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The Friction Coefficient of Cohesive Soils and Geotextile: An Approach Based On the Direct Shear Test Data

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Abstract

The soil reinforcement designing by using geotextile requires the friction coefficient of soil-geotextile interface, both granular and cohesive soils. For cohesive soils, this coefficient was usually defined by [⅔ tan ¤]. *Is this approach efficient enough or conservative? This paper presents an approach to determine the friction coefficient of soil-geotextile interface based on the empirical data from some researchers. It was used direct shear test data on cohesive soil-geotextile interfaces. Result show that the friction coefficient of soil-geotextile interface higher than the value of* tan ¤. *It was also proved by the interface friction angle* ¢ *tend to higher than the soil internal friction angle* ¤. *Hence, the approach by* [⅔ tan ¤] *would be yield excessive safety design, which the safety factor would be added for soils and geotextiles. The new approach in determining the interface friction coefficient was conducted by using direct relationship between interface friction coefficient and soil internal friction angle.*

Keywords: *cohesive soils, direct shear test, friction coefficient, soil-geotextile interface, geotextiles*

1. INTRODUCTION

In the designing of soil reinforcement construction using a geotextile reinforcement material, in addition to known properties of the soil and geotextile materials, is also required behavior of the interaction between soil and geotextile. Interaction of soil and geotextile can be expressed by a coefficient called interface friction coefficient, «. The problem is, not every design can be conducted the testing to determine this coefficient, so often the value of the friction coefficient of interface is taken as an approach value. Approach value of the friction coefficient of soil-geotextile interface is often used for « = tan ¾ ~⅔ ¤, where ¤ is the angle of soil internal friction.

However, whether such approaches can be used for all types of soil, whereas granular soil and cohesive soil having different properties. Is this approach efficient enough or conservative? Puri (Puri, 2003) has proposed a determination of the friction coefficient of sand-geotextile interface which is relatively efficient compared with the approach that is often used. How does the friction coefficient of cohesive soil-geotextile interface, will be discussed in this paper? This study aims to determine the coefficient of friction between the cohesive soil and geotextile, and approaches in determining the friction coefficient of the cohesive soils-geotextile interface.

2. LITERATURE REVIEW

Geometry, roughness and stiffness of reinforcement, as well as the types and soil conditions are the main factors that influence the characteristic of friction between soil and reinforcement (Puri, 2003; Mitchell & Villet, 1987; Makiuchi & Miyamori, 1988; Puri, et al., 2003). Interaction between soil and reinforcement is generally stated as the apparent friction coefficient, «*. This coefficient can be calculated by using Equation 1.

«* = tan ¢ (1)

Where ¢=is the soil-geotextile interface friction angle.

Two types of testings can be done to determine the coefficient of friction; they are the direct shear tests and pull out tests. Therefore, if both tests are not available, then the general point of friction angle between soil and geotextile (¢) is taken the approach of assuming that ¢ is lower than the soil internal friction angle (¤), for example ¢ = tan^{-1} (⅔ tan ¤) (Mitchell and Villet, 1987) or sometimes used ¢ = ⅔¤ (Mitchell and Villet, 1987; Das, 1995), for all woven and non woven geotextiles tan ¢ = 0,60¼1,00 tan ¤′ (Williams and Houlihan, 1987), rough woven geotextiles tan ¢ = 0,80¼1,00 tan ¤′, granular soil-solid polymer sheet tan ¢ ù 0,6 tan ¤′ (Jewell, 1996), and tan ¢ = ⅔¼¾ tan ¤ which is generally taken tan ¢ = ⅔ tan ¤ for geotextile and tan ¢ = ¾ tan ¤ for geogrid (Suryolelono , 2000), so that in certain cases the value of these approach to be conservative.

Puri (2003), through his research by using well rounded beach sand and non woven geotextile and data from other researchers from the direct shear test, proposed the Equation 2 to predict the apparent friction coefficient at the sand-non woven geotextile interface.

«* = 0,00004¤'^{2} + 0,0158¤' (2)

Since the first term of Equation 2 does not give significant results, and then the equation can be written as

«* = 0,0158¤' (3)

Equation 3 shows the prediction of the friction coefficient only required soil internal friction angle, ¤'. This equation can be used in case of testing on the interface is not available.

