

Lubricating Effects Against Interfaces Shear Strength Of Soil–Concrete And Concrete–Concrete

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Abstract

Box Jacking is a trenchless method of underpass construction that consists in pushing one or more prefabricated concrete boxes into the soil using high capacity hydraulic jacks, while excavating the soil. The Box Jacking method generates soil-concrete frictions at all sides of a box and concrete-concrete friction while it is still on concrete platform. To minimize this friction, lubricant such as oil and grease can be applied on all sides of the box. Objectives of this study are: 1) to identify soil classification, cohesion (c) and internal friction angle (ϕ); 2) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact; 3) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact lubricated by oil; 4) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact lubricated by grease. Soil samples collected from soil investigation at Underpass Project Site at Tatakan, South Kalimantan, using soil boring test. Samples used for laboratory test are soil below 1.50-2.00 m, 2.50-3.00 m, and 4.50-5.00 m from ground surface. Cylindrical concrete samples are a diameter of 63.1 mm and a height of 20 mm. The concrete strength of concrete sample is 25 MPa. Lubricants used are oil and grease. Types of viscosity of oil used are SAE 5W-40, SAE 10W-40, SAE 15W-40, and SAE 20W-50. Type of viscosity of grease used are NLG#1, NLGI#2 and NLGI#3. Direct shear test was conducted to obtain soil-concrete and concrete-concrete friction values. Addition of grease to surface contact influences adhesion (c_a) and interface friction angle (δ) significantly. In case of soil-concrete contact, adhesion (c_a) and interface friction angle (δ) are 10.87 kPa and 22.64°. Addition of lubricant can decrease adhesion (c_a) and interface friction angle (δ) to 11.80 kPa and 10.87° for oil and 0.44 kPa and 3.88° for grease. In case of concrete-concrete contact, adhesion (c_a) and

interface friction angle (δ) are 6.20 kPa and 32.93°. Addition of lubricant can decrease adhesion (c_a) and interface friction angle (δ) to 4.26 kPa and 33.76° for oil and 0 kPa and 3.17° for grease.

Keywords: box jacking, adhesion, interface friction angle, oil, and grease.

INTRODUCTION

Box Jacking is a trenchless method of underpass construction that consists in pushing one or more prefabricated concrete boxes into the soil using high capacity hydraulic jacks, while excavating the soil. The Box Jacking method can be applied under or below highways with active traffic flow and is designed to avoid any impact on traffic during construction process. The Box Jacking method can reduce the amount of time in constructing.

The Box Jacking method generates soil-concrete frictions at all sides of a box. However, this method also generates concrete-concrete friction at the bottom of the box while if it is on the concrete platform. In this research, representative parameters for soil-concrete friction and concrete-concrete friction are adhesion, c_a , and interface friction angle, δ .

Fucale et al (2018) evaluates the friction angle of soil-wall in contact with different materials and surface roughness. In this study, internal friction angle equals to interface friction angle for concrete-clayey sand friction. In addition, $\left(\frac{\delta}{\phi}\right)$ ranges from $\frac{3}{4}$ to 1 for clayey sand and from $\frac{1}{3}$ to 1 for low compressibility soil.

Interface friction angle is about $\frac{2}{3}$ of $\tan \phi$ for concrete-non cohesive soil interface (Ilori et al, 2017). Moreover, rougher surface of concrete generates higher value of concrete-soil interface friction angle and adhesion (Konkol and Mikani, 2021).

This paper studies effects of applying lubricants on concrete surfaces because there is not the similar study about. In this study, lubricants are applied are oil and grease. Objectives of this study are: 1) to identify soil classification, cohesion (c) and internal friction angle (ϕ); 2) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact; 3) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact lubricated by oil; 4) to obtain adhesion (c_a) and interface friction angle (δ) for soil-concrete and concrete-concrete contact lubricated by grease.

THEORIES

Soil classification is classification different soils into groups according to their engineering behavior. Classification systems provide a common language to concisely express the general characteristics of soils, which are infinitely varied, without detailed descriptions

(Das, 1995). Soil classification aims to predict bearing capacity performance and to build information behaviors of soil to others (Bowles, 1989).

There are some soil classifications used in civil engineering. However, Unified Soil Classification System (USCS) is much used in foundation work (Bowles, 1997). The original form of this system was proposed by Casagrande in 1942 for use in the airfield construction works undertaken by the Army Corps of Engineers during World War II.

