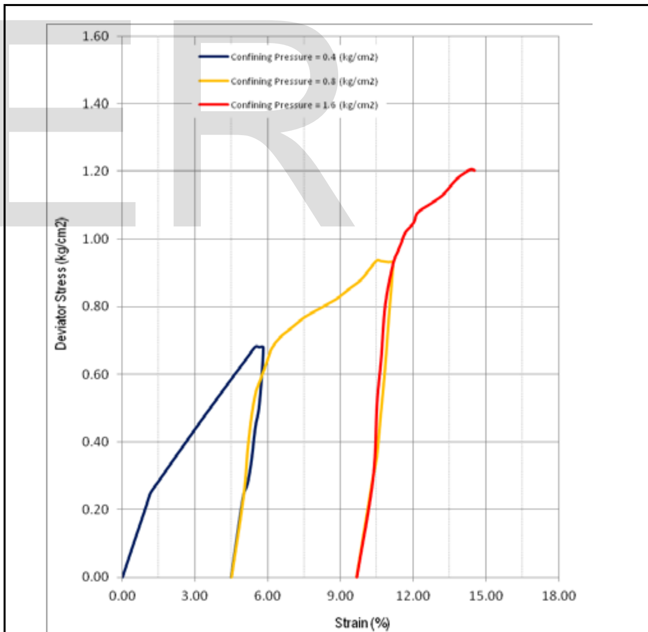

Fig. 5. The stress-strain relationship triaxial test result 0% boulder.

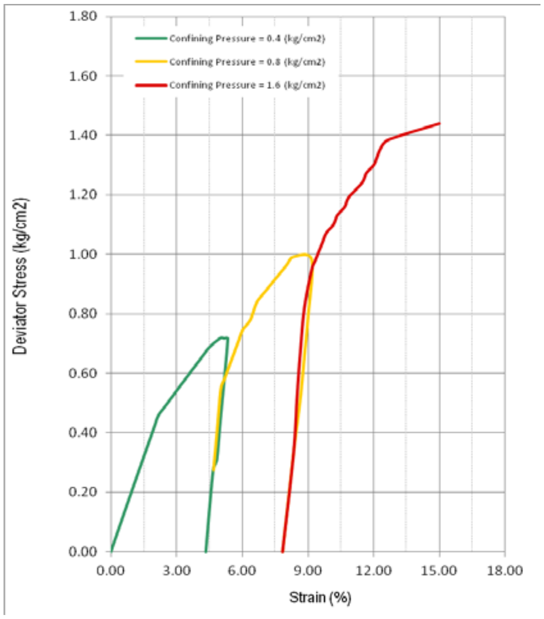

Fig. 6. The stress-strain relationship triaxial test result 10% boulder.

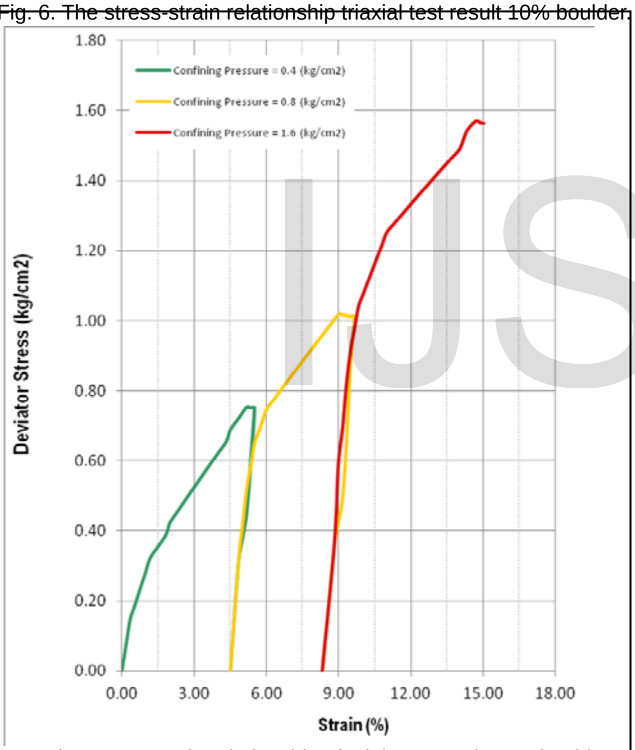

Fig. 7. The stress-strain relationship triaxial test result 20% boulder.

