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Large Negative Friction and Friction-Free Pile Methods

Frottement Négatif Puissant et Méthodes de Pieux sans Frottement

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SYNOPSIS Long-term field measurement of negative skin friction on piles charged with bank was executed in alluvial deposit where N-value was 0 to 5 to the depth of 30 m and 5 to 10 in the depth of 30 to 40 m. Negative skin friction amounted partially to about 20 t/m² which was much larger than that on the basis of current design methods, and when a pile with negative skin friction was surcharged with a weight as heavy as design load, its neutral point shifted first upward and with the lapse of time it moved downward. Owing to evident appearance of conspicuously large negative skin friction, more effective and reliable friction-free pile methods, or cased pile method and special grouped pile method, were developed and they were successfully applied to actual foundations in the construction of highly automated marshalling yard.

INTRODUCTION

Japanese National Railways decided on the construction of the Outer Tokyo Loop Line and a large-scale freight yard for the increase in freight service on railways in and around Tokyo and for the modernization of transport system. In this yard, freight cars roll down from a hump by gravity force, and the composition and decomposition of trains are computer-controlled. JNR was forced to choose the yard site on a paddy field of a prefecture adjacent to Tokyo on account of the shortage of land. In the construction of highly automated yard on soft ground, negative skin friction is one of the most important problems for the design of pile foundations.

So far there have been useful researches on this problem and relatively effective methods reducing negative skin friction: e.g., negative skin friction has been one of the most popular themes in the International Conferences on Soil Mechanics and Foundation Engineering. But, there have been several cases of pile failure due to large negative skin friction in recently constructed structures, and therefore an elaborate field measurement of negative skin friction and development of more reliable method reducing it will come to be very significant for the construction of the above-mentioned highly automated yard.

In this paper, conspicuously large negative skin friction is reported and negative frictions are estimated on the basis of long-term measurement of axial force, unconfined compression test, in situ vane test and triaxial compression test.

GENERAL ASPECTS OF YARD

The yard is 5 km in length and 400 m in maximum width, and it covers an area of 1 million m². The low wet paddy field zone exists only 2 to 3 m above sea level and it is very weak even down to the depth of 40 m. Furthermore, in this zone there has been large subsidence of ground of more than 10 cm per year as a result of excessive pumping out of ground water in the urban districts.

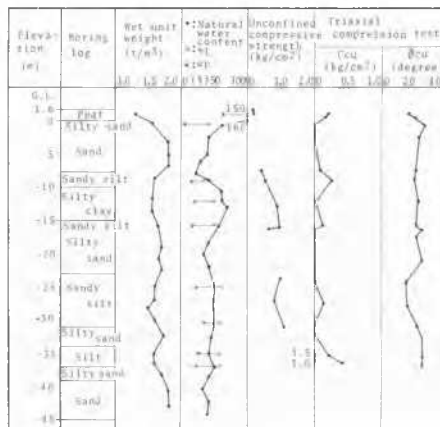


Fig. 1 Properties of ground

Fig. 1 shows the typical geological properties of the test site where the geological profile is conspicuously variable. The deposit is roughly divided into four layers; i.e., upper and lower alluvial layers and upper and lower diluvial layers. In the upper alluvial layer (0 to 10 m deep) N-value of clay layer is 0 to 1, and that of sand layer is about 5. The lower one (10 to 30 m) consists of sandy silt and silty clay with N-value of 0 to 5. In the upper-most diluvial layer, clay layer which is overconsolidated shows N-value of 5 to 10 and unconfined compressive strength of more than 3 kg/cm², and sand layer shows N-value of about 20. Finally, the upper diluvial layer consists of medium-grained sand with gravels whose N-value is about 50.

TESTING METHOD

Instrumented full-scale steel piles were driven by Diesel hammer and at the same time embankment was started to be finished 150 days after pile driving. The piles were equipped with differential transformer type strain gauges, earth pressure cells and pore water pressure cells, and in the surrounding ground were set settlement gauges to measure settlement from surface to lower layer and pore water pressure cells.

The sorts of piles and their purposes are as follows:

Pile No. 1 (point-bearing pile, diameter=60 cm, length=43 m) is for estimation of time-dependent intensities of negative skin friction in the deposit with large natural subsidence accompanied by that due to embankment;

Pile No. 2 (point-bearing pile, diameter=60 cm, length=39 m) is for estimation of pattern of negative skin friction due to surcharging with a weight as heavy as design load in addition to embankment;

Pile No. 3 (friction pile, diameter=60 cm, length=21 m) is for examination of pattern of friction on friction pile for comparison.

RESULTS OF MEASUREMENT

The time-dependent patterns of axial force and friction distributions are shown in Fig. 2. Axial forces increased with increasing bank height. Maximum axial forces at each stage were 440 t at the end of embankment work (150 days after pile driving), 530 t at the time 460 days after pile driving and 1660 days after driving 700 t.

