Bearing Piles and Open Caissons for Foundations

Pieux à base élargie

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Summary

In Soviet Russia, both screw and bearing piles are widely employed. Various methods are used for enlarging the bases of piles ; these include explosive charges at the base, a process known as « blow piling », boring and vibration of the concrete in the case of cast-in-place piles.

The authors give a method of calculating the explosive charges and the load bearing capacities of such piles ; experimental data on the bearing capacity of piles with and without enlarged bases are given. The section dealing with bored piles contains the results of experimental work on the making of piles with bases enlarged to a diameter of 3 metres using special boring methods and the mud flush system. Load bearing capacity is determined by loading tests.

The authors also describe the process of enlarging the bases of piles by vibrating concrete to consolidate it beneath the cutting edge ; the results of loading tests on piles with and without enlarged bases are given. They give the results of many tests on the bearing capacity of screw anchor piles and groups of piles in both clays and sands. A method for calculating the load bearing capacity of screw piles is included.

Sommaire

En U.R.S.S. on utilise fréquemment dans les fondations des pieux à base élargie ou à vis. L'élargissement à la base est obtenu par différents moyens, soit par explosion d'une charge d'explosifs à la base du fût, soit avec des outils spéciaux, soit enfin en vibrant et comprimant le béton à la base d'un pieu foré.

Le présent rapport décrit les procédés d'exécution de pieux explosés, la méthode de calcul de la charge, soit concentrée soit annulaire, et l'évaluation de la force portante de ces pieux. Il comporte également une comparaison des forces portantes des pieux avec et sans bases élargies.

La partie du rapport relative aux pieux forés expose les résultats d'expériences au sujet de l'exécution de pieux à base élargie de 3 mètres de diamètre au moyen d'un appareillage approprié fonctionnant dans une suspension d'argile, et donne la force portante de ces pieux telle qu'elle résulte d'essais de charge.

La méthode d'exécution de pieux à base élargie par battage et vibration du béton à la base des tubes à trousse coupante est également décrite ainsi que les résultats d'essais comparatifs sur pieux avec et sans base élargie.

Enfin le rapport comporte les résultats de nombreuses déterminations de force portante de pieux à vis et de groupes de pieux dans le sable et dans l'argile. Il se termine par des indications sur la force portante des pieux à vis.

In Soviet Russia bearing piles formed by camoufletting or by special boring, as well as with vibrated concrete, are widely used. Screw piles are also used.

The enlarged toe of the camoufletted pile (blow pile) is formed by exploding a charge below the base of the pile.

Blow piles are simple and are claimed to be comparatively cheaper than other alternative piles of the same bearing capacity.

The pile is made by driving or jetting to the required depth a pipe with a conical base. If the base is not protected by a cone, soil must be removed. An explosive charge and four electric detonators connected to a current source are placed below the pile.

The pipe is then filled with concrete, the consistency of which is determined by a slump of from 20 to 25 cm.

After firing the charge a spherical cavern is formed beneath the pile. It is filled with concrete from the pipe and so forms a bulb. The height of concrete remaining in the pipe after the explosion should be at least 2 metres.

When the shell is less than 1·2 m in diameter, concentrated charges of explosive are used; for shells of larger diameter it is better to use ring charges.

A method for determining the bearing capacity of the pile and the quantity of explosive has been suggested by A. A. Luga (Fig. 1). (Diagrams 1 (a), 1 (b) are used also for determining the bearing capacity of standard piles.)

Safe load on piles, shells and thin-walled open caissons is determined by means of the following formula :

$$P = m(u \Sigma l_i A F_i + n \Omega \sigma)$$

where

- m : ratio assumed according to Table 1, Fig. 1,
- u : pile circumference,
- A : ratio assumed according to Table 3,
- l_i : depth of each stratum passed by the pile,
- F_i : ratio assumed according to the scheme in Fig. 1 (a),
- n : ratio assumed according to Table 2, Fig. 1,
- Ω : the pile cross section,
- σ : for piles assumed according to the scheme in Fig. 1 (b), for pile shells and thin walled open caissons $\sigma = 1{\cdot}7\ R$, R- allowable soil pressure assumed for solid foundations.