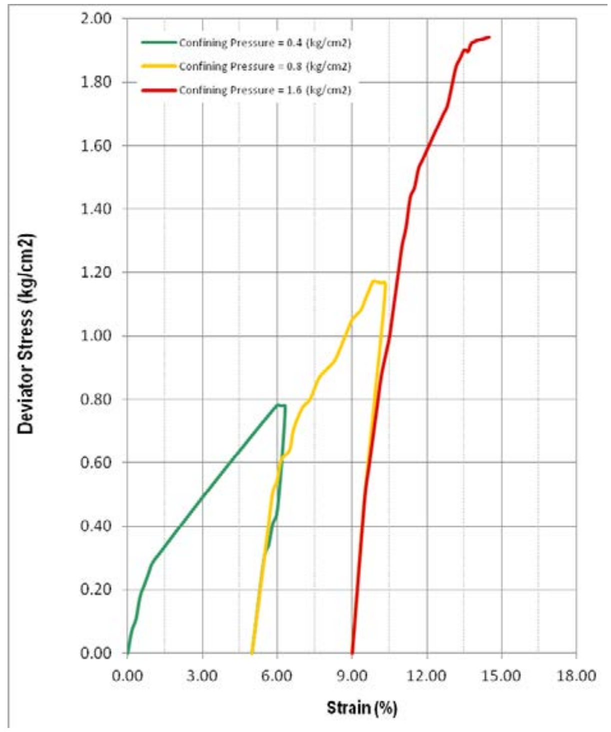

Fig. 8. The stress-strain relationship triaxial test result 30% boulder.

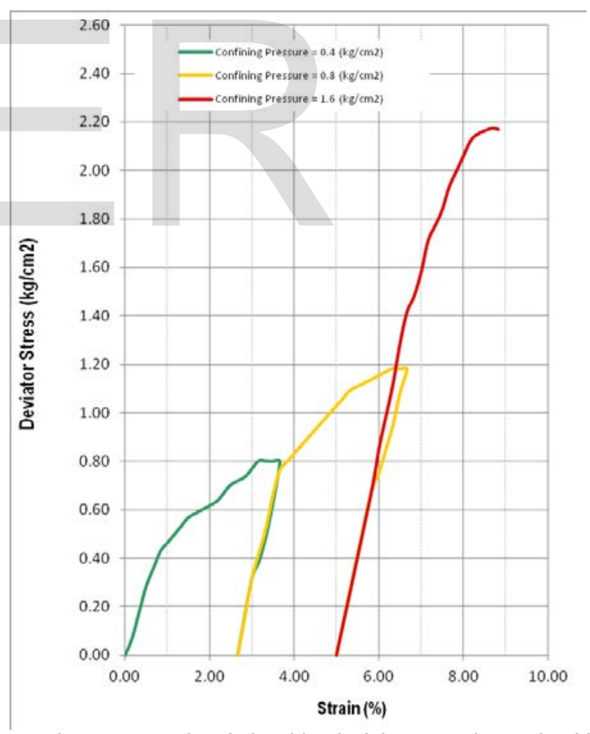

Fig. 9. The stress-strain relationship triaxial test result 40% boulder.

