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Determination of Friction Angles Between Soil and Steel - FRP Piles

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Abstract

Forces of friction between structure and soil are taken into account in the design of geotechnical engineering constructions such as piles, retaining walls, sheet piles and diaphragm walls. Although many studies were carried out about the soil-structure interaction in recent years. However, in pile design, frictional forces are still calculated by using the empirical formulas proposed in the first half of the 20th century. Throughout history, wood was often used as friction piles. Steel piles are used extensively in practice. Nowadays, in harsh environmental conditions fiber-reinforced polymer (FRP) piles come into use in numerous cases. As is known, the effect of pile point tip resistance on the bearing capacity is ignored particularly in loose sands and the bearing capacity is fully taken equal to the skin friction. Hence, it is understood that correct determination of skin friction angle is very important in engineering calculations. In this study, various ratios of low plasticity clays (CL) were added to the sandy soil and compacted to standard Proctor density. Thus, soils with various internal friction angles were obtained. By performing interface shear tests (IST), skin friction angles of these soils with steel (st37) and FRP were determined. Based on the data obtained from the test results, a chart was proposed, which engineers can use in pile design. By means of this chart, the skin friction angles of the soils, of which only the internal friction angles are known, with steel and FRP materials can be determined easily.

Keywords: Skin Friction; Design Chart; Pile Materials; Direct Shear Test.

Çelik ve FRP Kazıklar ile Zemin Arasındaki Sürtünme Açısının Belirlenmesi

Özet

Zemin ile yapı elemanları arasındaki sürtünme kuvvetleri temel mühendisliği açısından hayati öneme sahiptir. Son yıllarda zemin-yapı etkileşimi konusunda çok sayıda çalışma yapılıyor olsa da sürtünme kuvvetlerinin belirlenmesi için hala 20. yüzyılın ilk yarısında önerilen yaklaşık bağıntılar kullanılmaktadır. Tarih boyunca sürtünme kazığı olarak genellikle ahşap kullanılmıştır. Son yüzyılda ise çelik kullanılmaya başlanmıştır. Günümüzde ise bu malzemelere alternatif olarak özellikle olumsuz çevre koşullarında uzun yıllar hizmet edebilmesi nedeniyle FRP (fiber-reinforced polymer) kazıklar yoğun şekilde kullanılmaktadır. Bilindiği gibi özellikle gevşek kumlu zeminlerde kazık uç direncinin taşıma gücüne etkisi ihmal edilmekte ve taşıma gücü tamamen yüzey sürtünmesine eşit alınmaktadır. Buradan, mühendislik hesaplamalarında yoğun bir şekilde kullanılan yüzey sürtünme açısının doğru olarak belirlenmesinin ne kadar önemli olduğu anlaşılmaktadır.
Bu çalışmada, kum zemine farklı oranlarda düşük plastisiteli kil (CL) eklenmiş ve Proctor sıkılığında sıkıştırılmıştır. Bu sayede farklı içsel sürtünme açılarına sahip zeminler elde edilmiştir. Bu zeminlerin, çelik (st37) ve FRP malzemeleri ile yaptıkları yüzey sürtünme açıları belirlenmiştir. Deney sonuçlarından elde edilen verilerden yola çıkarak mühendislerin kazık tasarımında kullanabileceği bir abak önerilmiştir. Bu abak sayesinde sadece içsel sürtünme açısı bilinen zeminlerin çelik ve FRP malzemeleriyle yaptıkları yüzey sürtünme açıları kolaylıkla belirlenebilmektedir.

Anahtar Kelimeler: Yüzey Sürtünmesi; Tasarım Kartı; Kazık Malzemeleri; Direkt Kesme Deneyi.

1. Introduction

Skin friction angle between soil and pile materials emerges as an important component in the designs made by geotechnical engineers. Frictional forces between structure and soil are taken into consideration in the design of civil engineering constructions such as retaining walls, sheet piles, diaphragm walls and piles. As is known, the effect of pile point tip resistance on the bearing capacity is ignored particularly in loose sand soils and the bearing capacity is fully taken equal to the skin friction. Hence, it is understood that correct determination of skin friction angle is very important in geotechnical design.