Puri & Wanim (2003) compared the friction coefficient of Pekanbaru clay-geotextile interface with friction coefficient values calculated using Equation 2. Provided that the calculated coefficient closes to the friction coefficient of test results, both for the reinforcement in the form of woven and non woven geotextile. Nevertheless, the conclusion is still very limited because of soil used only one type.

3. RESEARCH METHODOLOGY

The research was conducted by using direct shear test data for the interface of cohesive soil and geotextile. Data are obtained from various sources that have been published, they are Williams and Houlihan (1987), Puri and Wanim (2003), Gource (1982), Garbulewski (1990), Mahmood and Zakaria (2000), and Rifa'i (2004). The type of shear test is the laboratory direct shear test. The steps undertaken in this study include: collection and sorting of data, analysis and interpretation, preparation of research reports, and publication of research results.

Soil internal friction angle data and soil-geotextile interface friction angle depicted in graphic form and in the same way for the angle of soil internal friction and friction coefficient of soil-geotextile interface. Tabulation of data and drawing graphs was using Microsoft Office Excel. Statistical tests performed included the *t* test, correlation test and regression test, using SPSS 12 application program.

4. RESULTS AND DISCUSSIONS

Soil Types and the Interface

Based on data from various researchers, it can be resumed that the soil types are clay, silt, sandy clay, silty clay, and kaolinite. Woven and non woven geotextiles manufactured from various companies was used. Direct shear box size used by all researchers are also vary from the smallest 100 mm × 100 mm up to the largest size of 3000 mm × 300 mm. Summaries of soil types and soil-geotextile interfaces are given in Appendix A.

Relationship of Interface Friction Angle and Soil Internal Friction Angle

Recapitulation of interface friction angle is presented in Appendix B. Relationship of soil-geotextile interface friction angle ¢ and the soil internal friction angle ¤ is given in Figure 1. Interface friction angle ¢ tend to be higher than the soil internal friction angle ¤, as well as to the value of ⅔ ¤. This suggests that the frictional resistance at the interface is greater than the soil one. Approach value [tan ¢ = ⅔ tan ¤] which is commonly used will always be smaller than the real resistance. Figure 2 shows that the ratio ¢/¤ tend to be higher than 1.0. The lowest, the largest and the average value of ratio ¢/¤ are 0.87; 6.97 and 1.67 respectively.

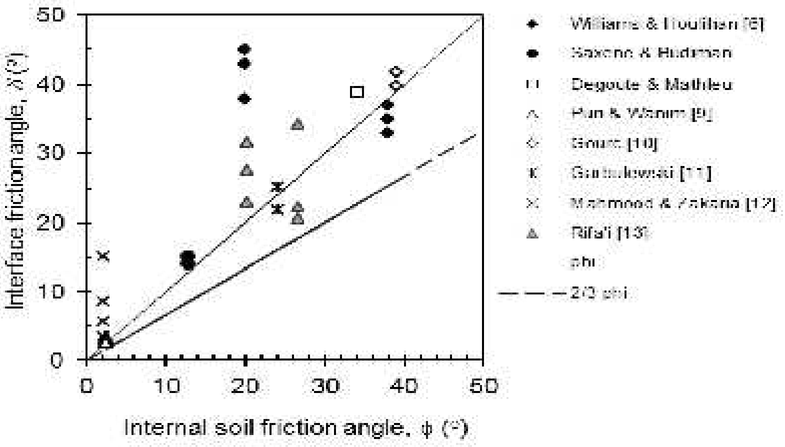

Figure 1. Relationship of interface friction angle ¢ and the soil internal friction angle ¤

