CORRELATION OF FRICTION BETWEEN SOIL AND CONCRETE WITH DISPLACEMENT+

ارتباط الاحتكاك بين التربة و الخرسانة مع الإزاحة

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Abstract:

The paper presents the experimental study of mobilizing friction between soil and concrete. The series of laboratory tests have been carried out on coarse and fine-grained soils. Using statistical approach, the best fitting relationships describing the mobilized friction dependence on displacement have been determined for different soil types. It was found that the behaviour of sand soil unlikes that of clayey soil, so for each type of the soil behaved differently regarding the mobilized friction and displacement. In addition to that, the critical horizontal displacement, at which the whole friction is mobilized, is larger for fine sand than coarse one. The critical horizontal displacement for the normally consolidated clay exceeds more than twice the value for sand. The overconsolidation ratio for clay soil increases the mobilized shear resistance and reduces the displacement.

المستخلص:

الدراسة تمثل النتائج المختبرية للحصول على الاحتكاك الناتج بين التربة و الكونكريت. حيث تم تنفيذ سلسلة تجارب مختبريه لنماذج تربة خشنة و ناعمة الحبيبات. و باستخدام الطرق الإحصائية تم الحصول على أحسن تمثيل للعلاقة بين الاحتكاك و الإزاحة و التي أظهرت اعتماد الاحتكاك على الإزاحة و لجميع أنواع التربة المفحوصة. أظهرت الدراسة التباين في التصرف بين التربة الرملية و التربة الطينية فيما يخص مقاومة الاحتكاك و الإزاحة. يضاف إلى ذلك أظهرت النتائج بأن الإزاحة الأفقية الحرجة للتربة الطينية اعتيادية الانضمام أكثر من تلك الخاصة بالتربة الرملية بحوالي المرتين. إن نسبة فوق الانضمام للتربة الطينية تزيد مقاومة الاحتكاك و تقلل الإزاحة.

Introduction:

With increasing the pile length, the part of side friction increases in the overall resistance, for long piles – over the 20 meters – the side friction forms the most part from the whole bearing capacity, commonly over 50% [1]. Most of the side friction mobilizes before the point resistance takes place. The actual characteristic load on the single pile is (taking into account the mean factor of safety about two) less than a half from ultimate resistance [2]. In this case, it can be supposed that the skin friction takes most of load and lower part of pile moves very little or not at all and thus, the pile displacement is induced mostly by strain of

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the pile material. To calculate the pile head displacement, the load distribution in the pile shaft must be known. The load distribution is dependent on mobilized side friction and is connected accordingly with the displacement of the pile segment [1].

Several authors have investigated the dependence between displacement and side friction. Kezdi (1964),[3], proposed the relationship:

$$\tau/\tau_{max} = 1 - e^{-K_z/(Z_c - Z)} \tag{1}$$

where, Z_c is the movement of pile at which the friction reaching its maximum value τ_{max} and K_z is a constant and τ is the mobilized shear resistance at the displacement Z between soil and concrete and τ_{max} is the ultimate shear resistance

Vijayvergiya (1979),[4], proposed the following empirical equation:

$$\frac{\tau}{\tau_{max}} = 2\sqrt{\frac{Z}{Z_c}} - \frac{Z}{Z_c} \tag{2}$$

Georgadis et.al (1989),[5], gave a relationship:

$$\tau/\tau_{max} = f(Z) \text{ in tabular form.} \tag{3}$$

where Z is the displacement between soil and concrete.

A theoretical relationship in the following form was generated, [6]:

$$\tau/\tau_{max} = \frac{Z}{K - Z} \quad , \tag{4}$$

where the constant $K = \tau_{max}/G_i$ (G_i is the initial shear modulus).

Unfortunately, there is not enough information for the practical application of these relationships. It is unknown which formula gives the best fit. There is not enough knowledge about the dependence of constants on soil type and on stress conditions. The values of the constants K and Zc are defined very roughly in the literature.