Many geotechnical engineers consider the skin friction angle (δ) as equal to 2/3 of the internal friction angle (ϕ) of soil in their designs [1]. However, it is known that δ can change in the event of frictions between the same soil and different materials. Even today, skin friction angles (δ) between soil and pile materials are not exactly known and design engineers use approximate values. δ values used in designs are of essential in the determination of pile number, diameter and length. A low δ value leads making non-economic designs and increases project costs substantially. On the other hand, a high δ value causes to safety problems.

Wood was used as a driven pile material up to the first half of the 20th century. However, the use of wood declined almost non-existing in today due to increasing costs. Nowadays, steel is commonly used as the driven pile material. Plastic composite materials have also been started to be used in recent years as alternative to steel. Today, FRP (fiber-reinforced polymer) material is ever-increasingly used due to the reasons such as being economic, having high tensile and compressive strengths and its resistance to harsh environmental conditions.

Potyondy (1961) conducted interface shear tests (IST) on the soils prepared in four sand/clay ratios and determined the skin friction angles of wood, steel and concrete materials. When examine the IST results, it is seen that the critical value for the cohesion is the situation where sand/clay ratio is 1. The cohesion rises quickly in all values over this ratio [2]. Uesugi and Kishida (1986) determined the friction between mild steel and dry sand by using IST. They found that the type and mean grain diameter of sand (D_{50}) had significant effects on friction angle [3]. There are many studies where the frictions between geosynthetics and sands were analyzed thorough IST [4, 5, 6, 7]. When articles in the literature are examined, it is generally seen that the frictions of clean sands (without fine-grained soils) and pile material surfaces were determined [6, 8, 9, 10]. However, clean sands are hardly seen in nature. Therefore, mixing various ratios of sand and clay soils will allow more realistic results to be obtained in the in laboratory of the soils encountered in the field [11].

Clayey sand soils containing various ratios (0%, 20%, 30%, 40% and 45%) of clay were used in laboratory tests. The produced soils have different internal friction angles, skin friction angles between the soils and pile materials (steel and FRP) were obtained. As a result of the laboratory studies, a chart was proposed, which shows the relationship between the internal and skin friction angles. By means of this chart, the skin friction angles between soil and pile materials can be obtained based only on the internal friction angles of soils.

2. Material and Method

The index properties of the sand and low plasticity clay (CL) soil used in the tests were determined and given in Table 1. Black basalt originated river sand (specific gravity 2.77) used in the tests. The sieve analyses, Atterberg limits tests and specific gravity tests were conducted according to standards [12, 13, 14]. Sieve analysis of sand and clay soils can be seen in Figure 1.

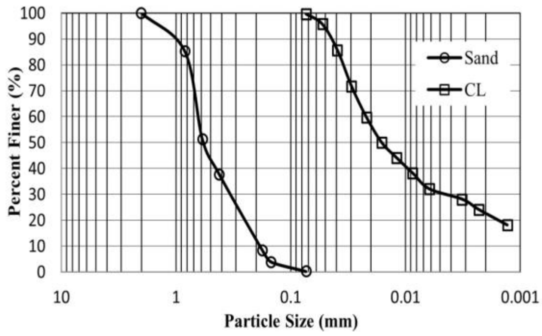

Figure 1. Grain size distribution of soils.

CL at the ratios of 0%, 20%, 30%, 40% and 45% in weight were mixed in the sand and optimum water contents (w_{opt}) were determined by performing standard Proctor tests on these mixtures [15]. w_{opt} values and soil classifications according to Unified Soil Classification System (USCS) are shown for each mixture in Table 2. The mechanical properties of the steel and FRP materials used in the tests are shown in Table 3.

Table 1. Index properties of soils.

