

# INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING



*This paper was downloaded from the Online Library of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE). The library is available here:*

<https://www.issmge.org/publications/online-library>

*This is an open-access database that archives thousands of papers published under the Auspices of the ISSMGE and maintained by the Innovation and Development Committee of ISSMGE.*

# Friction Bored Piles of Higher Bearing Capacity

## Les Pieux Forés Flottants d'une Capacité Portante Elevée

A.A. GRIGORYAN  
B.S. FEDOROV  
M.Y. SMORODINOV  
D.A. ROMANOV

Dr.Sc., Research Institute of Bases and Underground Structures, Moscow, USSR  
Cand.Sc., Research Institute of Bases and Underground Structures, Moscow, USSR  
Dr.Sc., Prof., Research Institute of Bases and Underground Structures, Moscow, USSR  
Cand.Sc., Research Institute of Structures Production, Kiev, USSR

**SYNOPSIS** Buildings and industrial structures on thick subsoil layers of quaternary clayal soils are constructed in the USSR on friction bored piles that cut through soft soils all the way to the harder supporting ones. The present paper gives some specifics of behaviour of these piles disclosed by statical tests accompanied by stress measurements that displayed the poor work of the piles lower tips. Special design has been worked out to increase bearing capacity of these piles in soils with low water content said design envisaging soil compaction at the hole bottom before concreting. Cast pile-supports in water saturated soils are arranged with clay slurry used.

There is not much available data on stress-strain state of the system pile-soil during vertical loading in the range from zero to base pile failure. This especially pertains to pile performance in clayal soils when angle of internal friction  $\varphi \neq 0$  and cohesion  $C \neq 0$  (Mello, 1969). Stress-strain state is basically linked up with pile design, its arrangement technique and physico-mechanical characteristics of soils. Grigoryan (1973) proposed a kinematical scheme of failure of vertically loaded pile in loess soils. Such soils greatly decrease their volume (compaction) when simultaneously loaded and moistened that results from deterioration of soil strength parameters, cohesion in particular. "Load-versus-settlement" relationship in such soils for any water content and density is described by Prandtl diagram; when a pile is loaded all the way to the ultimate load the settlements are very small and characterize the system's elastic state but when the load slightly exceeds the ultimate value and achieves the critical point this results in a drastic subsidence due to soilbase failure. Under constant critical load the pile in homogeneous soil settles progressively due to a series of successive failures. Each failure results from disturbance of limit equilibrium on some critical surface in the soil. The traces of the successive failures are clearly seen on the photograph of the vertical cut of soil around driven or forced-in pile as short inclined cracks departing from the pile shaft (Grigoryan, 1973).

Thus soilbase failure is not continuous but is rather a series of periodical failures that produce traces having the form of the above cracks. Therefore pile settlement rate under critical load is never constant and the settlement progresses intermittently. This soilbase failure process has been obtained during the tests of pile models of 20 mm dia in non-loess loams (Fig. 1). The test have been performed in box with a glass wall with a rectangular grid made on it. Grid distortion enables to approximately plot the failure surfaces that depart from the



Fig. 1 Photo of successive failures traces in soil around the pile with two critical surfaces 1,2 plotted.

open inclined cracks near the pile. The figure shows the traces of repetitive failure surfaces for a pile settlement of 20 mm. As has been shown in the above mentioned paper failure surfaces nearby pile are not continuous slip surfaces. Shear in soil occurs on the soil pile contact. Below the tip the lower part of the failure surface is spherical and the principle major compressive stress is applied to all points of this surface in 3-D axial soil compression. Pile models were put into the test-box and soil was poured around them. The density of the soil was  $1.55 \text{ g/cm}^3$ . The densified core under the lower end of the pile does not appear if the performance of the pile is such like. The cast pile soilbase behaviour, however, is basically similar to that of the driven pile,

the only difference being the fact that ultimate state for the cast pile occurs after formation of the densified core under the pile that under driven pile is generated in the process of driving. Some specifics concerning long cast bored piles have been disclosed by field tests ( Grigoryan et al., 1978 ). The tests verified the presence of a rectangular diagram with constant unit friction along the pile when the ultimated load was achieved, i.e. at the end of the test. Moreover, a regularity has been obtained for the variation of unit friction along the pile versus load from zero to the critical value. Piles 18 m long and 1 m dia were tested. Piles cut through the loam with dry density 1.45-1.58 g/ cm<sup>3</sup> and void ratio 0.878 - 0.734 down to layer of loam with the following characteristics: dry density 1.68 g/ cm<sup>3</sup>, void ratio 0.662, plasticity index 14, friction angle 19°, cohesion 0.03 MPa. Tests were carried out when soils were water saturated (Fig. 2). Especially interesting is the relationship of mean point resistance versus load