In order to verify the above ralations an experimental work has been implemented by author. Different types of soil have been tested utilizing Direct Shear Apparatus.

Materials:

Specimens of coarse and fine-grain soils were prepared for testing. The grain size distribution of these types of soil is shown in figure 1 and the other index properties are shown in tables 1and 2. The samples were classified according to Unified Soil Classification System (USCS), [7].

Figure 1: Grain size distribution of tested soils

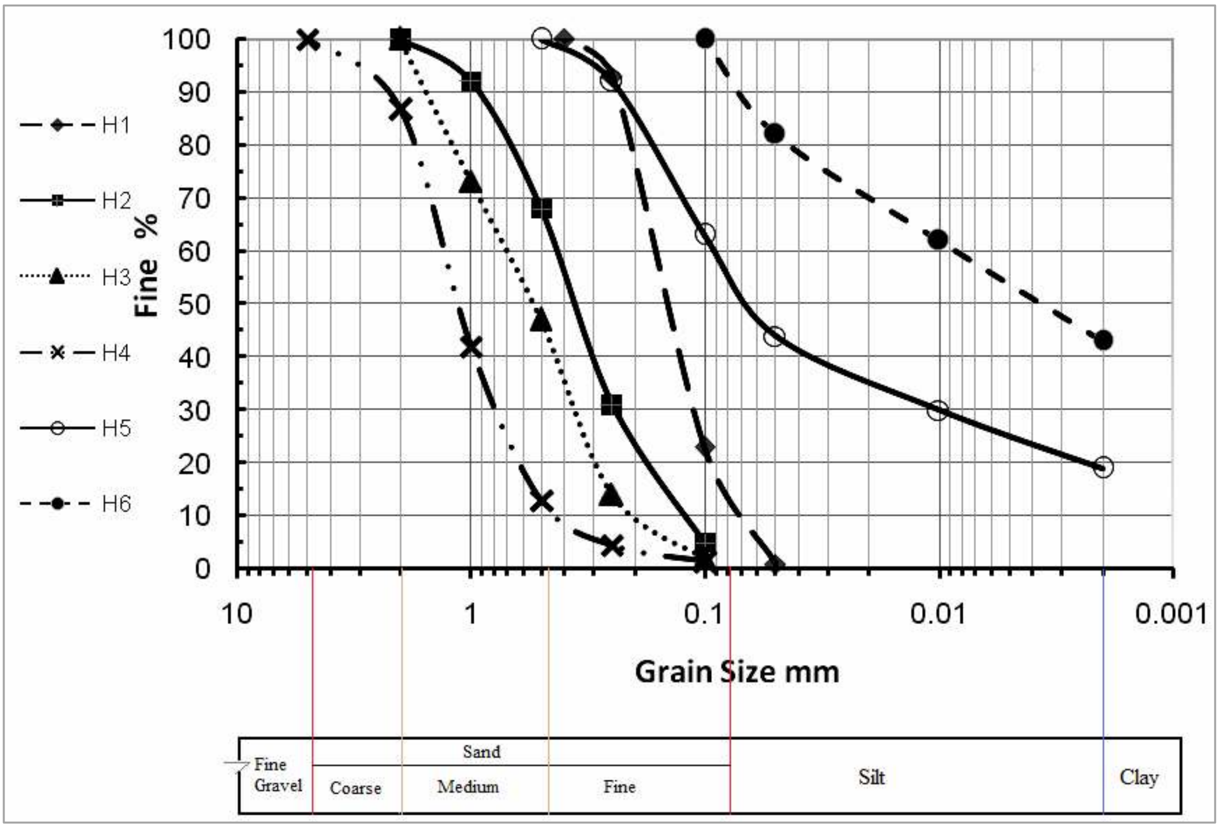


Table 1: Index properties of sandy soil.