	Sand	CL
D_{30} (mm)	0. 33	0.0045
D_{50} (mm)	0.57	0.016
Liquid Limit, W_L (%)	-	30
Plastic Limit, W_P (%)	-	15
Specific Gravity, γ_s	2.77	2.68

Table 2. Mixing ratios and optimum moisture content.

Mixture	Clay (%)	Sand (%)	Soil Group (USCS)	w_{opt} (%)
m_0	0	100	SP	6.0
m_{20}	20	80	SC	9.0
m_{30}	30	70	SC	10.0
m_{40}	40	60	SC	11.5
m_{45}	45	55	SC	13.0

Table 3. Properties of pile materials.

	Steel (st37)	FRP (50% glass)
Compression strength (Mpa)	240	200
Tensile strength (Mpa)	360	240
Tensile Elasticity Modulus (Gpa)	210	23
Density (gr/cm^3)	7.85	1.8

The direct shear test (DST) was performed to obtain the internal friction angles (ϕ) of the soil mixtures [16]. Interface shear tests (IST) were conducted in order to determine the skin friction angles (δ) between the produced soil samples and steel, FRP [17]. Test setups can be seen in Figure. 2. and Figure 3. DST and IST tests were performed at a rate of 0.5 mm/min horizontal displacement. Samples prepared at the standard Proctor density and optimum water content were used in DST and IST tests and the results obtained from the tests can be seen in Table 4.

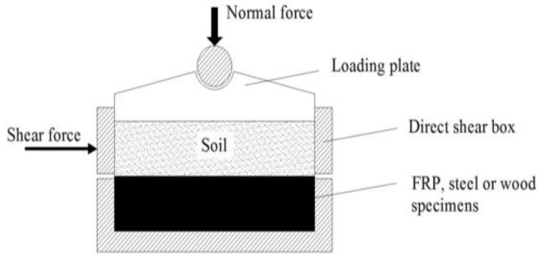

Figure 2. Sketch of interface shear test setup.

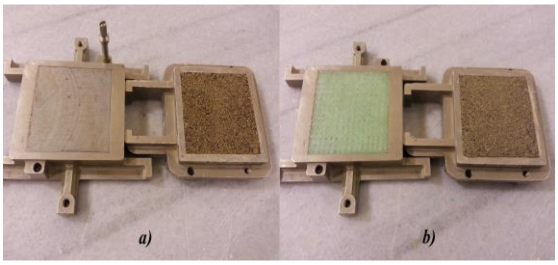

Figure 3. Interface shear test setup; a) IST (steel soil) b) IST (FRP-soil).

Table 4. Direct shear test (DST) and interface shear test (IST) results.

Mixture	Internal friction angle of soil, ϕ (°)	Skin friction angle, δ (°)	
		Steel	FRP
m_0	43.0	26.5	34.5
m_{20}	39.5	31.5	37.0
m_{30}	41.5	29.2	36.0
m_{40}	35.0	27.0	32.0
m_{45}	28.0	18.0	22.7

Even today, in most projects, skin friction angle is calculated by using $\delta=2\phi/3$ equation. But every material have different skin friction angle with soils [11]. Especially for FRP this equation gives significantly lower δ values than test results. For example, for $\phi=35°$ it is calculated that $\delta=23.3°$. This δ value obtained from IST tests for FRP as 32.0°. Therefore, as skin friction angle assumed lower values causes increase in number, diameter and depth of piles. Consequently non-economical designs can be made by using this equation.

3. Skin Friction Chart

The results determined from the tests and then analyzed. A skin friction chart was proposed to be used in pile design (Figure 4.).

Thanks to this chart, geotechnical engineers will be able to obtain the skin friction angles between the soil and pile materials based on the internal friction angle of soil in the field.