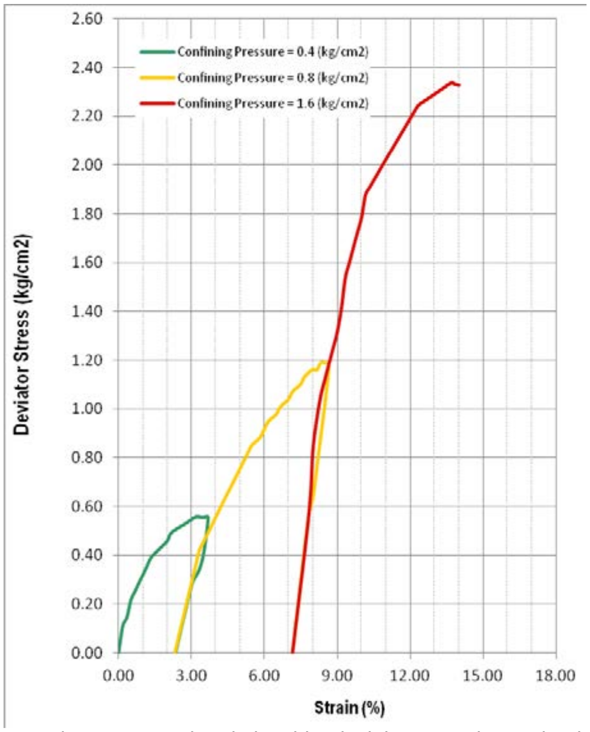

Fig. 10. The stress-strain relationship triaxial test result 50% boulder.

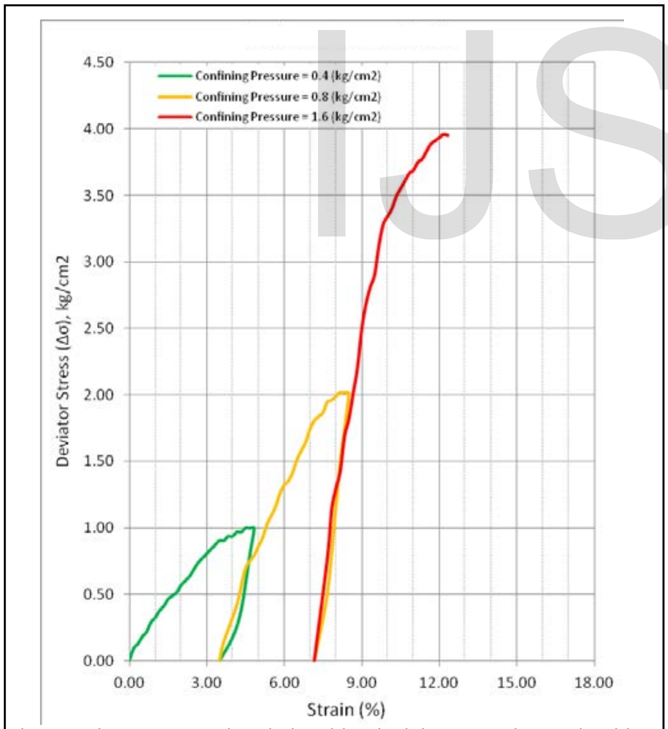

Fig. 11. The stress-strain relationship triaxial test result 60% boulder.

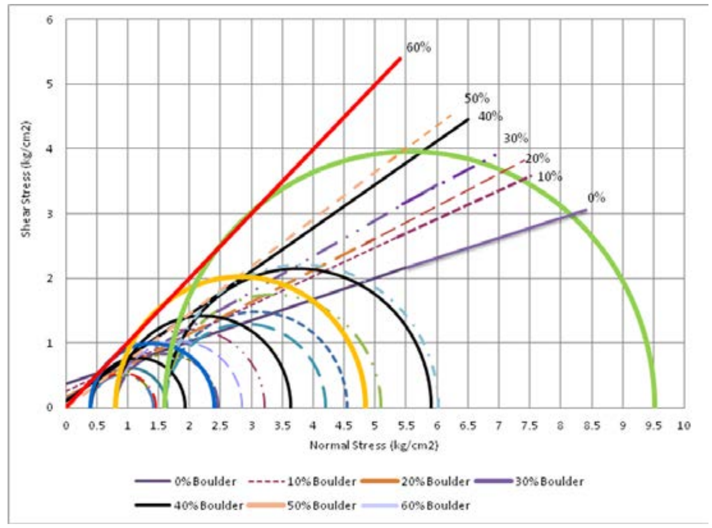

Fig. 12. Shear strength data of bouldery soils increase as a percentage increase of 0% - 60% boulder by using the large-scale triaxial test in a calibration chamber.