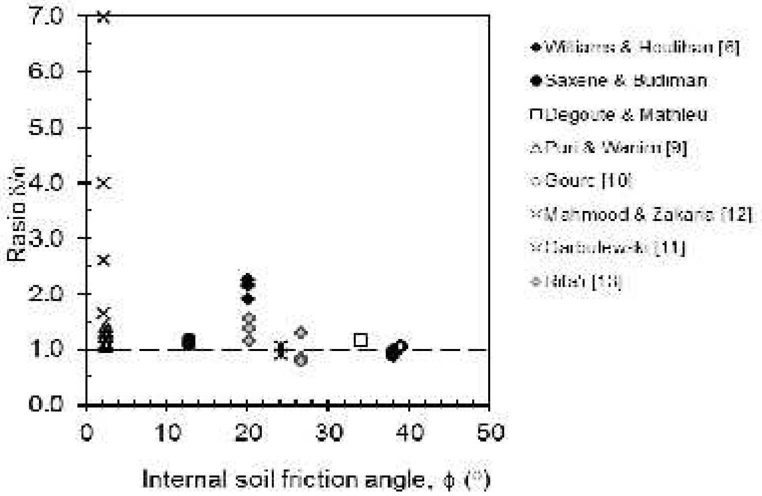

Figure 2. Rasio ¢/¤ vs. the soil internal friction angle ¤

Relationship of Interface Friction Coefficient and Soil Internal Friction Angle

Figure 3 shows the relationship of interface friction coefficient « with soil internal friction angle ¤. Seen that the interface friction coefficients tend to be above [⅔ tan

¤] and increase with increasing soil internal friction angle. Interface friction coefficient values range from 0.045 to 1.00. From the statistical tests, the soil internal friction angle has standard deviation of 14.87° with a mean of 16.08° and the average standard error 3.04°. The coefficient of friction has a standard deviation of 0.35 with a mean of 0.40 and the average standard error 0.07. The *t* test results for one-sided test and two-sided test was qualified, where *t* calculation > *t* table. The probability of sig. is 0.000 < 0.05.

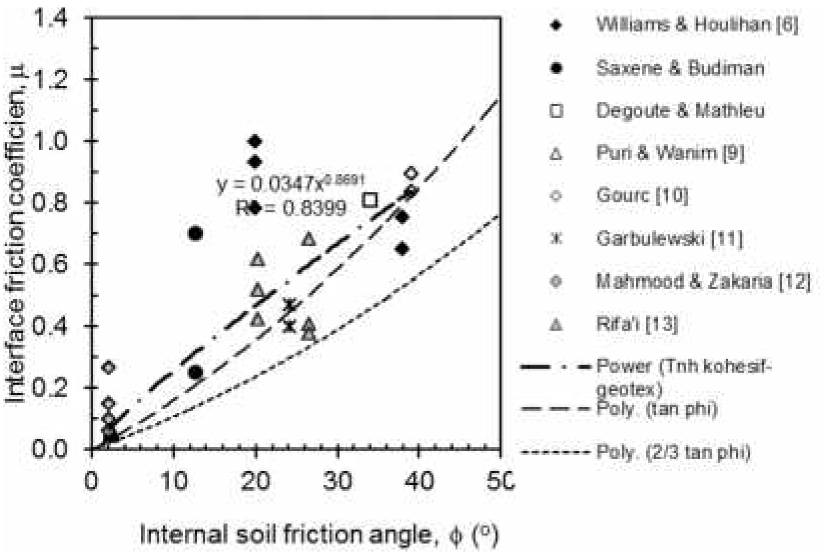

Figure 3. Interface friction coefficient « *vs.* the soil internal friction angle ¤

Correlation of interface friction coefficient and the soil internal friction angle is significant at the level of confidence 99%. It is based on Product moment correlation test (Pearson), Spearman rank and Kendall tau. Furthermore, the relationship of « vs. ¤ is obtained as Equation 4.

« = 0,034¤^{0,869} (4)

The Equation 4 has a correlation coefficient R = 0.858. It means the «-¤ relationship is 85.8%. The coefficient of determination R^2 = 0.838 (or R^2 = 0.839 from MS Excel analysis), which means 83.8% of the variation that occurs is caused by soil internal friction angle or soil frictional resistance, while the remaining 16.2% due to something else. Based on the *F* test (Anova) was obtained *F* calculation > *F* table and the probability of sig. < 0.05. It is also found the satisfying the *t* test and significance < 0.05. Regression models are not susceptible to heteroskedastisity interference and multicollinearity (not random), but having otocorrelation. So in general the Equation 4 is acceptable to model the relationship « vs. ¤.

