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Agus Darmawan Adi
Teuku Faisal Fathani

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KATA PENGANTAR

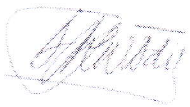
Puji syukur kami panjatkan ke hadirat Tuhan YME, karena berkat rahmat-Nya kami dapat menyelesaikan prosiding SEMINAR NASIONAL GEOTEKNIK 2014.

Kami mengucapkan terima kasih kepada semua pihak yang telah membantu sehingga prosiding ini dapat diselesaikan sesuai dengan waktunya. Prosiding ini masih jauh dari sempurna, oleh karena itu kami mengharapkan kritik dan saran yang bersifat membangun demi kesempurnaan prosiding ini.

Semoga prosiding ini memberikan informasi bagi masyarakat dan bermanfaat untuk pengembangan ilmu pengetahuan bagi kita semua.

Atas kerjasama yang baik dan bantuan dari semua pihak dalam menyukseskan SEMINAR NASIONAL GEOTEKNIK 2014, panitia mengucapkan terima kasih.

Yogyakarta, Juni 2014
Ketua Panitia



Ir. Agus Darmawan Adi, M.Sc., Ph.D.

Daftar Isi

Evaluation of Factors Affecting Shear Strength of Cohesive Soils

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ABSTRACT: This paper evaluates the effects of normal load variation, consolidation time and shearing rate on the shear strength obtained by direct shear tests on cohesive soil. The soils were sampled at three different locations at depths of 2 to 3 m such that the in-situ overburden pressures were about 30 – 40 kPa. The normal pressures used in the test are: 6, 12.5, 25, 50, 100 kPa; while the shearing rates are: 0.1, 0.5, and 1.0 mm/minutes. The samples were consolidated prior to shearing in the direct shear apparatus. Preliminary test indicated that the average time required for consolidating the sample before shearing is less than 10 minutes. Test results show that normal load variations as well as shearing rate introduce variations in the shear strength obtained by direct shear test. Therefore, it is important that the normal load used for this type of test be comparable with the in-situ overburden pressure and the shearing rate should be calculated based on the time of consolidation prior to shearing.

Keywords: direct shear test, consolidation time, normal load, shearing rate, shear strength

1 INTRODUCTION

One of the oldest methods for obtaining shear strength parameter of soil is direct shear test. The test is usually selected for practical reason *i.e.* the procedure is simple and quick. The test requires a small size of sample. Furthermore, K_o consolidation can be achieved automatically, and the shear plane represents the actual failure plane (Hanzawa, 1992) at some location along a failure plane (point 2 in Figure 1). As shown in the figure, soil element at point 1 will fail due to compression, element at point 3 fail due to tension, while element at point 2 will fail due to shearing at horizontal plane.

In laboratory, the failure of soil at point 1 can be modeled by Triaxial Compression (TXC) test and failure at point 3 can be modeled by Triaxial Extension (TXE) test while failure at point 2 is modeled by Direct Shear (DS) test. Both Triaxial Compression test and Direct Shear test is relatively easy to perform but Triaxial Extension test involves a very tedious procedure and analysis. Hanzawa pointed out that the actual shear strength along the failure plane can be approximated by the average of the results of TXC, TXE, and twice the shear strength obtained by DS, In the absence of the results of triaxial extension test, the shear strength can be approximated by the shear strength obtained by direct shear test.

The direct shear test was originally developed for cohesionless soil. However, modifications to the equipment have enabled the test to be applicable for cohesive soil. The modifications were explained by Takada (1993). Currently, the procedure for direct shear test on cohesive soil can be referred to ASTM D3080-04.

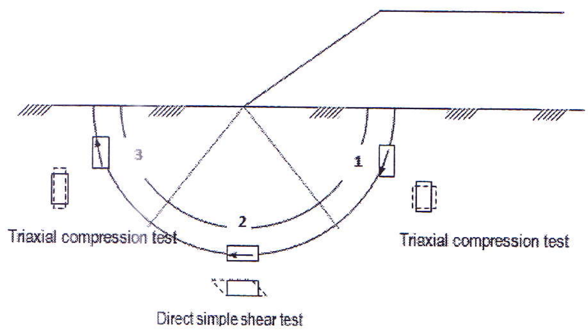

Figure 1. Failure condition of soil element based on the location in failure plane.