TABLE 2.
Shear strength parameter of bouldery soils obtained from the large-scale triaxial test on calibration chamber analysis using the Mohr-Coulomb criterion.

Shear strength of bouldery soils							
Boulder (%)	0%	10%	20%	30%	40%	50%	60%
c (kg/cm^2)	0.37	0.25	0.18	0.13	0.08	0.02	0.00
φ (°)	19.00	24.00	27.00	31.00	33.85	39.50	45.10

The summary of the shear strength parameters of bouldery soils can be shown on the graph as in Figure 4.13 and Figure 4.14.

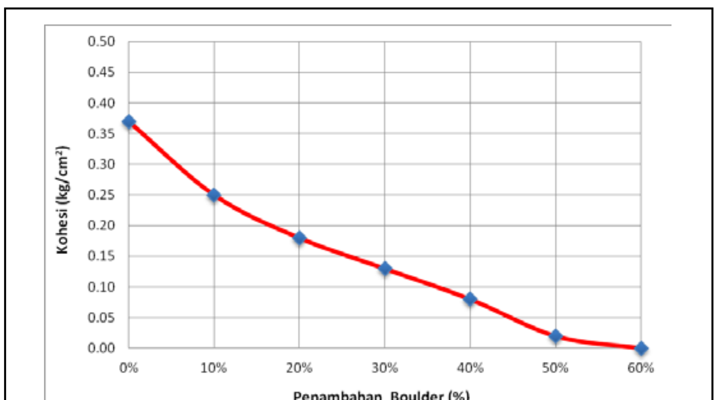

Fig. 13. Effect of boulder composition by adding the percentage of boulder to the cohesion (c) bouldery soils.

7.4 Influence Of Adding The Percentage Of A Boulder To Shear Strength Bouldery Soils

The effect of boulder composition with the addition of boulder percentage from 0% to 60% to the value of internal friction angle and the value of cohesion "Bouldery Soils" there is a significant influence.

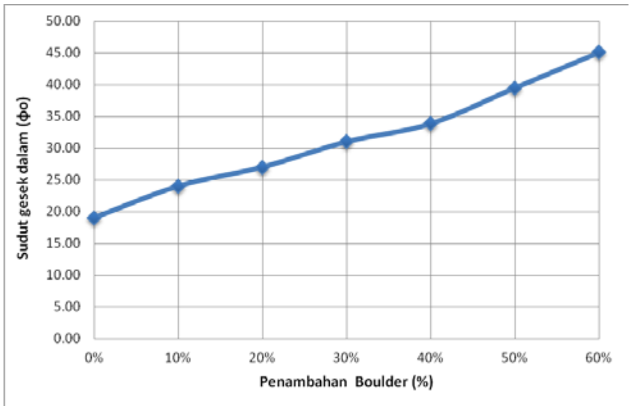

Figure 14. Effect of boulder composition by adding the percentage of boulder to the internal friction angle (φ) bouldery soils.

8 Discussion

The multistage triaxial testing procedure applied to the calibration chamber can be used to evaluate the shear strength of bouldery soils. The axial strain during a failure in the bouldery soils material increases with increasing confining stress. The friction angle value in (φ) bouldery soils decreases with increasing confining stress (σ_3). The effect of boulder composition by adding the percentage of the boulder from 10%, 20%, 30%, 40%, 50% and 60% boulder to the internal friction angle (φ) and cohesion value (c) bouldery soils is significant.

In the test sample without boulder (0% boulder), the internal friction angle of φ is 19°, this condition describes the mixture of sand and gravel which is compacted in the chamber is still at very low (loose). The increasing percentage of a boulder, in the bouldery soils material, the internal friction angle (φ) is increasing at 60% boulder with φ value of 45.10°. The change in the number of boulders in the percentage of a boulder in bouldery soils material influences the interlocking characteristics between the boulder grains with the sand and gravel soils in the soil bouldery material so that the internal friction angle value increases with the percentage of the boulder.