Test *No.*	Soil Type	Void Ratio(e)	Natural Water Content(Wn) %	Degree of Saturation(S_r)
1	Fine silty sand (H1)	0.75	~0	0
2		0.80	20.8	0.68
3	Medium sand (H2)	0.58	-0	0
4		0.61	16.3	0.71
5	Coarse and Medium sand (H3)	0.68	~0	0
6		0.57	15.7	0.49
7	Coarse sand (H4)	0.57	~0	0
8		0.61	15.4	0.67

Table 2: Index properties of clayey soil.

Test $N_{o.}$	Soil Type	Void Ratio (e)	Natural Water Content(Wn)%	Liquid Limit(W_L)%	Plastic Limit(W_P)%	Plasticity Index(I_p)%
9	Low plasticity clay (H5)	0.46	18.6	23.5	13.6	9.9
10		0.42	15.2	23.5	13.6	9.9
11		0.46	19.1	23.5	13.6	9.9
12	Medium plasticity clay (H6)	1.06	37.6	44.4	22.4	22.0
13		0.88	30.4	44.4	22.4	22.0

Equipment and Procedure:

A direct shear apparatus with square shear box of 71 mm in dimension, manufactured by Alfa-California, USA, was used for executing the experimental work. The procedure that was followed for implementation of all tests was described by ASTM, [8]. In the lower moving part of the box was poured concrete up to the shear plane and the upper part of the box was filled by the soil specimen. The surface of concrete was moderately rough. The height of the soil specimen was 23 mm. The vertical load was applied using the load frame and the horizontal load by the hand-operated reduction gear. The proving ring was used for the load measurement. The horizontal displacements were measured with digital dial gauge. All soils are tested using three different vertical stresses - for sands 100, 200 and 300 kPa, while for clays 50, 100 and 150 kPa respectively. Some clay specimens were consolidated under vertical pressure 150 kPa one day to permit for testing the overconsolidated specimens. The shear load was increased to the maximum resistance in 10 to 15 steps. Each shear load step was hold until the horizontal displacement stabilized (rate of the displacement less than 0.01 mm/min).

Test results and Discussion:

All the individual test results (more than 39) are plotted as $t = f(z)$ curves in which t is the ratio τ/τ_{max}, where τ is the mobilized shear resistance at the displacement Z between soil and concrete and τ_{max} is the ultimate shear resistance. Using the least squares method the t-z curves were fitted by several relationships. The chosen relationships for fitting are:

1. The generalized formula [4]:

$$t = \left[\frac{Z}{Z_r}\right]^{K-1} - \left[\frac{Z}{Z_r}\right]^{K} \qquad (5)$$