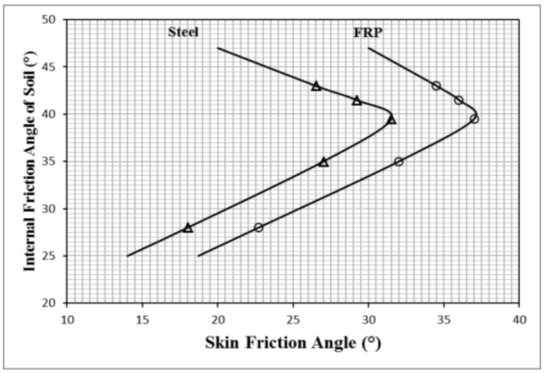

Figure 4. Skin friction chart for steel and FRP.

4. Literature Review with Cases

The results determined through the chart and the studies conducted in the past are shown in Table 5. When the table is examined, it is seen that the δ values obtained through the proposed chart and the values determined in the study performed by Potyondy (1961) show nearly 100% similarity for steel [2]. When results of the chart and the study of Pando et al. (2002) are compared, it is seen that the δ values obtained for FRP material show approximately 90% of similarity [18]. When the results of the chart are compared with the study of Sakr et al. (2005), the δ values show 91% similarity for steel and 94% for FRP material [8]. And when the results of the chart and the studies of Tiwari et al. (2010) and Tiwari and Al-Adhadh (2014) are compared, it is seen that δ values show approximately 90% similarity for steel [10, 19].

Consequently, when δ values obtained from the chart and the studies conducted in the past are compared, these values show similarity more than 90%. The small differences around 10% are considered to arise from types of pile materials (steel hardness and FRP types) used in the tests and the use of dry sand in most studies.

Table 5. Comparison between chart and other studies

Soil (ϕ) (°)	Potyondy (1961), δ (°)	Pando *et al.* (2002), δ (°)	Sakr *et al.* (2005), δ (°)		Tiwari *et al.* (2010), δ (°)	Tiwari and Al-Adhadh (2014), δ (°)	Skin Friction Chart δ (°)		Similarities between Literature and Skin Friction Chart (%)	
	Steel	FRP	Steel	FRP	Steel	Steel	Steel	FRP	Steel	FRP
31.0	-		-	-	24.4	-	21.7	26.7	89	-
31.4	-	-	-	-	-	26.1	22.4	27.4	86	-
33.1	-	-	-	-	27.6	-	24.6	29.7	89	-
33.3	-	-	-	-	28.5	-	24.9	29.8	87	-
33.4	-	-	-	-	-	27.4	25.1	30.0	92	-
34.7	-	29.2	-	-	-	-	26.6	31.4	-	93
37.0	-	-	26.6	32.3	-	-	29.1	34.2	91	94
40.0	31.5	-	-	-	-	-	31.2	37.0	99	-
43.4	-	29.5	-	-	-	-	25.8	33.9	-	87
44.5	24.2	-	-	-	-	-	24.3	32.8	100	-

5. Conclusions

The use of different pile materials, significantly changes the angle of skin friction (δ). Diameter, length and number of piles are considerably affected from these changes.

- IST were performed on the interfaces between soils and pile materials (steel and FRP). The skin friction angles between these materials and various soils were determined.
- In laboratory studies, soils with internal friction angles ranging between 28° and 43° were used.
- When the results determined from the tests and then analyzed, a chart is proposed which allows acquiring the angle of skin friction to take place between soil, the internal friction angle of which is known, and various pile materials.
- Many articles are found in the literature and then these studies were compared with the chart proposed and it was observed conformity over 90% in the δ values determined. Nowadays, design engineers use equations that accept δ

values equal for all pile materials (δ=2ϕ/3). This approach prevents make more realistic designs. True skin friction angles (δ) can be determined by means of the proposed chart. Thus, more economic designs can be made by selecting reasonable pile diameter, length and number.

When the internal friction angles (ϕ) of sand-clay mixture soils are examined, it can be seen that ϕ value decreases as the clay percentage increases. However, a slight increase occurred in ϕ in any cases where the clay content is around 30%. These slight increases in the internal friction angles of sand-clay mixtures with the increase of the clay content were observed by Dafalla (2013) and Bayoğlu (1995) as well [20, 21].

