FRICTION VALUES FOR CAST-IN-PLACE CONCRETE PILES IN A TYPICAL WINNIPEG CLAY

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LIST OF SYMBOLS

c	Cohesion
c_a	Adhesion
ϕ	Angle of shearing resistance
δ	Angle of skin friction
s	Shearing strength
s_a	Skin friction
s_n	Natural shearing strength of the clay
s_s	Softened shearing strength of the clay
α	Coefficient of friction
C_s	Coefficient of softening
p	Normal pressure
Q_u	Ultimate bearing capacity
Q_p	End bearing capacity
Q_s	Skin friction capacity
W	Weight of pile
N_c	Bearing capacity factor
N_{cr}	Bearing capacity factor of rectangular pile
N_{cs}	Bearing capacity factor of long strip pile
D_f	Depth of pile below ground surface
γ	Average density of the soil
A_s	Circumferential or skin area of the pile shaft embedded in clay
A_p	Area of pile point

W/C	Water cement ratio
T	Distance of shear plane from mortar
w	Moisture content at the shear plane
Δw_1	Change in moisture content at the interface of clay-mortar
Δw_2	Change in moisture content at 3/8 in. from the mortar
Δw_3	Change in moisture content at 3/4 in. from the mortar
K_A	Coefficient of active earth pressure
K_o	Coefficient of earth pressure at-rest
K_s	Coefficient of earth pressure of the clay
μ	Poisson's ratio

SUMMARY

Friction values for cast-in-place piles in a typical Winnipeg clay were studied. Shear conditions in the soil near a pile were simulated in the laboratory, using a direct shear apparatus and undisturbed samples of the clay were placed in contact with wet mortar.

Softening of the clay due to soaking under controlled pressures was investigated. In addition, the shear strength of the clay at various distances from the clay-mortar interface was investigated to determine effects of the water/cement ratio and the time of curing of the mortar.

It was found that the consolidated undrained shear parameter c, decreased with increasing moisture content whereas ϕ remained unchanged.

The friction value between the clay and cast-in-place mortar was increased due to the effect of cementing action of the mortar. At the contact surface, the friction was about 2.2 times the shear strength of the clay. The strength of the clay-mortar decreased with increasing distance from the mortar. At a distance of about 0.25 inches from the mortar, its value was approximately equal to the natural shearing strength of the clay for the same moisture content.

The weakest plane was found to be a short distance from the clay-mortar interface, it was at the distance where

the shear strength of the clay-mortar was about the same as the clay strength. The clay was softened by water from the cast-in-place mortar. The coefficient of softening (C_s) of the clay depended on the W/C ratio of the mortar.

The test results indicated that the friction value of the clay for cast-in-place concrete piles was actually the shearing strength of the clay, reduced for water-softening.

The clay used for the test was a clay of medium strength. A safe friction value equal to 200 psf may be used for design practices.

CHAPTER I

STATEMENT OF PROBLEM, SCOPE AND METHOD OF INVESTIGATION

1.1 THE PROBLEM

The friction pile, where a bored hole is made by an auger and filled with concrete to form a pile, is one of the most widely used types of pile foundations in cohesive soils. The advantages of a cast-in-place concrete pile are that the required length is known exactly, there is no wasted length to be cut off and no need of handling and driving. Disadvantages of the cast-in-place concrete pile include the uncertainity of the final condition of the concrete. The concrete may be non-homogeneous because the soil in the bored hole may become mixed with the concrete; the proportion of the mix may not be uniformly distributed due to the segregation of the aggregate during the pouring of the concrete.

The use of the friction value for calculation of pile bearing capacity is very complicated and is still based to a large extent on the empirical correlationships obtained from field loading tests. The variation of the friction value is not well understood due to lack of data. The boundary conditions at the considerable depth of a pile below the ground surface are generally unknown. Friction between a pile and soils around it depends on many factors such as types of soil, types of pile, depth, moisture content and time. In design practice, the friction value is assumed to be a fraction of the shear strength of the soil so as to give an adequate safety factor, usually of about 2 to 3. Settlements must be also considered, but are not part of the present study.