Table 1 Unified Soil Classification System (USCS) (Hary Christady, 1996)

Divisi Utama			Simbol	Nama Umum		Kriteria Klasifikasi		
Tanah berbutir kasar≥ 50% butiran tertahan saringan No. 200	Kerikil 50%≥ fraksi kasar tertahan saringan No. 4	Kerikil bersih (hanya kerikil)	GW	Kerikil bergradasi-baik dan campuran kerikil-pasir, sedikit atau sama sekali tidak mengandung butiran halus	Klasifikasi berdasarkan prosentase butiran halus ; Kurang dari 5% lolos saringan no.200: GM, GP, SW, SP. Lebih dari 12% lolos saringan no.200 : GM, GC, SM, SC. 5% - 12% lolos saringan No.200 :	$Cu = \frac{D_{60}}{4 D_{10}}$	Antara 1 dan 3	
			GP	Kerikil bergradasi-buruk dan campuran kerikil-pasir, sedikit atau sama sekali tidak mengandung butiran halus		$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$		
		Kerikil dengan Butiran halus	GM	Kerikil berlanau, campuran kerikil-pasir-lanau		Tidak memenuhi kedua kriteria untuk GW		
			GC	Kerikil berlempung, campuran kerikil-pasir-lempung		Batas-batas <i>Atterberg</i> di bawah garis A atau $PI < 4$	Bila batas <i>Atterberg</i> berada didaerah arsir dari diagram plastisitas, maka dipakai dobel simbol	
	Pasir≥ 50% fraksi	Pasir bersih (hanya pasir)	SW	Pasir bergradasi-baik , pasir berkerikil, sedikit atau sama sekali tidak mengandung butiran halus		$Cu = \frac{D_{60}}{6 D_{10}}$	Antara 1 dan 3	
			SP	Pasir bergradasi-buruk, pasir berkerikil, sedikit atau sama sekali tidak		$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$		
						Tidak memenuhi kedua kriteria untuk		

				mengandung butiran halus		SW						
		Pasir dengan butiran halus	SM	Pasir berlanau, campuran pasir- lanau		Batas-batas <i>Atterberg</i> di bawah garis A atau PI < 4			Bila batas <i>Atterberg</i> berada didaerah arsir dari diagram plastisitas, maka dipakai dobel simbol			
			SC	Pasir berlempung, campuran pasir- lempung		Batas-batas <i>Atterberg</i> di bawah garis A atau PI > 7						
Tanah berbutir halus 50% atau lebih lolos ayakan No. 200	Lanau dan lempung batas cair ≤ 50%	ML	Lanau anorganik, pasir halus sekali, serbuk batuan, pasir halus berlanau atau berlempung		Diagram Plastisitas: Untuk mengklasifikasi kadar butiran halus yang terkandung dalam tanah berbutir halus dan kasar. Batas <i>Atterberg</i> yang termasuk dalam daerah yang di arsir berarti batasan klasifikasinya menggunakan dua simbol.							
		CL	Lempung anorganik dengan plastisitas rendah sampai dengan sedang lempung berkerikil, lempung berpasir, lempung berlanau, lempung “kurus” (<i>lean clays</i>)		60	CL			CH			
		OL	Lanau-organik dan lempung berlanau organik dengan plastisitas rendah		50							
	40											
	Lanau dan lempung batas cair ≥ 50%	MH	Lanau anorganik atau pasir halus diatomaee, atau lanau diatomaee, lanau yang elastis		30	CL-ML			Garis A			
					20							
					4							
					0							
		CH	Lempung anorganik dengan plastisitas tinggi, lempung “gemuk” (<i>fat clays</i>)		Batas Cair LL (%)							

		OH	Lempung organik dengan plastisitas sedang sampai dengan tinggi	Garis A : PI = 0.73 (LL-20)
Tanah-tanah dengan kandungan organik sangat tinggi		PT	<i>Peat</i> (gambut), <i>muck</i> , dan tanah- tanah lain dengan kandungan organik tinggi	Manual untuk identifikasi secara visual dapat dilihat di ASTM Designation D-2488

Interface friction of soil is resistance of soil particles to other materials. It can be interpreted by of Mohr-Coulomb Envelop (Konkol & Mikina, 2021). Interface friction of soil can be calculated as:

$$\tau_{max} = \sigma \tan \delta + c_a \quad \text{.....} \quad (2.1)$$

where: δ = angle of interface friction; τ_{max} = interface shear stress at failure; σ = normal stress applied during shearing, c_a = adhesion.