Skin friction is estimated by dividing the difference of two neighboring axial forces by circumferential surface of pile between two neighboring strain gauges, and large negative skin friction as much as about 20 t/m² appeared between 29 to 35 m from surface of ground. Pile No. 1 shrunk itself as much as 1 cm and the settlement of its top was about 7 cm, and so it penetrated as much as

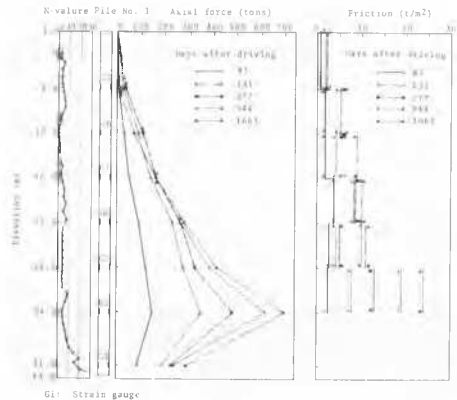


Fig. 2 Axial force and friction (Pile No. 1)

6 cm into the lower layer. That is, negative skin friction by itself seemed to produce the ultimate bearing capacity.

Neutral point defined as the boundary of negative and positive frictions is here considered to exist at the depth where the settlement of pile is equal to that of surrounding ground 8 m apart from the pile. The neutral point of Pile No. 1 existed near its lower end, or at the point of 0.9 times the pile length. Fig. 3 shows the results of measurement on Pile No. 2 which was driven under the almost same conditions as those of Pile No. 1 and was then charged with a weight as heavy as design load; N-value (about 10) at the lower end is less than that of Pile No. 1 (about 40). The maximum axial force was about 340 t at the time 460 days after pile driving and the neutral point existed at the depth of 0.8 times the pile length, and when the pile was surcharged with a weight of 170 t, the neutral point shifted first upward and with the lapse of time it moved downward.

The axial force distribution of Pile No. 3, above its maximum value, was in good agreement with those of Pile No. 1 and Pile No. 2 (before surcharging) in intensity and pattern.

Fig. 4 shows negative skin friction estimated from measured axial force and those based on the results of unconfined compression test, in situ vane test and consolidated-undrained triaxial compression test.

Negative skin friction based on measured axial force is estimated by the following equation.

$$F_a = \frac{(N_k - N_{k+1})}{\pi D l_k}$$

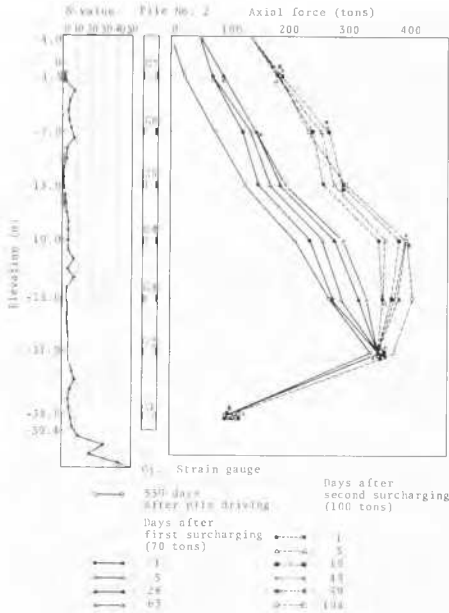


Fig. 3 Axial force after surcharging (Pile No. 2)

in which F_a = skin friction of each layer (geological profile is here divided into 7 layers based on boring log above the maximum axial force point of Pile No. 1)

N_k = maximum axial force of k_{th} layer

D = pile diameter

L_k = thickness of k_{th} layer

And the following expressions are used to estimate negative skin friction from the results of soil test.

$$F_1 = \frac{q_u}{2}$$

F_2 = in situ vane shearing resistance

$$F_3 = K_0 \sigma \tan \phi_{cu}$$

in which q_u = unconfined compressive strength

K_0 = coefficient of earth pressure at rest

σ = overburden pressure

ϕ_{cu} = consolidated-undrained angle of shearing resistance

F_a , F_1 , F_2 and F_3 are shown by full lines, solid black circles, white circles and

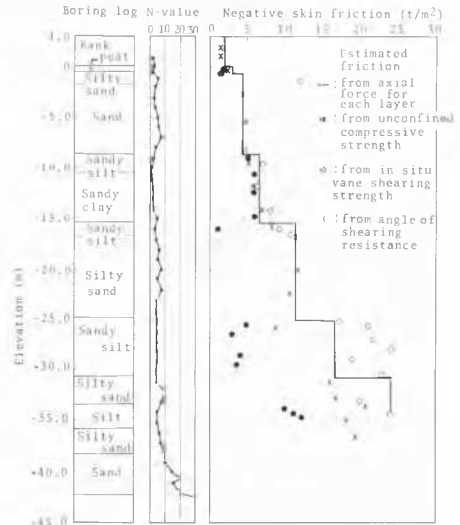


Fig. 4 Negative friction of each layer

crosses respectively in Fig.4.