The shear strength of clay will decrease with increasing moisture content in the clay. Friction between the clay and pile is directly proportional to the shear strength of the clay(3), so that it will also decrease when moisture content increases. This may be seen from :

$$c_a = \alpha c \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

c_a = Unit skin friction, or adhesion value, between the soil and the pile.

α = Coefficient of friction value.

c = Shear strength of the soil.

From previous studies, they indicated that value of α is not constant and frequently falls between 0.5-1.0

The change of moisture content in the clay around the pile is still one of the main problems and only a few field investigations have been reported(14). Clay will be softened by water from fresh concrete or from the boring equipment, and its strength and friction value will decrease to some extent.

The load carrying capacity of a friction pile in a cohesive soil seems to be well established after a period of time, when the soil strength lost by the effect of disturbance during boring, placing or driving the pile is regained. Such action has been attributed to thixotropy, or when the excess water diffuses away into the surrounding area, the soil strength will increase automatically. From the observations of pile pulling tests it has been shown that a thin layer of cohesive soil adheres to the pile. This indicates that the true skin friction at the pile shaft is greater than the soil strength at the failure surface. In general, the failure surface of a friction pile in clay occurs in the clay mass at some distance beyond the pile shaft, and it is thus quoted by many engineers that the friction value of a cast-in-place concrete pile should be the same as the soil strength around the pile (2,9)

1.2 SCOPE AND METHOD OF THE INVESTIGATION

The object of this thesis was to study the friction value of clay for cast-in-place concrete piles. An attempt was made through laboratory investigations, using direct shear tests, to represent the actual movement of the pile. Mortar was used instead of concrete to carry out the test. More details are given in Chapter III.

The testing program included :

1. Investigating the shearing strength of the clay at different moisture contents and different normal pressures.

2. Investigating the friction values between the clay and cast-in-place mortar blocks. The observations were made under the variation of the following factors :

- water/cement ratio of mortar,
- normal pressure,
- distance of shear plane from mortar face,
- aging of mortar in contact with soil.

(More details are also given in Chapter III).

3. Investigating the change in moisture content of the clay specimen due to cast-in-place mortar for different W/C ratios and different periods of aging.

The author has tried to interpret the test results using forms of graphical representation to establish, where possible, correlations between the strength and friction value of clay on cast-in-place mortar under different conditions so that the results may be used as a guide for further study or for practical purposes.

CHAPTER II

THEORIES OF FRICTION PILE CAPACITY AND PREVIOUS INVESTIGATIONS

2.1 DEFINITION OF STRENGTH PARAMETERS

In general, the skin friction is closely related to the soil properties and the characteristics of the pile. Thus, the shearing strength of soils can be expressed by :

$$s = c + p.\tan\phi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

in terms of total stresses, where :

c = cohesion,

p = normal pressure on shear plane,

ϕ = angle of shearing resistance.

Similarly, the skin friction between a soil and a pile can be expressed by :

$$s_a = c_a + p.\tan\delta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

in terms of total skin friction, where :

c_a = adhesion,

p = normal pressure on shear plane,

δ = angle of skin friction.

2.2 FRICTION PILE FORMULAS

Pile formulas, based on static conditions for friction pile, are semi-empirical. These formulas use the relationship :

Ultimate bearing capacity = Skin friction capacity + End bearing capacity

The simplified form of the static formula, based partly on the average skin friction and shear strength of soil, and partly on the observation of field loading tests, has been proposed by Terzaghi & Peck(1) and is known as Terzaghi's Semi-Empirical formula. This formula has been put forward by Skempton and has become one of the most widely used formulas for friction piles.

Skempton's solution for clays

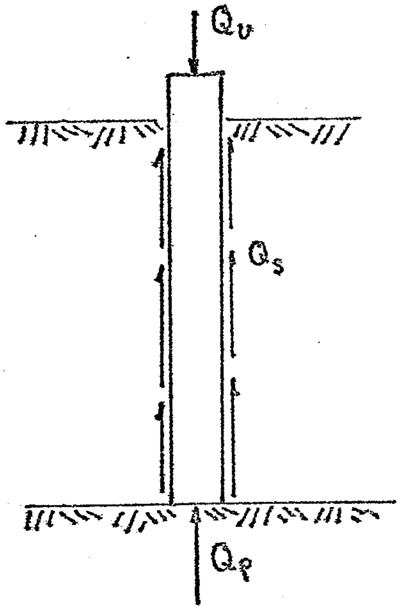

Figure 1.Friction Piles

The simplest formula, partly theoretical and partly empirical, has been proposed by Skempton for piles embedded in saturated clay, where ϕ can be assumed to be zero :

$$Q_u = Q_p + Q_s \quad \text{......(4)}$$

Q_u= ultimate bearing capacity,

Q_p= end bearing capacity,

Q_s= shaft bearing capacity or skin friction capacity.