Interface shear stress is determined by:

1. Adhesion (c_a) describes two dissimilar substances face the force of attraction. Roughness of surface determines adhesion value (Konkol & Mikina, 2021)
2. Angle of interface friction (δ) depends on some variables. It is very sensitive to roughness of surfaces face (Al-Mhaidib, 2005; Canakci, Hamed, Celik, Sidik, & Eviz, 2016; Ferreira, Fucale, Oliveira, Sá, & Moura, 2016; Nardelli, Cacciari, & Futai, 2019)

Amonton's First Law states that for any object which is under motion the friction is proportionate and perpendicular to normal load. A constant which proportioned with friction force is friction coefficient:

$$\mu = \tan \delta = \frac{F}{W} = \frac{\tau}{\sigma}$$

$$\delta = \tan^{-1} \left(\frac{\tau}{\sigma} \right) \quad \text{.....} \quad (2.2)$$

Where: τ = shear stress; σ =normal stress; and δ =angle of surface friction

Equation can not be applied in this study because friction coefficient varies for one type material. Therefore friction force is influenced by adhesion and plowing (Dove & Frost, 1999):

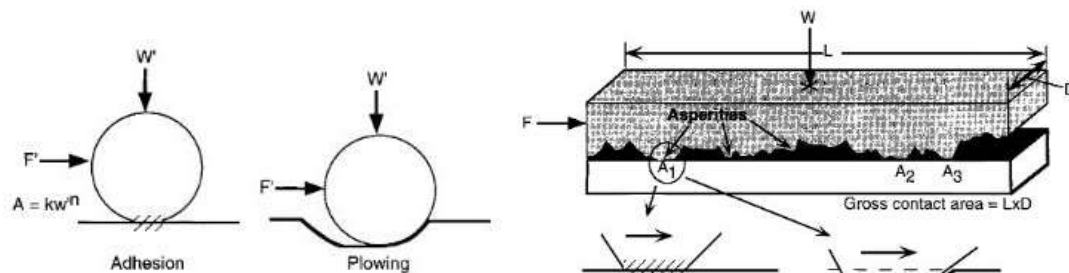


Figure 1 Adhesion and Plowing Concept

$$F = F_{adhesion} + F_{plowing} \dots\dots\dots (2.3)$$

$$F_{adhesion} = \tau_a \cdot A$$

$$F_{plowing} = \tau_p \cdot A_p$$

Where: τ_a = shear stress at contact point; A = Area of real contact of materials; τ_p = bulk stress of smoother material; and A_p = cross sectional area of plowed track

MATERIAL AND METHOD

Soil samples collected from soil investigation at Underpass Project Site at Tatakan, South Kalimantan, using soil boring test. Samples used for laboratory test are soil below 1.50-2.00 m, 2.50-3.00 m, and 4.50-5.00 m from ground surface.

Cylindrical concrete samples are a diameter of 63.1 mm and a height of 20 mm. The concrete strength of concrete sample is 25 MPa. Lubricants used are oil and grease. Types of viscosity of oil used are SAE 5W-40, SAE 10W-40, SAE 15W-40, and SAE 20W-50. Type of viscosity of grease used are NLG#1, NLGI#2 and NLGI#3.

Laboratory tests conducted were sieve analysis, water content test, specific gravity test, density test, unconfined compression test, and direct shear test. Direct shear test was conducted for soil-concrete friction test and concrete-concrete friction test.

RESULTS DAN DISCUSSION

Concrete sample was tested before direct shear test as shown in Table 1. According the test result, average of compressive strength of the sample is 26.92 MPa or meet the

compressive strength as stated in material specification.

Laboratory tests conducted results soil properties as shown in Table 2 and unconfined compression test, direct shear test, and consolidation characteristic in Table 3. Soil properties tests show the soil samples can be classified into silt and very stiff silty sand in USCS Classification. Direct shear test for soil-soil contact is shown in Table 4. The test results average of cohesion and internal friction angle are 051 kPa and 32.67°.

Case study 1a is a study about addition oil to soil-concrete surface contact. The result of this study is shown in Table 5 and Figure 1. Figure 1 shows correlation viscosity to adhesion and interface friction angle. According Figure 1, viscosity influences interface friction angle significantly. It shows that the higher viscosity is the lower the interface friction angle. The viscosity can decrease interface friction angle. However, the viscosity does not influence the adhesion. According Figure 1, the adhesion has almost the same value.

Case study 1b is a study about addition oil to concrete-concrete surface contact. The result of this study is shown in Table 7 and Figure 3. Figure 3 shows correlation viscosity to adhesion and interface friction angle. According Figure 2, viscosity does not influence adhesion and interface friction angle due to increasing viscosity affects the values irregular.