The condition of the shear test has to be determined based on critical condition for failure *i.e.*: short term or long term. Short term failure can be modeled by testing the sample in Unconsolidated Undrained (UU) condition while long term failure can be modeled by Consolidated Undrained (CU) or Consolidated Drained (CD) depending on the type of soil. The direct shear test for cohesive soil should be conducted in CU or CD condition (Hanzawa, 1993; Bardett, 1997). In this condition, the sample is back-pressurized by normal load equal or slightly higher than overburden pressure to send the soil to its original condition and to cause consolidation to take place. Rate of 1 mm/min is suitable for shearing in CU test (Bardett, 1997) but much slower rate is required for CD test. In this type of test, the rate of shearing depends on the permeability of the soil. Ladd and Fott (1974) suggested for a sample of width 60 mm, the rate of shearing should be between 0.06 to 0.6 mm/min. A simple calculation was suggested based on the data obtained during consolidation stage (Bardett, 1997). The data was analyzed by Taylor method to obtain t_{90} in minutes. Time required to reach failure was empirically estimates as $t_f = 11.7\ t_{90}$. The estimated strain to reach failure of the soil sample (δ) depends on the type of clay. For hard clay, $\delta = 1 - 3$ mm, stiff clay, $\delta = 3$ mm, while for plastic clay, $\delta = 8 - 10$ mm. Thus the rate of shearing $v = \delta / t_f$ mm/min.

2 METHODOLOGY

The study was performed on undisturbed clay samples collected from three locations in UNSRI Campus Bukit Besar Palembang. Six samples were collected from two boreholes at depths between 2 and 3 m from each location, hence 18 sets of data were used in this study.

Preliminary tests including sieve analysis and Atterberg limit tests were carried out to determine the soil classification.

Procedure suggested by ASTM D3080-04 for direct shear test under CU and CD conditions was followed. The direct shear apparatus used for this study is shown in Figure 2.

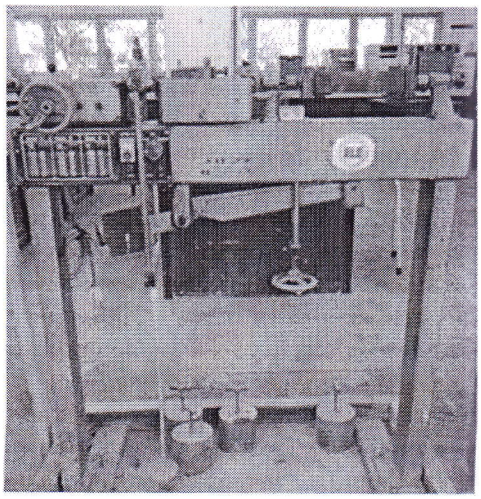

Figure 2. Direct shear apparatus used in this study

The samples used for the test are of diameter 63.5mm and height of 20mm. Consolidation stage was performed under load slightly higher than the in-situ overburden pressure to determine the time required for consolidation of each soil.

Various shearing rates (0.1, 0.5 dan 1.0 mm/min) were applied upon completion of consolidation process to investigate the effect of shearing rate on the shear strength.

The shear test was performed under normal pressures of 6, 12.5, 25, 50, 100 kPa. Different normal load combinations were considered from the test results to investigate the effect of load combination on the shear strength of clay samples. Set of three load that give consistent results in term of shear stress were selected and these loads can be compared with the overburden pressure.

For comparison purposes, similar tests were performed on sand. The samples were formed in direct shear box with identical relative density. Normal pressures of 6, 12.5, 25, 50, 100 kPa were used with shearing rate of 0.1 mm/ min and 1 mm/min.

3 RESULTS AND ANALYSIS

3.1 *Soil samples and Properties*

The samples were retrieved from three locations by open drive (OD) sampler from six boreholes at depths of 2 – 3 m. Ground water table was located at 1 m below ground surface, hence; all samples were located below the ground water table. The overburden pressure calculated for these soils are in the range of 30 to 40 kPa.

Table 1 show the properties and classification of the soil used in this study. The soils from each locations are quite uniform, hence; average values can be used for this presentation. All soils are classified as highly plastic clay (CH).