2. Kezdi's equation [3]:

$$t = 1 - e^{-K_z/(Z_c - Z)} \qquad (6)$$

3. The hyperbolic relationship with two parameters [6]:

$$t = \frac{z^{K_1}}{z^{K_1+K_2}} \tag{7}$$

4. The hyperbolic relationship with one parameter [6]:

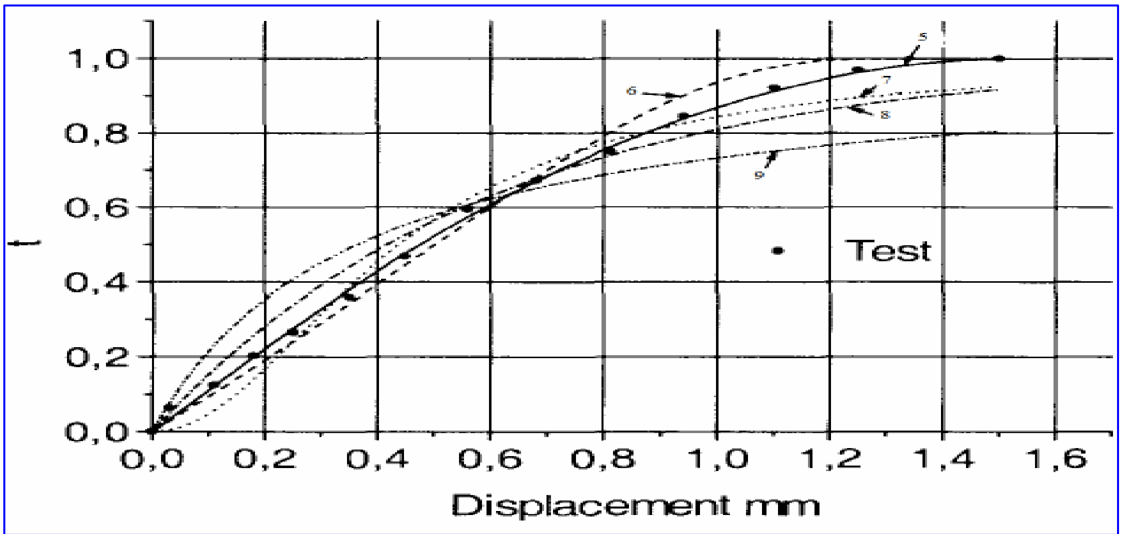
$$t = \frac{z}{z+K} \tag{8}$$

5. The exponential relationship (simplified Kezdi's formula), [3]:

$$t = 1 - e^{(-Kz)} \tag{9}$$

For all relationships were determined the values of the parameters (*K, Zc*) and the standard deviations. An example of the test results and fitting curves is shown in figure 2. As the test results indicate the unlike behavior of sand and clay, both soil types would be discussed separately.

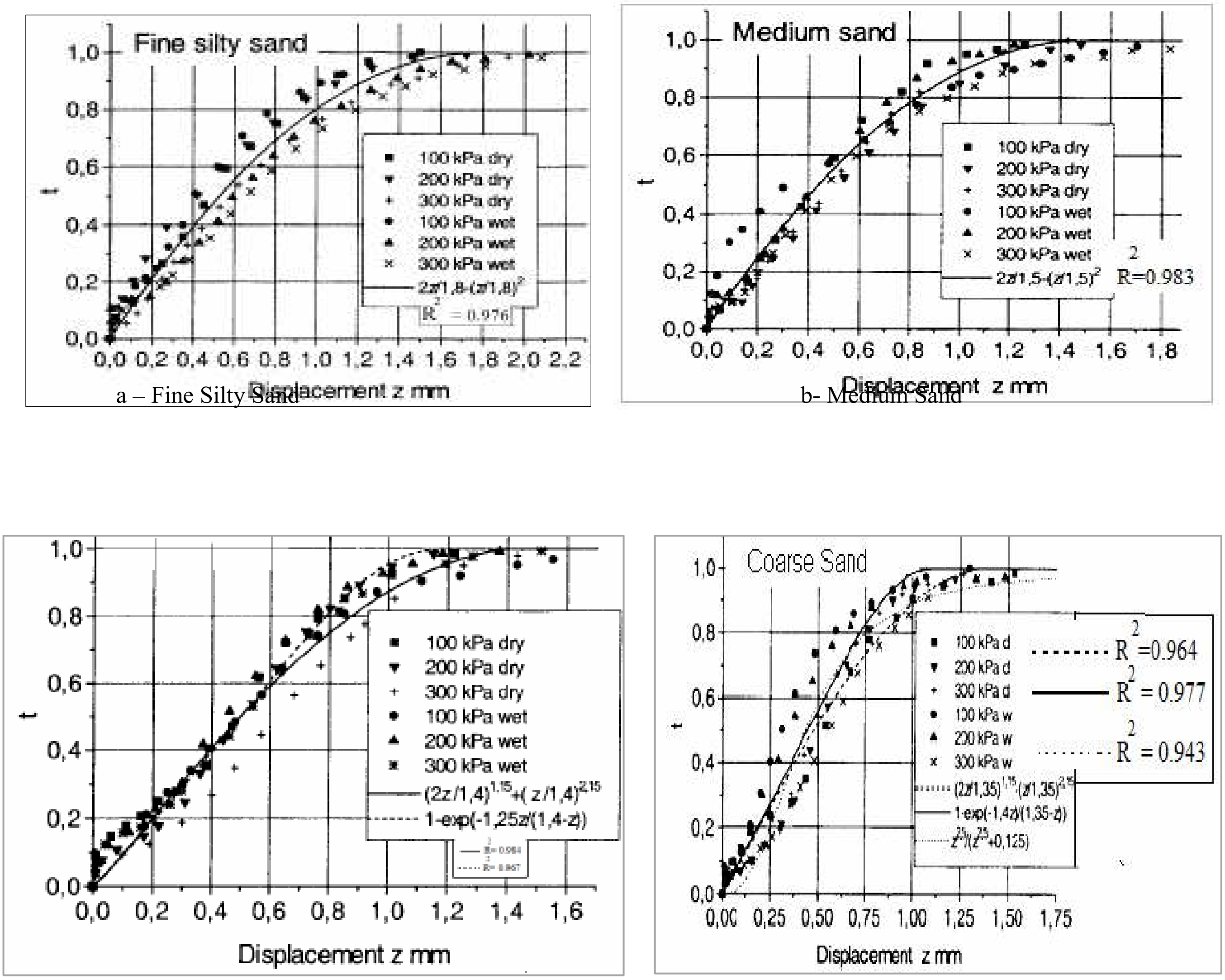
Figure 2: Test results and fitting curves of test 1 (100 kPa). Numbers at curves represent the fitting formula.