Table 1 Compressive Strength Test of Cylindrical Concrete

No.	Mix Ratio	Slump	Weight	Height	Dia	Area	Density	Age	Load	Load/ Area	Age Factor	Compressive Strength	f_c'	Cubic Compressive Strength (Conversion)	Code
		(cm)	(kg)	(cm)	(cm)	(cm ²)	(kg/cm ²)	(days)	(kg)	(kg/cm ²)	γ	(kg/cm ²)	(MPa)	(kg/cm ²)	
1.	-	8	12,982	30	15	176,79	2447,78	9	41297,85	233,60	0,7160	326,26	-	281,45	f_c' 25 MPa
2.	-	8	13,015	30	15	176,79	2454,01	9	41297,85	233,60	0,7160	326,26	-	281,45	f_c' 25 MPa
	Sum											467,21	-	562,90	
	Average											233,60	26,92	281,45	

Table 2 Soil Properties

		Water Cont	Density	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	Sieve Analysis					Soil Classification
		w	g	G s	LL	PL	PI	Gravel	Sand		Silt/Clay	USCS	
		(%)	tonf/m³		(%)	(%)	(%)	(%)	(%)	(%)	(%)		
	Depth (m)								Fine	Medium	Coarse		
BH-1	11.50-12.00	29.09	1.86	2.69	54.56	34.51	20.05	0.77	11.48	17.63	25.41	44.71	SM
	14.50-15.00	25.62	2.00	2.84	53.43	33.19	20.24	1.32	9.49	14.57	34.75	39.87	SM
	15.50-16.00	19.90	2.07	2.67	46.12	27.50	18.62	1.99	8.61	21.11	35.28	33.01	SM
BH-2	1.50-2.00	23.29	2.08	2.67	40.66	32.56	8.10	0.16	15.61	10.72	9.17	64.34	ML & OL
	4.50-5.00	15.25	1.97	2.61	59.23	32.46	26.77	8.13	8.44	8.63	15.04	59.76	MH & OH
BH-3	1.50-2.00	14.13	1.69	2.66	40.66	25.42	15.24	5.08	24.98	10.49	16.99	42.46	SM
	2.50-3.00	12.25	1.95	2.64	55.33	28.43	26.90	1.44	24.70	10.72	13.52	49.62	SM
	4.50-5.00	21.71	1.91	2.57	54.46	29.22	25.25	2.59	15.33	17.80	14.78	49.50	SM
BH-4	3.00-3.50	17.91	1.79	2.63	71.62	34.06	37.56	1.35	16.21	15.52	13.45	53.47	MH & OH
	4.50-5.00	19.34	1.84	2.65	54.53	28.57	25.96	1.24	15.88	10.27	9.75	62.85	CH
BH-5	1.50-2.00	19.04	1.84	2.83	30.13	16.80	13.34	6.13	17.34	9.59	12.02	54.92	CL
	4.50-5.00	16.67	1.84	2.63	23.61	13.58	10.03	3.21	22.61	10.88	18.04	45.25	SM
	5.50-6.00	16.90	1.79	2.58	56.37	30.28	26.08	4.22	14.51	17.90	12.97	50.39	MH & OH

Table 3 Direct Shear and Consolidation Characteristics of Soil

		Unconfined Compression Test				Direct Shear Test		Consolidation			
		q _{u-undist.}	q _{u-dist.}	s _t	C _u	c	φ	e _o	C _c	C _s	C _v
	Depth (m)	(kg/cm ²)	(kg/cm ²)		(kg/cm ²)	(kg/cm ²)	(°)				(cm ² /s)
BH-1	11.50-12.00	0.23	0.06	3.56	0.11	0.16	20.18	0.82	0.18	0.030	2.26E-03
	14.50-15.00	0.12	0.05	2.27	0.06	0.17	19.80	0.89	0.14	0.016	2.61E-03
	15.50-16.00	0.07	0.05	1.38	0.03	0.01	20.41				
BH-2	1.50-2.00	0.85	0.08	10.51	0.43	0.35	10.62				
	4.50-5.00	0.92	0.10	8.89	0.46	0.23	24.80				
BH-3	1.50-2.00	0.13	0.02	7.23	0.07	0.00	16.46	0.49	0.11	0.015	9.26E-03
	2.50-3.00	1.06	0.07	15.65	0.53	0.02	9.79	0.30	0.09	0.013	6.22E-03