Interface Cohesion

Figure 4 shows the relationship of cohesive soil-geotextile interface cohesion (adhesion) c_a with soil cohesion *c*. Seen that the interface cohesion tends to decrease with increasing soil cohesion, so that the adhesion factor will be decrease, too. The curve for approache c_a = ⅔ *c* which is often taken in the desiging is also shown. It turns out that there is trend data contrary to the approach. Presumably the failure that occurred was not on the interface of soil-geotextile but rather in the soil near the interface.

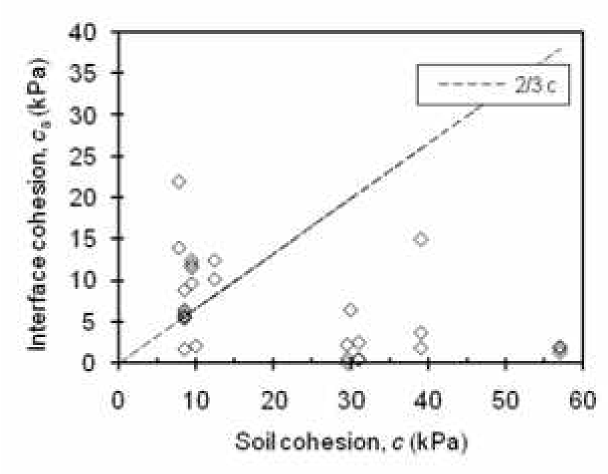

Figure 4. Relationship of c_a vs. c

Plastisity Index Effects to Interface Shear Strength Parameters

Shear strength parameters of the soil interface are the interface cohesion c_a and interface friction angle ¢. The relationship of interface friction angle ¢ with plasticity index *PI* of cohesive soil is shown in Figure 5. The interface friction angle tends to decrease with increasing *PI*. This is due to soil with a higher *PI* resulted in decreasing of friction between soil particles; here the role of cohesion tends to be more dominant. This phenomenon can lead to the failure tends to occur in the soil near the interface.

Figure 6 shows the relationship of interface cohesion and *PI*. It appears that the interface cohesion tends to increase with increasing *PI*. This means that cohesion in cohesive soil is an important part to the formation of bond resistance in the interface. It is also concluded by Mahmood & Zakaria (2000). Therefore, interface cohesion should be taken into account in soil reinforcement design. Relationship c_a vs. *PI* in the cohesive soil-geotextile interface can be expressed as

$$c_a = 0,2316PI + 0,5773 \qquad (5)$$

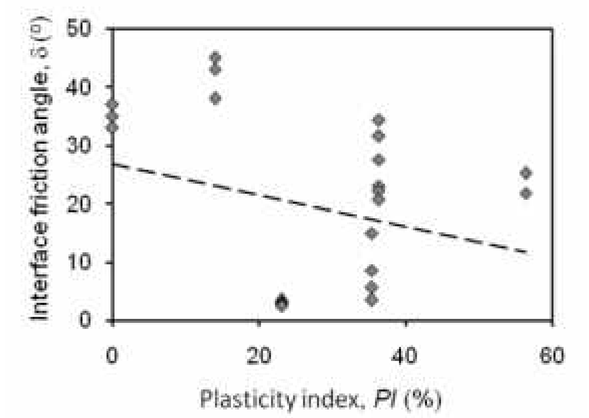

Figure 5. Relationship of interface friction angle ¢ with plasticity index *PI*

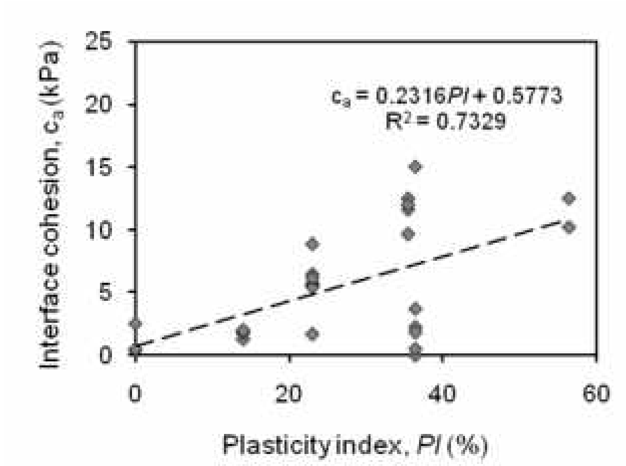

Figure 6. Relationship of cohesion of cohesive soil-geotextile interface and *PI*