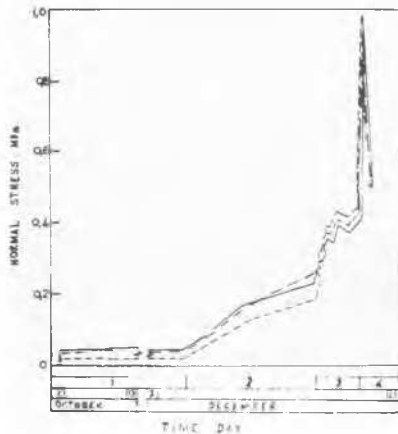


Fig. 2 Variation of the contact pressure under the pile during performance of the pile 1, wetting of the soil 2, loading 3, failure and unloading 4.

during the core formation when the settlement achieves 70 mm, increases from 0.4 to 1.0 MPa. This increased resistance, however, cannot be used in analysis due to great magnitude of settlement prohibitive for the superstructure. Therefore a new pile design involving soil pre-compaction in a borehole have been elaborated to increase the cast pile resistance.

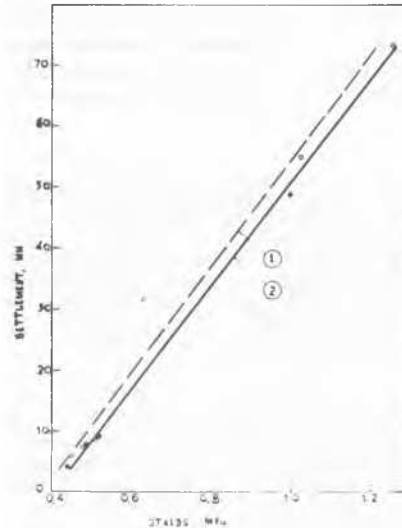


Fig. 3 Growth of the contact pressure under the pile during failure by critical load  
 - - - - for the pile 1  
 \_\_\_\_\_ for the pile 2

Two methods to compact soil have been proposed: tramping-in either gravel or driving-in a pre-fab reinforced unit sunk into the borehole or hammer-driven in the soil. This section of the paper has been written by A.A.Grigoryan. To investigate bearing capacity of deep rectangular pile-support arranged with the help of clay slurry large scale field vertical load tests have been carried out under the guidance of B.S.Fedorov and M.Y.Smorodinov. The test were staged at the site of an official building in Moscow. The size of pile-support were 2.2x0.8 m, it was 16 m deep. Subsoil was mainly fine and medium grain size sand down to 13.5 m and clay below this depth. Pressure gauges were incorporated in the pile to measure soil reaction. Vertical load was produced by ten 100 t hydraulic jacks fixed at the upper end of the support. The load from the jacks was transmitted to loading trusses whose ends were fixed on special anchor footings located on both sides of the tested support. Pressure in the hydro-system was generated by an electrical pump and maintained at the necessary level by a special automatic device designed and manufactured in the Insti-

(Fig. 2) during the failure process (Fig. 3). At the beginning of loading of the test-pile the load is not practically transferred to the lower end. The contact pressure under the lower end of the pile when the ultimate load is acted just before the slump produces is equal only 0.4 MPa inspite of the rather high original soil density under the lower pile end. When a cast pile slumps a densified core is formed. The pressure under the lower end,

tute of Bases and Underground Structures. The supports were tested in compliance with GOST 5686-78 "Piles. Field test technique". The support was loaded stepwise 500 kN each step, up to the rate of stabilization of 0.1 mm during the last hour of observations.

The load on the support achieved 65000 kN for the settlement 21 mm (Fig.4). Soil reaction to the support lower end was just 560 kN that testifies to the presence of high friction on its side surface.

When cast bore piles or concrete tube piles are being arranged the soil in a bore hole is loosened by a boring tool that deteriorates bearing capacity of the piles that is linked up with soil properties. When such piles are being mass fabricated the quality of bore hole conditioning cannot be checked reliably. So necessity arises to develop and implement reliable technique for arranging cast bored piles-supports that provide for high bearing capacity.