	4.50-5.00	0.60	0.04	16.86	0.30	0.05	5.82	0.55	0.14	0.032	5.11E-03
BH-4	3.00-3.50	0.68	0.04	18.99	0.34	*	*				
	4.50-5.00	1.48	0.05	31.32	0.74	0.34	20.71				
BH-5	1.50-2.00	0.69	0.03	27.30	0.35	0.10	8.28	0.75	0.13	0.027	6.75E-03
	4.50-5.00	0.12	0.02	6.92	0.06	0.00	20.28	0.46	0.13	0.012	3.90E-03
	5.50-6.00	0.96	0.06	15.73	0.48	0.00	16.97	0.54	0.11	0.022	2.36E-03

Table 4 Direct Shear Test for Soil-Soil Contact

NO.	Sample	c (kPa)	ϕ (°)
1	I	-	33.81
2.	II		33.73
3.	III	1.54	30.46
Average		0.51	32.67

Case study 2a is a study about addition grease to soil-concrete surface contact. The result of this study is shown in Table 8 and Figure 3. Figure 3 shows correlation viscosity to adhesion and interface friction angle. According Figure 3, viscosity influences interface friction angle significantly. It shows that the higher viscosity is the lower the interface friction angle. The viscosity can decrease interface friction angle. However, the viscosity does not influence the adhesion. According Figure 1, the adhesion has values high and low as increasing grease viscosity.

Table 5 Direct Shear Test for Soil-Concrete Contact with Oil Addition

NO.	Sample	Viscosity (cSt)	Vr (cSt)	c_a (kPa)	(%)	δ (°)	(%)
1.	Soil-Concrete (Without Oil Addition)	0,0	0.0	10.87	100.00	22.64	100.00
2.	Soil-Concrete With SAE 5W-40 Oil	3.8 – 12.5	8.15	7.80	71.76	23.58	104.15

3.	Soil-Concrete With SAE 10W- 40 Oil	4.1 – 12.5	8.30	9.35	86.02	17.85	78.84
4.	Soil-Concrete With SAE 15W- 40 Oil	5.6 – 12.5	9.05	9.94	91.44	16.72	73.85
5.	Soil-Concrete With SAE 20W- 50 Oil	5.6 – 16.3	10.95	11.80	108.56	10.87	48.01

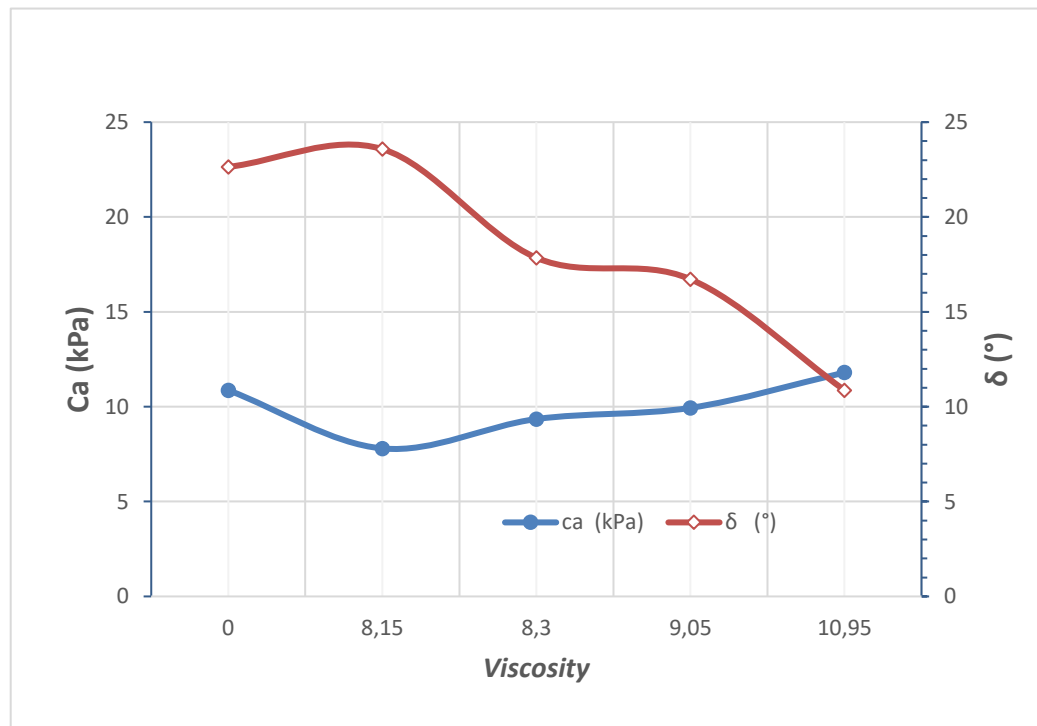


Figure 1 Correlation Viscosity to Adhesion and Interface Friction Angle for Soil-Concrete Contact with Oil Addition