Table 1. Properties of clay used in this study

Properties	**Soil 1**	**Soil 2**	**Soil 3**
Specific Gravity (G_s)	2.71	2.65	2.58
Passing # 200 (%)	53.45	60.66	90.08
Liquid limit (LL%)	59.00	55.70	54.50
Plasticity Index (IP%)	37.17	33.74	21.80
Classification (USCS)	**CH**	**CH**	**CH**
Degree of Saturation (%)	98.95	98.09	98.55
Dry unit weight (kN/m^3)	12.70	15.00	12.57
Sat unit weight (kN/m^3)	17.84	19.53	17.52
Overburden pressure (kPa)	33.74	38.81	32.78

Results of Direct Shear Test on Clay

The test under CU and CD conditions required that the samples to be consolidated before shearing. Preliminary results of consolidation stage were analyzed by Taylor's (square root of time) procedure. The results show that an average of 8.35 minutes (t_{90}) is required for the dissipation of pore-water pressure in all soil samples. This figure is slightly lower than previous finding by Hanzawa (1993) on Japan's soil whereby he suggested 10 minutes consolidation time before shearing. Thus, the subsequent tests were performed with consolidation time of 10 minutes.

The direct shear tests were carried out for variation of normal pressures of 7.5, 15, 30, 60, 120 kPa and sheared at 0.1, 0.5 and 1.0 mm/min. The rate of 1 mm/min was the rate suggested for CU test (Bardett, 1997) while the slower rate was determined based on the results of consolidation stage. Based on the t_{90} value obtained in the consolidation stage, the rate for CD test for the soil samples used in this study i.e. clay of high plasticity, can be approximated as 0.1 mm/min.

Figure 2 shows the stress-strain curves obtained for shearing rate of 0.1 mm/min and 1 mm/min under various normal load. In general, higher failure stress was reached under higher shearing rate but at higher strain. At shearing rate of 1 mm/min, failure was reached at strain of 15 to 20% while at lower shearing rate (0.1 mm/min), failure was reached at strain of 2 to 3 % indicating that the sample was not disturbed. At higher shearing rate, the soil did not have the time to adjust with strain and a higher shear stress was required to overcome the inter-particle contact. This is the reason why direct shear test give higher ϕ value for clay.

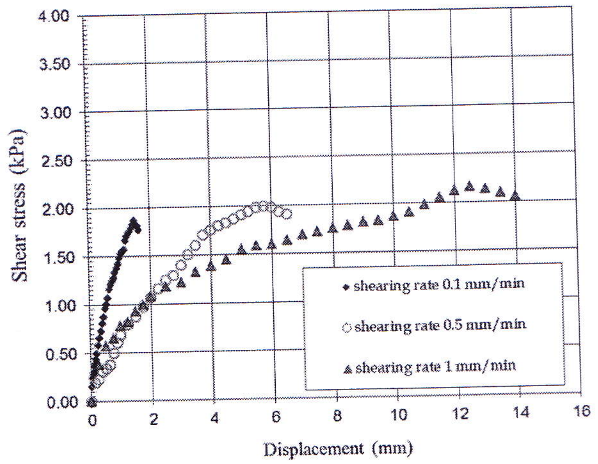

Figure 3. Stress-strain curve for identical sample under different shearing rate

Figure 4 shows the graph of maximum shear stress vs. normal stress. It can be seen that some points form a straight line while others are off. The points forming a straight line are actually represents the load in the vicinity of in-situ overburden pressure of the sample because with this load combination the soil has not reached failure under normal load. For all samples, overburden pressure varies between 30 and 40 kPa, thus normal pressure of 12.5, 25, 50 kPa on direct shear test is appropriate. The results also indicate that the maximum shear stress reached under normal pressure of 6 kPa was relatively high while shear stress reached under normal pressure of 100 kPa is relatively low as compared to the maximum shear stress achieved for other loads. This might be due to the fact that under the pressure of 100 kPa, the sample has failed under normal load.

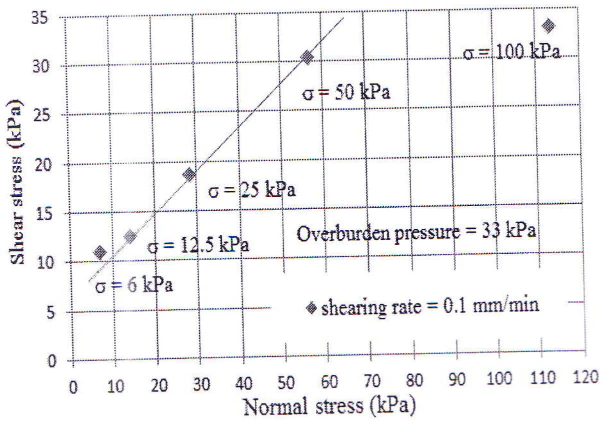

Figure 4. Typical results of direct shear test under different combination of normal load

Comparisons of shear strength parameters obtained from direct shear test on clay soil under different shearing rate for a set of data is shown in Figure 5. It can be seen from the figure that higher shearing rate results in higher shear strength both in terms of cohesion as well as angle of internal friction.