Table 3
Values of ratio A

	Driving				*Vibrodriving*			
	sands	*sandy loams*	*loams*	*clays*	*sands*	*sandy loams*	*loams*	*clays*
Piles $\varnothing \leq 0{\cdot}8$ m	1·0	1·0	1·0	1·0	1·1	0·9	0·7	0·6
Shells $0{\cdot}8 < \varnothing < 2{\cdot}0$	0·9	0·9	0·9	0·9	1·0	0·9	0·7	0·6

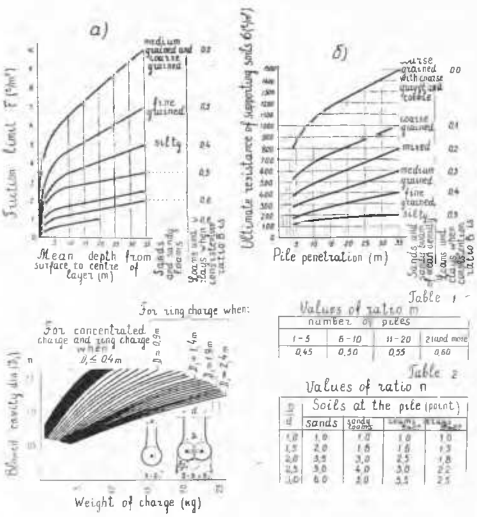

Fig. 1 Calculation of explosive charges. Bearing capacity of blow piles.
Graphiques des calculs de charges et de la portance des pieux explosés.

The diameter of the cavern beneath the pile is determined by the following formulae :

(a) When a concentrated charge is used

$$D \approx (1{\cdot}3 \div 1{\cdot}4)\ \sqrt[3]{V}$$

(b) When a ring charge is used

$$D \approx D_1 + \sqrt{(0{\cdot}4 \div 0{\cdot}5)\frac{V}{D_1}}$$

where :

D : the diameter of the cavern in metres,

D_1 : ring charge diam. in metres,

V : amount of concrete filling the cavern in cubic metres.

The calculations given in Fig. 1 refer to ammonium and trotyl explosives.

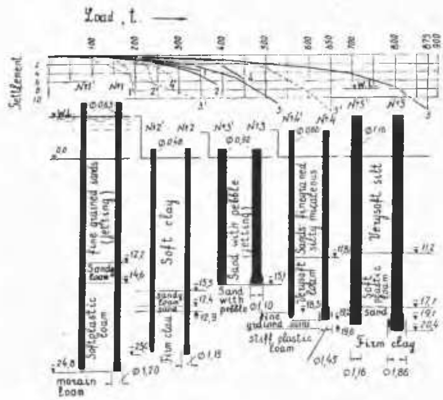

Fig. 2 Load test on piles before and after firing an explosive charge.
Résultats d'essais comparatifs statiques de pieux avant et après l'exécution de bases élargies par explosion.

The results of loading tests on piles before and after the explosion are submitted in Fig. 2.

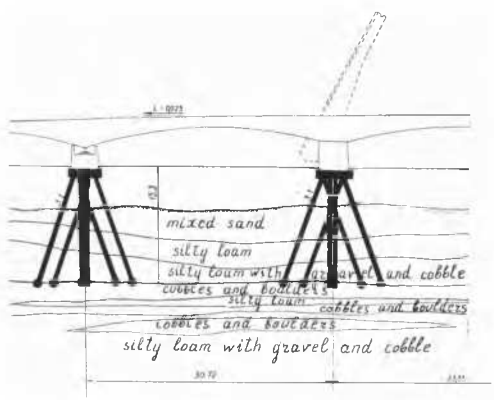

Fig. 3 Blow piles for piers of a bascule bridge.
Applications des pieux explosés pour la fondation des piles de ponts mobiles.

Blow piles may be used for different structures and are particularly valuable for large bridges. The use of blow piles for the high piers of a bascule bridge is shown in Fig. 3.

Bored pedestal piles (developed by Prof. Hlebnikov) consist of a concrete or *RC* shaft 100-150 cm in diam. with an enlarged concrete base about 300 cm in diam.

The pile is made with a special boring equipment suspended from a pile driver or crane. After boring the shaft, this machine is used for reamering the conical base. Drilling mud is poured into the borehole to prevent its collapse and to help in the widening process. Such piles may be vertical or inclined. The equipment enables piles to be bored at a batter of 4 to 1.

The depth of boring in sands with the aid of an air lift may reach from 40 to 50 metres. In clays the available depth is 25 m. Concrete bored piles with enlarged bases are made by filling the hole and the bottom widening with concrete.