Table 6 Direct Shear Test for Concrete-Concrete Contact with Oil Addition

NO.	Sample	Viscosity (cSt)	Vr (cSt)	c_a (kPa)	(%)	δ (°)	(%)
1.	Concrete- Concrete without Oil	0,0	0.0	6.20	100.00	32.93	100.00
2.	Concrete- Concrete with Oil SAE 5W- 40	3.8 – 12.5	8.15	10.77	173.71	40.43	122.78
3.	Concrete- Concrete with SAE 10W-40	4.1 – 12.5	8.30	22.38	360.97	29.46	89.46
4.	Concrete- Concrete with SAE 15W-40	5.6 – 12.5	9.05	12.89	207.90	32.95	100.06
5.	Concrete- Concrete with SAE 20W-50	5.6 – 16.3	10.95	4.26	68.71	33.76	102.52

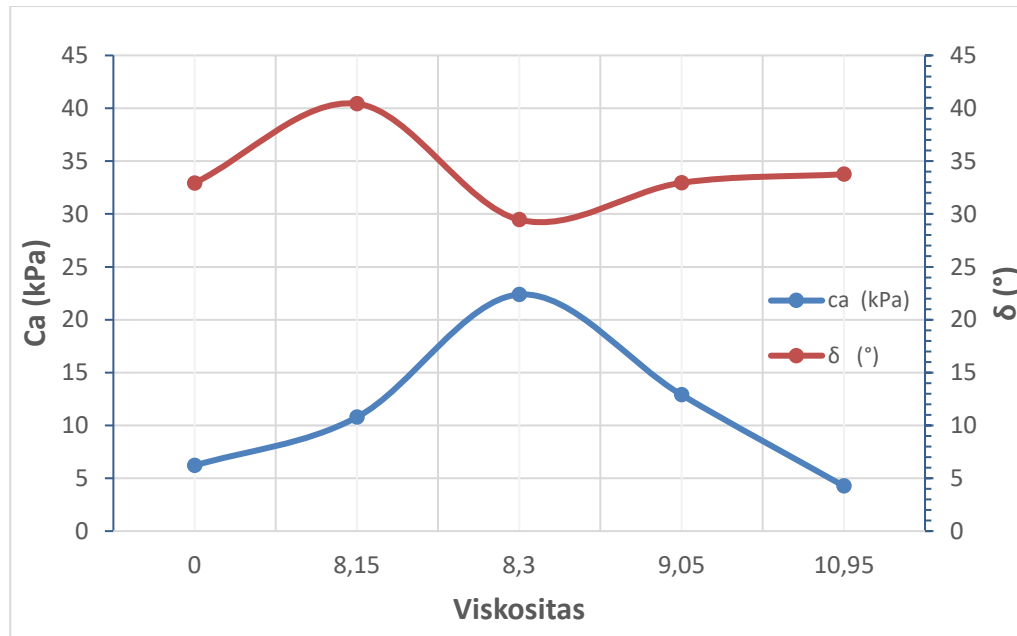


Figure 2 Correlation Viscosity to Adhesion and Interface Friction Angle for Concrete-Concrete Contact with Oil Addition

Table 7 Direct Shear Test for Soil-Concrete Contact with Grease Addition

NO.	Sample	ASTM – Worked Penetra tion	Average Penetra tion (1/100)	c_a (kPa)	(%)	δ (°)	(%)
1.	Soil-Concrete Without Grease	-	-	10.87	100.00	22.64	100.00
2.	Soil-Concrete With Grease NLG#1	355-385	3.7	-	-	12.78	56.45
3.	Soil-Concrete With Grease NLGI#2	265-295	2.8	4.16	38.27	8.98	39.66
4.	Soil-Concrete With Grease NLGI#3	220-250	2.35	0.44	4.05	3.88	17.14