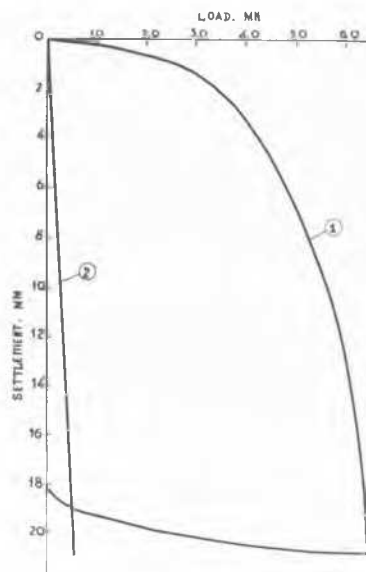


Fig. 4 Settlement versus load for the pile support - 1  
Load transferred to the lower end - 2.

An interesting example of solving such a problem is a known technique to produce footings similar to a rootlike system. A simple and effective method to erect bored support with manufacturable rootlike footing has been developed under the guidance of D.A. Romanov. The essence of the method is as follows. A steel or a ferro-concrete tube with open lower end is sunk with the help of vibro-unit or pile hammer. Then soil is taken out by boring or ejection. A hole is bored in stable cohesive soils with further stabilization of walls with standard casing with a diameter of 20-30 mm less than that of the bore hole. The package of five short ferro-concrete piles assembled together in a leader is dropped down the bore hole. Four small outside piles have lower tip faces oblique to outside while the middle one has a symmetrical tip. The package of piles is joined together through sling clamps by means of flexible wire links. The group of small piles (pilette) is driven by a vibro-unit or by a pile ram with the help of a tubular mast with a support plate. When driven the central pilette is sunk vertically while outside pilettes with oblique lower tip faces are radially moved apart thus densifying soil and affecting a considerable soil mass. The rootlike footing arranged, the support shaft is concreted, reinforcement put inside and standard casing taken out.

To highlight the formation process of the densified soil core, to substantiate rational shapes of sharpening of lower tips of root pilettes, to specify their separation gap received from driving and to determine the bearing capacity of the supports, model tests have been carried out in semi-field conditions in clay and in a versatile test-box 4.5x3.5x3m filled with sand. After load testing the models were dug out for collecting data and photographing (Fig.5). The angle of deviation of peripheral pilettes from the vertical axis in relation to soil density and water content as well as to their geometry was: in clay 14-28°, in sand 15-40°. It has been found that the oblique faces of the tip should be inclined at an angle of 35-40° for medium density soils and of 30-35° for dense soils. Various full size bored and compacted piles and supports have been erected and tested at eight construction sites with a purpose to develop the technique of erection and to determine technico-economic parameters of rootlike footings.

The results of the statistical tests have yielded the fact that bearing capacity of supports with rootlike footing is 70-130% percent higher than that of the piles of the same diameter without underdrilling and 20-50% higher as compared to piles with underdrilled lower tip of 1600-1800 mm dia. Bored supports with rootlike footing have been introduced into practice.

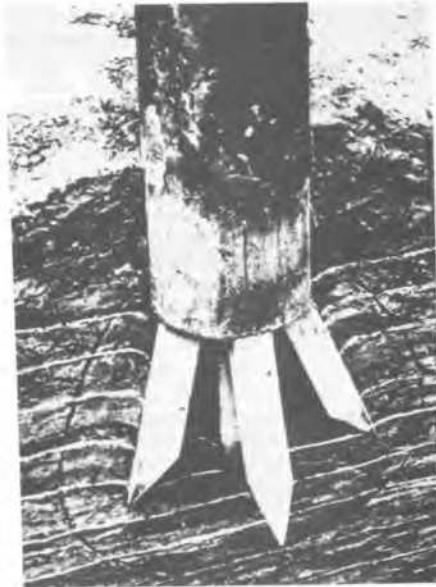


Fig.5 Model pile-support with rootlike footing.

REFERENCES

- Mello,V.(1969). Foundations of buildings in clay. State of the art volume 7<sup>th</sup> Int.Conf. Soil Mech.Found. Eng., 49-136, Mexico.
- Grigoryan,A.A. (1973).Bearing capacity of piles in loess soils. Proc.8th Int.Conf.Soil Mech.Found.Eng., (3), 125 - 130 ,Moscow.
- Grigoryan, A.A., Habibullin,I.I. (1978) The behaviour of large bored piles,Proc. of I.G.S. Conf. on Geotech.Eng., 169-171,New Delhi.