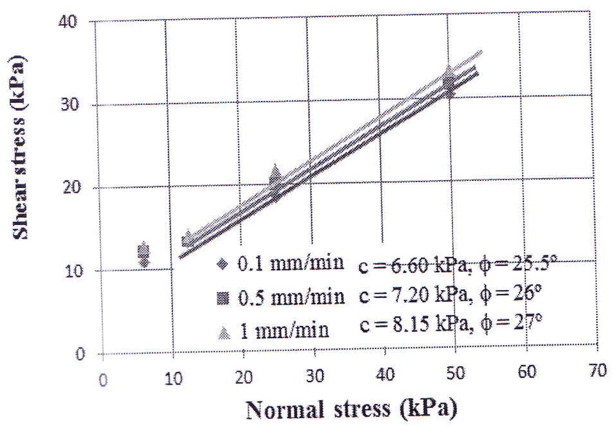

Figure 5. Effect of shearing rate on shear strength parameters of clay soil.

3.3 *Comparison with the behavior of sand*

Direct shear test was actually aimed for shear strength testing on cohesionless soil or sand. Therefore the same test was performed on sand for control of the behavior. In this case, sand was used formed in the shear box with identical relative density. The results are presented in Figure 6. It can be inferred from Figure 6 that for sand, the load variation and shearing rate does not give significant influence on the test results.

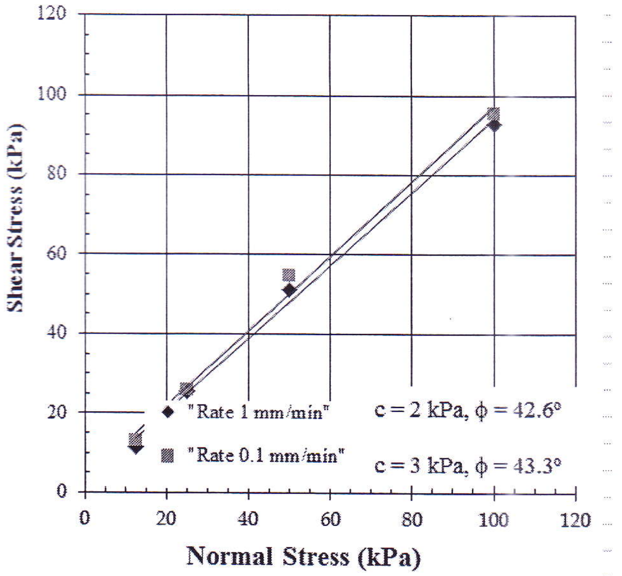

Figure 6. Effect of load combination and shearing rate on shear strength parameters of sand

4 CONCLUSIONS

It can be concluded from the study that the shear strength obtained from direct shear test on clay samples (CH) is affected by the consolidation time before actual shearing was implemented. Shearing rate is affected by soil permeability. Preliminary analysis on consolidation stage showed that the average consolidation time is 10 minutes which yields in the shearing rate of about 0.1 mm/min for testing in CD condition.

Higher shearing rate resulted in higher maximum shear strength, hence internal friction angle is higher. This is the reason why direct shear test performed under CU condition with recommended rate of 1 mm/min give higher ϕ value for clay. Never the less, the final results are not significantly scattered. The average shear strength parameters of clay is c = 6.6 – 8.15 kPa and ϕ = 25.5 – 27°.

Normal load combination should be determined based on overburden pressure. The normal load much higher that the overburden pressure will cause the soil to fail under the normal load itself, thus the maximum shear strength obtained from the test is lower than the actual strength. On the other hand, too low normal load will not be able to mobilize failure, hence the maximum shear stress will be reached at much higher strain.

The load variation and shearing rate give insignificant effect on the direct shear test on cohesionless soil or sand. The shear strength parameters of the sand used in this study are: c = 2.5 kPa and ϕ = 43°.

The above conclusion is made for the soil under study which is common in Palembang. The results in term of consolidation time and shearing rate may be different for soil from other locations or of different classification.

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