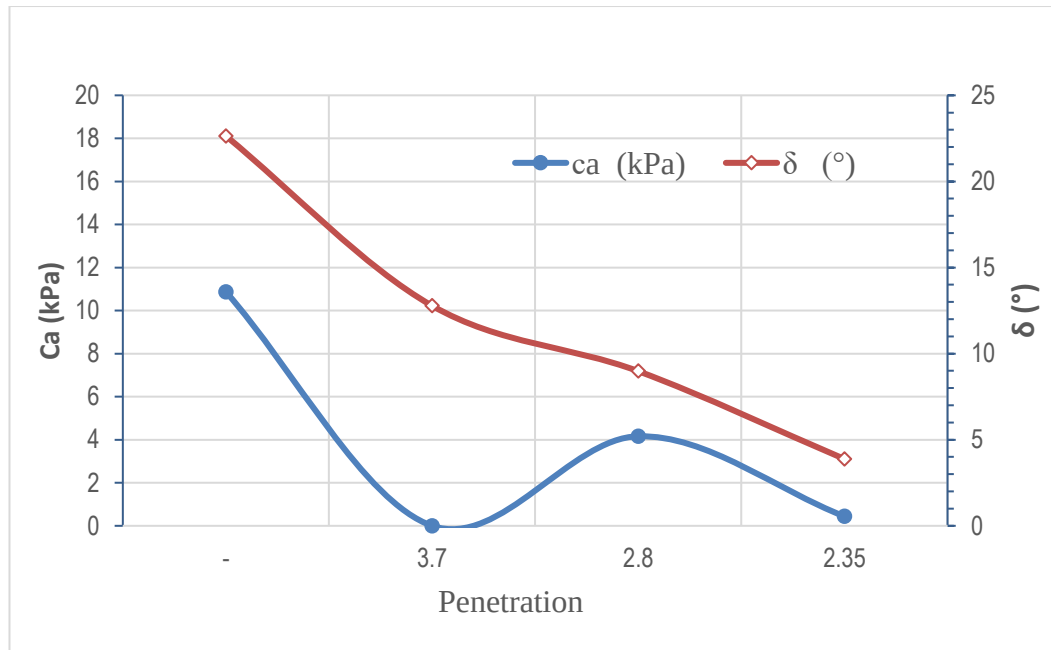


Figure 3 Correlation Viscosity to Adhesion and Interface Friction Angle For Soil-Concrete Contact With Grease Addition

Case study 2b is a study about addition grease to concrete-concrete surface contact. The result of this study is shown in Table 8 and Figure 4. Figure 4 shows correlation viscosity to adhesion and interface friction angle. According Figure 2, viscosity does not influence adhesion. However, it influence interface friction angle significantly.

Table 8 Direct Shear Test for Concrete-Concrete Contact with Grease Addition

NO.	Sample	ASTM – Worked Penetration	Penetration on Rate- Rate (1/100)	c_a (kPa)	(%)	δ (°)	(%)
1.	Concrete-concrete Without Grease	-	-	6.20	100.0	32.93	100.0
2.	Concrete-concrete with Grease NLGI	355-385	3.7	0.0	-	23.86	72.46

3.	Concrete-concrete with Grease NLGI#2	265-295	2.8	1.10	17.74	3.52	10.69
4.	Concrete-concrete with Grease NLGI#3	220-250	2.35	0.0	-	3.17	9.63