End bearing capacity can be calculated from :

$$Q_p + W = A_p(c.N_c + \gamma .D_f) \quad \text{..............(5)}$$

W = weight of pile,

A_p= area of pile point,

c = average shear strength of the soil, which

N_c = bearing capacity factor,

γ = average density of the soil within a depth of D_f below the ground surface.

The c value is equal to one-half of the unconfined compressive strength of the soil. Skempton(3) suggested that it would be more accurate if the shear strength of the soil at a depth of about two-thirds of the pile's diameter below its base be used.

In most case, it is a sufficiently close approximation to assume that the weight of the soil, which is replaced by the pile, is equal to the weight of the pile :

$$W = A_p . \gamma . D_f \quad \text{.........................(6)}$$

Thus, the equation (5) becomes :

$$Q_p = A_p . c . N_c \quad \text{.......................(7)}$$

The N_c value has been studied and observed by many investigators who have come to the conclusion that for circular areaa loaded at a considerable depth within a saturated clay, the value is equal to about 9. This value is accurate enough for practical purposes and has been generally accepted.

Figure 2 shows the N_c value, which is based partly on laboratory tests, on theory and on observation of full scale loading tests by A.W. Skempton(13). For a long pile the ratio of D_f/B is much more than 5, so that the N_c value of 9 is usually used in the case of a square or a circular pile.

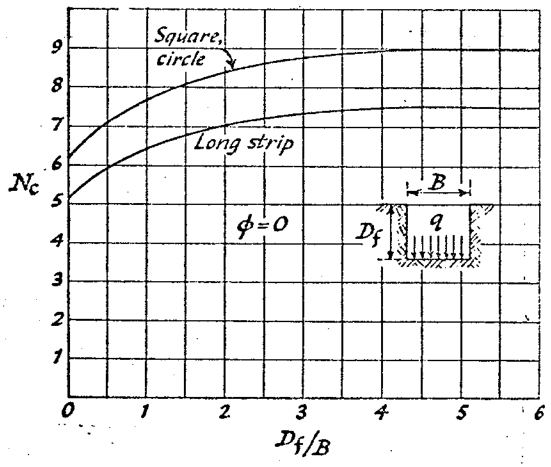

Figure 2. Bearing Capacity Factors
(after A.W.Skempton)

For the long strip (sheet pile) or square pile, N_c values may be obtained directly from the curves. For intermediate shapes, a rectangular strip of length L and width B, the N_c can be calculated from the equation :

$N_{cr} = (1 + 0.2\ B/L)N_{cs}$ ....(7.1)

N_{cr} = bearing capacity factor of rectangular pile,

N_{cs} = bearing capacity factor of long strip from Figure 2.

Shaft bearing capacity or friction capacity can be c calculated from :

$Q_s = A_s . c_a$ ....(8)

A_s = area of the shaft of the pile embedded in clay,

c_a = average unit skin friction or adhesion value on the pile in clay = αc.

2.3 UNIT SKIN FRICTION OR ADHESION VALUE(c_a) FROM PREVIOUS INVESTIGATIONS

The investigation of the friction value of clay on concrete piles has been made by many investigators. Most of them made the observations on field loading tests, and only a few laboratory tests were carried out. Equation (1) $c_a = \alpha c$, indicates that the adhesion is directly related to the cohesion of the clay. Golder and Leonard(3) suggested that the α value should be 0.7 for piles more than 30 feet long.

M.J.Tomlinson(4) assumed that the adhesion value between the pile and soil(c_a) is equal to the remolded cohesion (c_r),when the piles are loaded soon after driving, or full cohesion(c) when the piles are not loaded until the soil regains its strength by thixotropy.