1-Sand:

Analyze of the test results allow to conclude, that the moisture and the vertical stress do not affect the character of ***t-z*** curves remarkably. There are some tendency of increasing Z_c values with increasing the vertical stress, however the scatter of results do not allow to draw any final conclusion about that. Therefore, the test results of the specimens with the same grain size but with the different moisture content and the vertical stress were analyzed together. The best fit for most test results gives the relationship (5). Reasonably good results give the Kezdi's formula (6) too, especially for medium and coarse sand. The experimental ***t-z*** relationship for coarse sand is something unusual. At small displacements the increment of the mobilized friction is low and begins increase after 0.2-0.25 mm, (Figure

3). That phenomenon can be described only by formula (7). A formula (8) and (9) gives the less satisfactory approximation in all cases.



a – Fine Silty Sand

b- Medium Sand

c- Coarse-Medium Sand

d- Coarse Sand

Figure 3 Test results and the best fitting curves for sands

The critical horizontal displacement Z_c, at which the whole friction is mobilized, is larger for fine sand as presented in table 3.

Table 3: The values of Z_c mm

Soil type	Limits	Mean
Fine silty sand	1.46-2.08	1.77
Medium sand	1.22-1.83	1.53
Coarse-Medium sand	1.15-1.70	1.43
Coarse sand	1.22-1.87	1.55

In formula (5) the parameter K is approximately 2 for fine and medium sand. The parameter for coarse sand is something more (2.15). In formula (6) the parameter K is for coarse-medium sand and coarse one 1.25 and 1.4 respectively. The parameters in formula (7) for coarse sand are $K_1 = 2.5$ and $K_2 = 0.125$. All test results and the best fitting curves are shown in figure 3.

2-Clay:

For clay, the relationships (5) and (9) give the best fit. The parameter values of these relationships depend considerably on the overconsolidation degree. The critical horizontal displacement Z_c for the normally consolidated clay exceeds more than twice the value for sands and is on an average 3.8 mm. For the overconsolidated clay with OCR=3 the mean value of Z_c is 1.4 mm (minimum 0.9 mm). The parameters in the formulae (5) and (9) are shown in figure 4.

Test results and the fitting curves are shown in figure 5 and figure 6. The formula (9) contains only one parameter and is simpler to use. Therefore, it is used only for the final approximation of the test results.