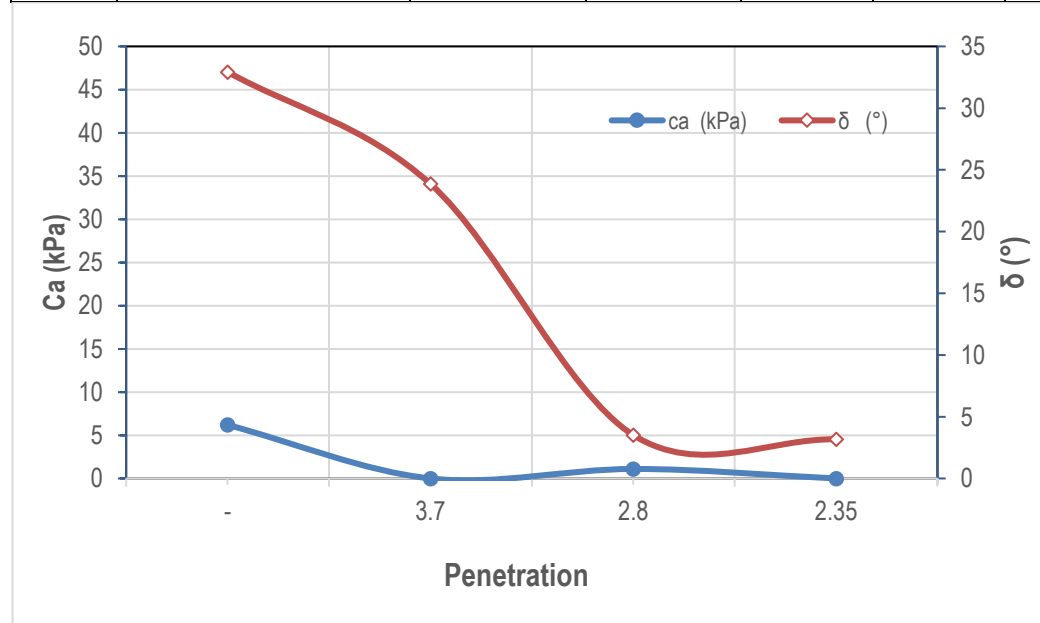


Figure 4 Correlation Viscosity to Adhesion and Interface Friction Angle for Concrete-Concrete Contact with Grease Addition

All Results of Direct Shear Test as shown Table 4, 5, 6, 7, and 8 are summarized into Table 9 below. According Table 9, grease can reduce adhesion and interface friction angle better than oil. Adding oil to surface contact affects inconsistent to decrease contact parameter. As seen in Table 9, adding oil increases adhesion value of 8.56% for soil-concrete contact and interface friction angle value of 2.52% for concrete-concrete contact.

Table 9 Comparison Adhesion (c_a) and Interface Friction Angle (δ) for All Case

No.	Contact	Without		With Lubricant							
		Lubricant		Oil				Grease			
		c_a (kPa)	δ (°)	c_a (kPa)	Reduction (%)	δ (°)	Reduction (%)	c_a (kPa)	Reduction (%)	δ (°)	Reduction (%)

1	Soil- Concrete	10.87	22.64	11.8	-8.56	10.87	51.99	0.44	95.95	3.88	82.86
2	Concrete- Concrete	6.20	32.93	4.26	31.29	33.76	-2.52	0.0	100.0	3.17	90.37

CONCLUSION

Addition of lubricant to surface contact influences adhesion (c_a) and interface friction angle (δ). In this study, lubricants used are oil and grease. According to laboratory tests, grease influences parameters more than oil because viscosity of grease is higher than oil.

In case of soil-concrete contact, adhesion (c_a) and interface friction angle (δ) are 10.87 kPa and 22.64°. Addition of lubricant can decrease adhesion (c_a) and interface friction angle (δ) to 11.80 kPa and 10.87° for oil and 0.44 kPa and 3.88° for grease.

In case of concrete-concrete contact, adhesion (c_a) and interface friction angle (δ) are 6.20 kPa and 32.93°. Addition of lubricant can decrease adhesion (c_a) and interface friction angle (δ) to 4.26 kPa and 33.76° for oil and 0 kPa and 3.17° for grease.

REFERENCES

- Al-Mhaidib, A. (2005). Shearing Rate Effect on Interfacial Friction Between Sand and Steel. *International Offshore and Polar Engineering Conference*, (p. 9). Seoul Korea.
- Bowles, J. E. (1989). *Sifat-sifat Fisis dan Geoteknis Tanah*. Jakarta: Erlangga.
- Bowles, J. E. (1997). *Foundation Analysis and Design*. Singapore: McGraw-Hill Companies, Inc.
- Canakci, H., Hamed, M., Celik, F., Sidik, W., & Eviz, F. (2016). Friction Characteristics of Organic Soil with Construction Materials. *Soil Found*, 56, 965-972.
- Das, B. M. (1995). *Mekanika Tanah (Prinsip-prinsip Rekayasa Geoteknis)* (Vol. 1). Jakarta: Erlangga.
- Dove, J., & Frost, J. (1999). Peak Friction Behaviour of Smooth Geomembrane Particle Interfaces. *Journal of Geotech*, 544-555.
- Ferreira, S., Fucale, S., Oliveira, J. T., Sá, W. B., & Moura, S. F. (2016). Evaluation of the Friction Angle of SoilWall in Contact with Different Materials. *Electronics Journal of Geotechnical Engineering*, 21, 4655-4672.



Konkol, J., & Mikina, K. (2021). Some Aspects of Shear Behaviour of Soft Soil-Concrete Interface and Its Consequences in Pile Shaft Friction Modeling. *Materials*, 14.

Nardelli, A., Cacciari, P., & Futai, M. (2019). Sand-Concrete Interface Response: The Role of Surface Texture and Confinement Conditions. *Soil Found*, 59, 1675-1694.