Meyerhof and Murdock (1953) proposed that the adhesion should be equal to the soil strength of the clay after it has been allowed to be fully softened under zero pressure. A series of laboratory tests(12) were carried out by Meyerhof using direct shear tests. Precast mortar blocks were placed in the lower part and clay specimens in the upper part of the shear box. The tests were performed under undrained conditions. He found that the amount of deformation to mobilize the full skin friction was about one times the shear strength of the clay ($\alpha = 1.0$). The same test had been performed at Ecole Polytechnique, Montreal in 1954 by J.E.Hurtubise and Jean Granger(12), the test results were similar to those obtained by Dr.Meyerhof.

Tomlinson(4) presented the results of his investigations on 56 pile loading tests. The approximate values of adhesion of clay on the piles can be reliably used for calculation of pile bearing capacity. The reduction of the ratio, adhesion/shear strength, with increasing shear strength, as shown below, may have been due to lack of contact between clay and the pile shaft.

ADHESION BETWEEN CLAYS AND PILES
(After Tomlinson)

Pile type	Soil type	Shear strength psf.	Adhesion psf.
Concrete	Soft clay	0 - 750	0 -700
or	Firm clay	750 - 1500	700 -900
Timber	Stiff clay	1500 - 3000	900 -1300

The allowable adhesion value for Winnipeg clay as shown in the Metropolitan Winnipeg Building Code(7-b) is 300 psf for firm clay and 150 psf for soft clay.

2.4 FAILURE PLANES OF FRICTION PILES

There is general agreement that, from the observations of pile pulling tests, a thin layer of cohesive soil adheres to the pile shaft and appears as a coating of soil around the pile. This indicates that the true skin friction at the pile surface is much greater than the soil strength. The failure surface of friction pile is not exactly at the surface of the pile but occurs at some distances beyond the pile shaft in the soil mass, as shown in Figure 3.

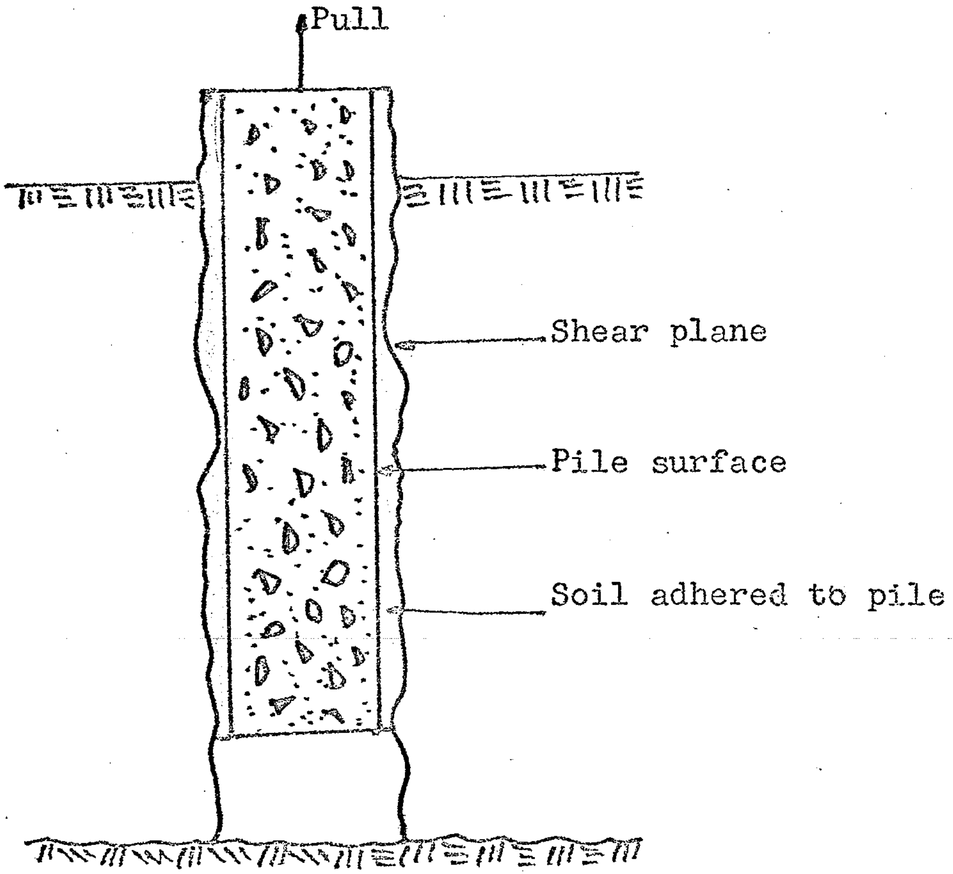

Figure 3.The failure plane of friction piles in cohesive soils (Pull-out tests)