5. CONCLUSIONS

The research results the value of the friction coefficient of cohesive soil-geotextile interface ranged from 0.045 to 1.00. Coefficient of interface friction « tends to be higher than tan ¤. This is also evidenced by the value of interface friction angle ¢ tends to be higher than the soil internal friction angle ¤. Therefore, determination the interface friction coefficient with the commonly approach of « = ⅔ tan ¤, will produce a very safe design (conservative), considering the safety factor is also given on the parameters of the soil, and geotextile tensile strength.

Equation 4 can be used to estimate the friction coefficient of cohesive soil-geotextile interface in case there is no available testing of the interface. The proposed approach in determining the friction coefficient of cohesive soil-geotextile interface should be tested with numerical analysis in a case of soil reinforcement structure using geotextile.

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Appendix A. Recapitulation of Cohesive Soil-Geotextile Interfaces

No.	Researchers	Description of Interface Area and Others	Type of Geotextile	δ (°)	c_a (kPa)	Soil Descriptions	ϕ (°)	c (kPa)
1	Williams & Houlihan (1987)	Area 30,5 cm x 30,5 cm. Soil two sides,	Typar 3401	38	1,3	Gulf Coast clay (CL), LL= 42%, PL=28%, PI=14%, w_{opt}=15,5%.	20	57
			Trevira 1155	45	1,8			
			Nicolon 900-M	43	2,0			
			Typar 3401	33	0,4	Silt Glacial till (ML), LL=47% PL=17%, w_{opt}=7,5%.		
			Trevira 1155	37	0,5		38	31
			Nicolon 900-M	35	2,5			
2*	Saxene & Budiman	Area 25 cm x 25 cm. Soil two sides, depth 1,27-7,6 cm displacement rate 0,75 mm/min normal stress 72-288 kPa.	Celenese 800X	14	14	45%DS, 5% bentonite, 50% kaolonite, saturated	12,8	7,8
			Monsanto C-34	15	22		12,8	
3*	Degoute & Mathleu	Area 3 x 0,3 m, soil depth 15cm, normal stress 200-1200 kPa, soil one side	Geotextile	39		Sandy clay, PL= 13%	34	50
4	Puri & Wanim (2003)	Area 10 cm x 10 cm soil thickness 1,0 cm, soil one side. Displacement rate 0,25 mm/menit	Non woven:			Pekanbaru clay,CH LL= 68,56%; PL= 45,56%; PI= 23%, G_s = 2,66. coloid (particle <2μm) 75% very fine particles (<0,001 mm) 35%	2,46	8,52
			Polyfelt TS 30	3,5	5,73			
			Polyfelt TS 50	3,22	5,54			
			Polyfelt TS 60	3	6,47			
			Polyfelt TS 70	3,03	8,88			
			Woven: Hate Reinfox					
			HT385-130XT	2,71	1,69			
			HT385-185XT	2,56	5,43			
			HT385-250XT	2,62	6,16			
5	Gourc (1982)	Area 40 cm x 25 cm. Normal stress 2-30 kPa. Soil two sides, depth 2x10 cm	BD 340	41,8	6,46	saturated clay (undrained)	39	30
			BD 340	39,9	2,09		39	10