6. References

1. Terzaghi, K. & Peck, R.B. (1948). Soil Mechanics in Engineering Practice. *John Wiley and Sons*, N. York.

2. Potyondy, J., G. (1961). Skin friction between various soils and construction materials. *Geotechnique*, 11(4): 339-353.

3. Uesugi, M., Kishida, H. (1986). Influential factors of friction between steel and dry sands. *Soils and Foundations*, 26(2): 33-46.

4. O'Rourke, T., Druschel, S., and Netravali, A. (1990). Shear strength characteristics of sand-polymer interfaces. *J. Geotech. Geoenviron. Eng.*, 116(3): 451-469.

5. Izgin, M. and Wasti, Y. (1998). Geomembrane–sand interface frictional properties as determined by inclined board and shear box tests. *Geotextiles and Geomembranes*, 16(3): 207-219.

6. Frost, J. and Han, J. (1999). Behavior of interfaces between fiber-reinforced polymers and sands. *J. Geotech. Geoenviron. Eng.,* 125(8): 633-640.

7. Palmeira, E. M. (2009). Soil-geosynthetic interaction: modelling and analysis. *Geotextiles and Geomembranes*, 27(5): 368-390.

8. Sakr, M., El Naggar, M., and Nehdi, M. (2005). Interface characteristics and laboratory constructability tests of novel fiber-reinforced polymer/concrete piles. *J. Compos. Constr.,* 9(3): 274-283.

9. Gireesha, N. T., and Muthukkumaran, K. (2011). Study on soil structure interface strength property. *International Journal of Earth Sciences and Engineering,* 4(6) SPL: 89-93.

10. Tiwari, B. and Al-Adhadh, A. R. (2014). Influence of relative density on static soil–structure frictional resistance of dry and saturated sand. *Geotechnical and Geological Engineering,* 32(2): 411-427.

11. Aksoy, H. S.,Gör, M. and İnal E. (2016). A new design chart for estimating friction angle between soil and pile materials. *Geomechanics and Engineering,* 10(3): 315-324.

12. ASTM D422-63(2007)e2 (2007). ASTM International, Standard test method for particle-size analysis of soils, West Conshohocken, PA.

13. ASTM D4318-10e1 (2010). ASTM International, Standard test methods for liquid limit, plastic limit, and plasticity index of soils, West Conshohocken, PA.

14. ASTM D854-14 (2014). ASTM International, Standard test methods for specific gravity of soil solids by water pycnometer, West Conshohocken, PA.

15. ASTM D698-12e1 (2012). ASTM International, Standard test methods for laboratory compaction characteristics of soil using standard effort (12 400 ft-lbf/ft3 (600 kN-m/m3)), West Conshohocken, PA.

16. ASTM D3080 / D3080M-11 (2011). ASTM International, Standard test method for direct shear test of soils under consolidated drained conditions, West Conshohocken, PA.

17. ASTM D5321 / D5321M-14 (2014). ASTM International, Standard test method for determining the shear strength of soil-geosynthetic and geosynthetic-geosynthetic interfaces by direct shear, West Conshohocken, PA.

18. Pando, M., Filz, G., Dove, J. and Hoppe, E. (2002). Interface shear tests on frp composite piles. *Deep Found.*, 1486-1500.

19. Tiwari, B., Ajmera, B., and Kaya, G. (2010). Shear strength reduction at soil structure interface. *GeoFlorida* 2010: 1747-1756.

20. Dafalla, M. A. (2013). Effects of clay and moisture content on direct shear tests for clay-sand mixtures. Advances in Materials Science and Engineering, 2013, Article ID 562726: 1-8.

21. Bayoğlu, E. (1995). Shear strength and compressibility behavior of sand - clay mixtures. *M.Sc. Thesis*, Middle East Technical University, Ankara, Turkey.