They are in good agreement to the depth of 15 m where N-value is less than 3 and the percentage of clay is more than 40%, while in the deeper layer, the frictions of $q_u/2$ are conspicuously small as compared with the others. These may suggest the necessity of review of the current friction design theories.

FRICION-FREE PILE METHODS

The evident appearance of large negative skin friction led to the development of the following two reliable methods reducing it.

CASED PILE METHOD

When a pile is cased with an outer pipe, negative skin friction on the inner pile will decrease with increasing length of the outer pipe. A cased pile foundation was applied to the foundation of abutment: design load = about 500 t; diameter of the pile = 70 cm and its length = 42 m; diameter of the outer pipe = 80 cm and its length = 24 m. Outer pipe can easily slide on inner pile owing to the installation of steel spacers and the pipe is equipped with flexible epoxy resin in its upper part about 5 m long which prevents soils from entering into the space. Fig. 5 shows the axial force distribution of cased piles equipped with strain gauges and that of an ordinary pile which was driven for comparison; they are the distributions of 1040 days after pile

driving. The maximum axial force of the former was one third that of the latter.

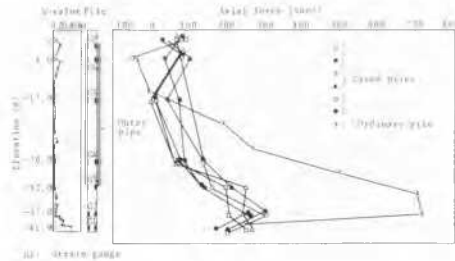


Fig. 5 Axial forces of cased piles and ordinary pile (1040 days after pile driving)

SPECIAL GROUPED PILE METHOD

The foundation by this method consists of inside point-bearing piles being closely driven and outside piles for protection against negative skin friction which are only vertically separated from a footing. A grouped pile foundation was applied to the foundation of pier: design load = 3000 t; diameter of pile = 70 cm; its length = 40 m; center-to-center interval = 1.5 m. As pile driving was considered to be very difficult, steel piles with stiffened open end were adopted; the lower ends of instrumented piles were closed. Fig. 6 shows the axial force distribution of 1040 days after pile driving of grouped piles and that of an ordinary pile for comparison. In the outside protection pile, axial force of 350 t appeared, while in the inside piles, negative skin friction seemed not to appear. Thus two new effective friction-free pile methods have been developed.

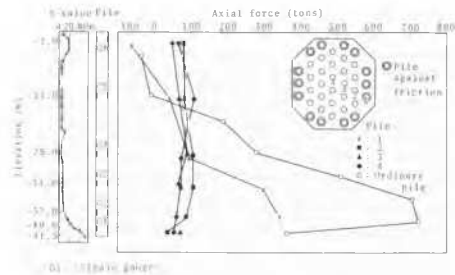


Fig. 6 Axial forces of grouped piles and ordinary pile (1040 days after pile driving)

CONCLUSIONS

The following conclusions may be derived from the results of long-term field measurement of negative skin friction and the application of newly developed friction-free pile methods to actual foundations.

- 1) Far larger negative skin friction than considered so far appears on a point-bearing pile driven in soft deposit with large subsidence.
- 2) It is difficult to estimate negative skin friction of such a pile from unconfined compressive strength except in an upper layer; this suggests the necessity of adoption of appropriate sounding methods.
- 3) The intensity of negative skin friction and the depth of neutral point increase with increasing stiffness of the layer near lower pile end.
- 4) The neutral point of a pile which is surcharged with a weight as heavy as design load shifts upward after surcharging and then it moves downward.
- 5) The two new type friction-free pile methods are very effective and reliable for a soft ground with large subsidence; cased pile method is suitable for a foundation with relatively small design load; and special grouped pile method is suitable particularly for a foundation with large design load.

REFERENCES

Bjerrum, L. and I.J. Johannessen (1965), "Measurement of the Compression of a Steel Pile to Rock due to Settlement of the Surrounding Clay," Proc. 6th Int. Conf. S.M.F.E., Vol. 2, pp.261-264

Bjerrum, L. et al (1969), "Reduction of Negative Skin Friction on Steel Piles to Rock," Proc. 7th Int. Conf. S.M.F.E., Vol. 2, pp.27-34

Florentin, J. and G.L. Heutean (1948), "About an Observed Case of Negative Friction on Piles," Proc. 2nd Int. Conf. S.M.F.E., Vol. 5, pp.155-156