Appandix A. ***Continued***

6	Garbulewski (1990)	Area 100mm x 100mm, soil one side, rate 0,1 mm/min conventional	Road geotextile-1000 (needle punched polypropylene)	μ = 0,47 (25,2)	10,2	Mud (organic mud), classified as silty clay with 2% of sand 77% silt, 21% clay.13% organic matter, w_n=54%, LL=90%, PL=33,7%, PI=56,3%, s_u=12 kPa, γ=15 kN/m^3	24,2	12,4
			Filtration geotextile J/Sm 5214 (polypropylene & polyamid)	μ = 0,4 (21,8)	12,5			
7	Mahmood & Zakaria (2000)	Area 10 cm x 10 cm soil one side. Displacement rate 1,27 mm/menit.	Non woven needle punched:			Organic clay, γ = 1,356 g/cm^3 w_n=115,41%; organic content 14,70%. PI = 35,4%; Undrained Gs = 2,54	2,15	9,44
			TS550	5,6	12,5			
			TS600	8,6	11,6			
			TS700	14,98	9,66			
			TS750	3,5	12,0			
8	Rifa'i (2004)	Standard direct shear	Soaked condition:			Wonosari clay, CH γ = 1,775 g/cm3, Gs=2,673 LL= 72,01%; PL= 35,65%; PI= 36,36%. OMC=37,64; MDD=1,292; fine grain 81,36%	20,2	29,6
			Non-woven TS600	27,5	2,24			
			Non-woven R206	31,6	0			
			Woven BW250	23,0	0,53			
			Unsoaked condition:				26,6	39,1
			Non-woven TS600	34,3	1,85			
			Non-woven R206	22,2	15,0			
			Woven BW250	20,7	3,69			

* see William & Houlihan (1987)

Appandix B. Soil Internal Friction Angle and Interface Parameters

No.	Researchers	Type of Interface	Frcition angle		Friction coefficient, «
			Soil internal, ¤' (^{o})	Interface, ¢ (^{o})	
1	Williams & Houlihan (1987)	Gulf Coast clay-Typar 3401	20	38	0,781
		Gulf Coast clay-Trevira 1155	20	45	1,000
		Gulf Coast clay-Nicolon 900-M	20	43	0,933
		Silt Glacial till-Typar 3401	38	33	0,649
		Silt Glacial till-Trevira 1155	38	37	0,754
		Silt Glacial till-Nicolon 900-M	38	35	0,700
2*	Saxene & Budiman	Kaolinite-Celenese 800X	12,8	14	0,249
		Kaolinite-Monsanto C-34	12,8	15	0,268
3*	Degoute & Mathleu	Sandy clay-Geotextile	34	39	0,810
4	Puri & Wanim (2003)	Pekanbaru clay-Polyfelt TS 30	2,46	3,5	0,061
		Pekanbaru clay-Polyfelt TS 50	2,46	3,22	0,056
		Pekanbaru clay-Polyfelt TS 60	2,46	3	0,052
		Pekanbaru clay-Polyfelt TS 70	2,46	3,03	0,053
		Pekanbaru clay-Hate Reinfox HT385-130XT	2,46	2,71	0,047
		Pekanbaru clay-Hate Reinfox HT385-185XT	2,46	2,56	0,045
		Pekanbaru clay-Hate Reinfox HT385-250XT	2,46	2,62	0,046
5	Gourc (1982)	Clay-BD 340	39	41,8	0,894
		Clay-BD 340	39	39,9	0,836
6	Garbulewski (1990)	Silty clay-Road geotextile-1000	24,2	25,2	0,471
		Silty clay-Filtration geotextile J/Sm 5214	24,2	21,8	0,400
7	Mahmood & Zakaria (2000)	Organic clay-Non woven TS550	2,15	5,6	0,098
		Organic clay-Non woven TS600	2,15	8,6	0,151
		Organic clay-Non woven TS700	2,15	14,98	0,268
		Organic clay-Non woven TS750	2,15	3,5	0,061
8	Rifa'i (2004)	Wonosari CH clay-Non woven TS600	20,20	27,52	0,521
		Wonosari CH clay-Non woven R206	20,20	31,6	0,615
		Wonosari CH clay-Woven BW250	20,20	23,04	0,425
		Wonosari CH clay-Non woven TS600	26,59	34,34	0,683
		Wonosari CH clay-Non woven R206	26,59	22,23	0,409
		Wonosari CH clay-Woven BW250	26,59	20,66	0,377

* See William & Houlihan (1987)