9. Conclusion

From the results of research that has been done, can be drawn the conclusion as follows:

1) Determination of design parameters for bouldery soils can be done by relying on triaxial tests in the laboratory using calibration chamber. By using the reconstituted sample triaxial test can be done in the laboratory with various variations of the test to obtain the shear strength parameters of bouldery soils.
2) Triaxial test results show that the shear strength of bouldery soils is strongly influenced by the composition and percentage of a boulder in it, both in the stress-strain distribution and the failure pattern that occurs. The stress-strain behavior of bouldery soil is quite different from the pure soil sample especially in the large percentage of a boulder (more than 10%).
3) On the triaxial test results, the Act in calibration chamber shows the effect of adding boulder percentage to the shear strength of bouldery soils. The effect of boulder composition by adding the percentage of the boulder from 10% to 60% to the value of the internal friction angle, φ (°) in the range 19° to 45.10°. While the bouldery soil cohesion value showed a decreasing cohesion value, although relatively small from c = 0.37 kg/cm² to zero. Data analysis of triaxial bouldery soils using Mohr-Coulomb criteria showed that the addition of boulder percentage in bouldery soil material resulted in higher internal friction angle and cohesion (c) decreases.

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References

[1] Rahardjo, P.P., (2014) Soil Investigation Report of Cikopo Palimanan (CIPALI) Tol Road Project; PT. Lintas Marga Sedaya, PT. Maratama Citra Mandiri in Final Report PT. GEC.
[2] Putra, S. (2015) Study of Boulder Effect Study On Slope Stability Using Three Dimensional Finite Element Methods, Skripsi Parahyangan Chatolic University.
[3] Sugianto, A. (2016) Slope Stability Analysis On Boulderly Soil, Tesis Parahyangan Chatolic University..
[4] Hencher S.R., Martin RP (1982) The description and classification of Weathered rocks in Hong Kong for engineering purposes. Proceedings of the 7th South East Asian Geotechnical Conference: Vol.1 125-142.
[5] Lindquist, E.S. (1994), The Strength and Deformation Properties of Melange; PhD dissertation, Univerity of California, Berkeley, (Dept.Civil Engineering); Distributed from Medley, E.W. with the permission of Dr.Eric S. Lindquist, P.E.
[6] Medley, E.W., (1994); The engineering characterization of melanges and similar block-in matrix rocks (bimrocks); PhD dissertation, University of California at Berkeley; publ. University Microfilms International, UMI Dissertations Service, Ann Arbor, Michigan.
[7] Wen-jie Xu, dkk., (2011), Study on the shear strength of soil–rock mixture by large scale direct shear test, International Journal of Rock Mechanics & Mining Sciences 48 (2011) 1235–1247.
[8] Wang Jiang-ying, Cao Wen-gui (2013) Large-scale direct shear tests on soil-rock aggregate mixture under complicated environment based on orthogonal design. Chin J Geo Eng 35(10):1849-1856.
[9] Li Yayong, dkk. (2014) Shear Strength and Failure Characteristics Identification of Soil-Rock Mixture, EJGE Vol. 19 [2014], Bund. W.
[10] A.Aghaei Araei, at all. (2010), *Large*-scale Triaxial Testing and Numerical Modeling of Rounded and Angular Rockfill Materials, © Sharif University of Technology, arvhive of SID, transaction A: civil engineering, vol.17,No.3,pp 169-183.
[11] Holden, J.C., (1991). Calibration Chamber Testing, Proceedings Of The First International Symposium On Calibration Chamber Testing/Isocctl, Potsdam, New York / 28-29 June 1991.
[12] Ghionna, V.N. and Jamiolkowski, M. (1991), Influence of Time on the Behaviour of Granular Soils, Panel Discussion – Session 1b, Proc.X ECSMFE, Florence.
[13] Craig, R.F., (1989), Craig's Soil Mechanics, Seventh edition 2004

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