From this point of view, many engineers have quoted that the adhesion value of a cohesive soil, for calculation of pile bearing capacity, should be the same as the soil strength.

2.5 FACTORS AFFECTING FRICTION VALUES

As mentioned before, the friction value between a pile and a soil depends on soil types, pile types, depth of pile, moisture content of the soil, and time after casting of the pile. Friction will increase with increasing grain size, good grading, and with the degree of compaction of a cohesive soil. For fine grained soil, friction will decrease with increasing moisture content in the soil.

Friction and strength of soils may also increase with depth of the pile because of the increase in lateral pressure. A concrete pile with a rough texture gives a greater friction value than the pile with a smooth surface texture as in the case of a steel pile.

In the case of a driven pile, the friction may also be less than the shear strength of the clay because of the lack of contact between the pile and the clay due to lateral whipping of the pile during driving(4). For a cast-in-place concrete pile, the small particles of the concrete mix, such as sand and cement, may be forced into the voids of the soil while the concrete is still fresh. The soil around the pile may become harder than in its natural state, because of possible cementing. During the same time, the moisture content in the soil may be increased by the water from the fresh concrete. The initial softening of the clay, is quite well established, and it seems possible that as the excess water diffuses away into the surroundings, there will be an improvement in the shear strength of the clay in contact with the pile. The shear strength of the clay around the pile is more markedly increased by the effect of hardening of the concrete.

An observation was made in London by W.H.Ward(8-b) on a bored pile which was cast in clay. The clay contained calcium sulphate and the bored pile was made with calcium resisting cement. The pile was exactly one year old when a pit was excavated along its side and the clay carefully removed in a small area. The clay was joined to the pile by a thin film of whitish translucent gel which dried to a white powder on exposure to the atmosphere. The natural rich brown colour of the clay had become faded within ½ inch from the pile, and the clay in this zone was of much higher strength than in its natural state.

This result confirms the statement, as mentioned before (Figure 3), that the failure plane of a friction pile in clay will not occur exactly at the pile shaft, where the strength of the clay is higher than that in the other regions around the pile.

2.6 THE INCREASE IN MOISTURE CONTENT OF THE CLAY DUE TO CAST-IN-PLACE CONCRETE PILES

The increase in moisture content of the clay due to cast-in-place concrete pile may be caused by any or all of the four following causes(14) :

1. Water flows through clay during the process of boring, more markedly in the more fissured clay.
2. Migration of water from the body of the clay towards the less-stressed zones around the bored hole.
3. Water from fresh concrete which usually must be placed at a fairly high W/C ratio.
4. Water from boring equipment.

For cases 1, 2 and 4, the increase of moisture content in the clay may be reduced by technical experience and good workmanship. For case 3, concrete should be placed with relatively dry mixes.

An observation was made in India on bored piles in an expansive clay by Mohan and Chandra(14). They found that the moisture content of the soil adjacent to the pile increased by about 2-3 % above the natural moisture content. It was also noticed that only a thin layer of clay adjacent to the pile was affected and that at a distance of about 1½ inches from the pile shaft, the moisture content was in its lower natural state.

Another observation was made by Meyerhof and Murdock (1953). They found that the moisture content of the clay adjacent to the shaft of a bored pile increased by about 4 % at the contact surfaces and also that at about 3 inches from the pile shaft, the moisture content was not altered.

Time is another factor affecting the friction value of the clay, especially for piles in sensitive clays whose strength decreases to a very large degree by the disturbance during boring and by the pouring of the concrete. After a period of time, when the soil reverts from the remolded state to its natural state, its strength and friction will increase automatically and may be greater than the original strength.