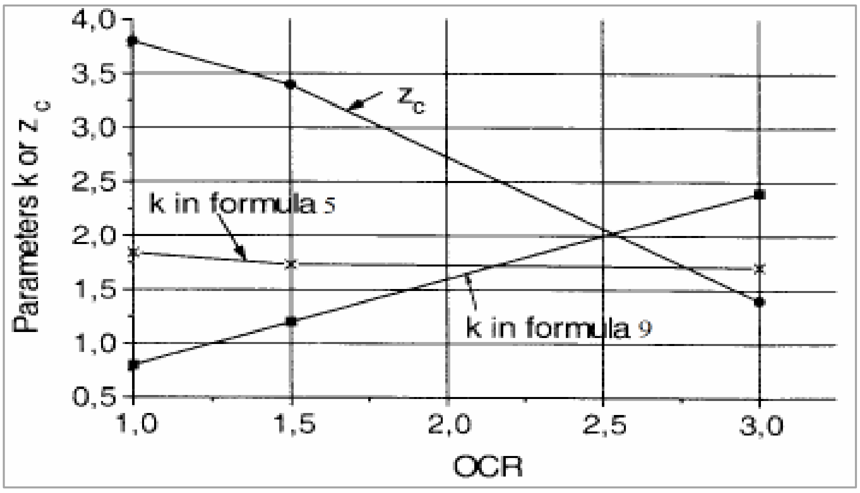


Figure 4: Parameters for clays

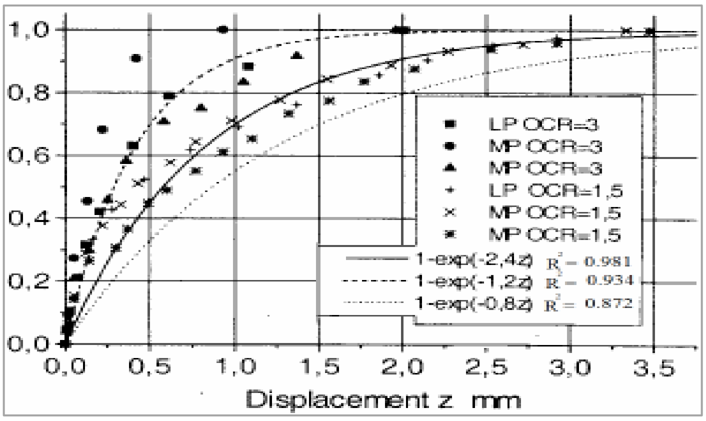


Figure 5: Test results and fitting curves for overconsolidated clay. CL – clay with low plasticity. MP – clayey silt with medium plasticity

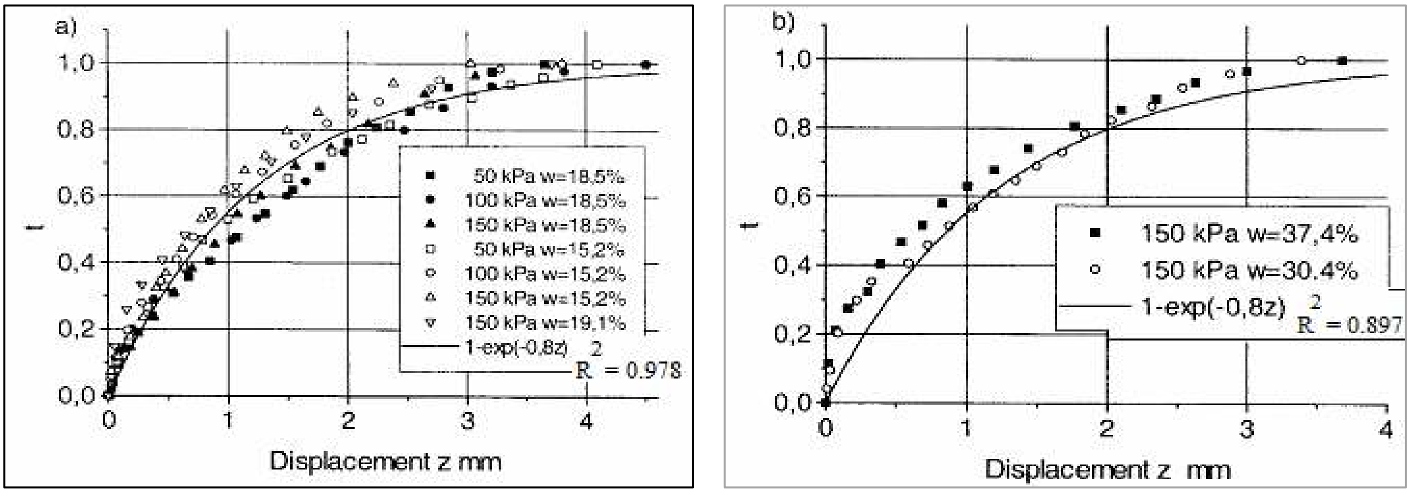


Figure 6 : Test results and fitting curves for normally clay, a) low plasticity, b) medium plasticity

Conclusions:

1. The nature of mobilizing friction between concrete and soil is somewhat different for clay and sand. Maximum shear resistance between concrete and sand develops at the displacement less than 2 mm. The displacement between concrete and normally consolidated clay which produce the full friction resistance is about 4 mm. Overconsolidation of clay reduces the critical displacement.
2. The formulae give the best fit of the laboratory tests results and are practical to calculate the mobilized friction between concrete and sand can be summarized in table (4).
3. For clay the formula is presented in the following form:

$$\tau/\tau_{max} = 1 - e^{(-0.8 \times OCR \times Z)} \quad , R^2 = (0.87\text{- } 0.98) \qquad (10)$$

which describes sufficiently the laboratory test results.

Table(4): Summary for equations of mobilized friction for Sand

Sand Type	Equation	R^2
Fine Silty Sand	$t = {}^{2Z}/_{1.8} - \left({}^{Z}/_{1.8}\right)^2$	0.976
Medium Sand	$t = {}^{2Z}/_{1.5} - \left({}^{Z}/_{1.5}\right)^2$	0.983
Medium-Coarse Sand	$t = \left({}^{2Z}/_{1.4}\right)^{1.15} + \left({}^{Z}/_{1.4}\right)^{2.15}$	0.984
	$t = 1 - e^{\left({}^{-1.25Z}/_{(1.4-Z)}\right)}$	0.967
Coarse Sand	$t = \left({}^{2Z}/_{1.35}\right)^{1.15} - \left({}^{Z}/_{1.35}\right)^{2.15}$	0.964
	$t = 1 - e^{\left({}^{-1.4Z}/_{(1.35-Z)}\right)}$	0.977
	$t = {}^{Z^{2.5}}/_{(Z^{2.5} + 0.125)}$	0.943

References:

1.Fleming W.G.K, Weltman A. J., Randolph M. F., and Elson W. K., *Piling Engineering*, Halsted Press; a Division of John Wiley & Sons, New York, 1985.

2.Dalmatov, B.I., *Soil Mechanics, Foundations and Footings*, Balkema A.A., Rotterdam, Netherland, 1991.

3.Kezdi A., *Bodenmechanik,* Band 2, VEB Verlag für Bauwesen, Berlin. (Translated from Germany), 1964.

4.Vijayvergiya, V.N. "Load-movement characteristics of piles" *Proceeding of Port and arbor Conf: Ports 77,* Long Beach, USA, pp 269-284, 1977.

5.Georgadis M., Pitilakis K., Tsotsos S., Valalas, D. "Settlement of a liquid storage tank founded on piles", *Proc. 12. ICSMFE,* Vol. 2, pp 1057-1060,1989.

6.Kraft L. M, Ray R. P., Kagawa T. "Theoretical t-z curves". *ASCE J. Geotech. Eng. Div.* Vol. 107, GT11, pp 1543-1561, 1981.

7.Frederick S. M., Ricketts J. T., *Building Design and Construction Handbook, sixth* edition, McGraw-Hill Companies Inc., 2001.

8.ASTM, "Direct Shear Test, D 3080", California, USA, 2002.