Reinforced concrete piles are formed by lowering a reinforcing frame into the borehole. The concrete is placed under water with the aid of a vertical moving tremie, the mud overflowing from the top of the hole.

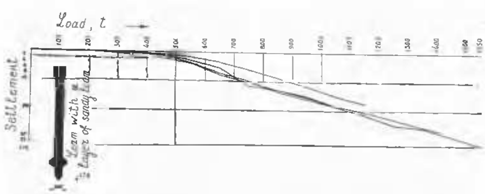

Fig. 4 Load tests on bored piles.
Résultats d'essais statiques de pieux forés du système Khlebnikov.

The results of load tests are given in Fig. 4.

Piles with enlarged bases, formed by tamping concrete into soil with the aid of vibration were used for the first time by I. A. Ten (1958) in bridge construction. Shells 1·2 m in dia. were driven into soft clays to a depth of from 18 to 20 m by a 40 ton out-of-balance vibro pile driver.

Vibrotamping was made by the same vibropiledriver with a 720 mm dia. steel pipe with a punch 5-10 mm in dia., less than the inside diameter of the shell.

The upper part of this pipe had a cap rigidly connected with the vibropiledriver.

The weight of the pipe must not be less than the weight of the vibropile driver. The weight of the pipe was therefore increased by concrete filling. When vibrotamping is used in saturated soils, crushed stone with cement grout injection is employed while in soils of lower moisture content or in dry soils stiff concrete is used. Material for tamping is supplied in several portions. After the shell has been sunk to a designed depth and the soil from within it has been excavated, the first 1·5 cub. m charge of the required material is supplied. Then the material is supplied in increments ranging from 0·2 to 0·5 cub. m with further reduction until completion of tamping, when the resistance of the soil is equal to the vibratory impact.

About four hours are needed to form a widening, about half of this time being spent in assembly and dismantling of the pipe; 1 ½ hours are needed for other operations and a further half hour for tamping.

The diameter of the widening is determined by the following formula (*m*) :

$$D = K\sqrt{\frac{\Sigma P}{R'}}$$

where ΣP = the sum of vertical forces, acting on the soil : the weight of the vibropiledriver, of the pipe and the value of the unbalanced vibropiledriver force :

R' : ultimate bearing capacity (t/m²),

K : coefficient of dynamic action and soil tamping assumed : for sand soils 2·7-3·0, for clay 1·5-1·7.

As a result of vibrotamping the point bearing capacity may be doubled.

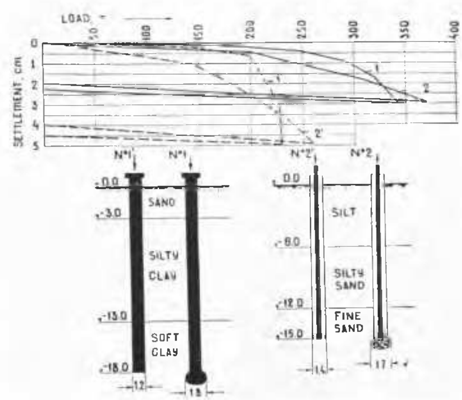

Fig. 5 Load tests on piles before and after making the enlarged bases by the method of vibrotamping the concrete.
Résultats d'essais statiques de pieux avant et après l'exécution de la base élargie au moyen du vibropilonnage du béton.

Tests results on bearing piles and conventional piles are shown in Fig. 5.

At present screw piles are widely used in foundation work. Special site investigation is necessary when considering extraction by pulsation, driving force and the load bearing capacity of a group of piles.

Since 1958 the "Fundament project" Institute has conducted over 100 extraction tests on screw piles from 0·25 m to 0·80 m in dia.*

During tests the following characteristics were investigated :

1. The uplift resistance of screw piles and the corresponding deformations in sands and clays.

2. The critical depth of the screw in the soil — L_{cr}. When the depth is less than critical, the failure of the soil spreads to the surface; when it is more than critical the inner cutting of the soil by the screw at failure takes place.

3. The resistance of a group of screw piles to extraction. The results of some extraction tests on single piles with screw dia. 0·25 m in moraine loam are shown in Fig. 6.

According to the laboratory tests for these loams φ = 22-26°, C = 0·25-0·5 kg/cm². The results of dynamical sound-

* V. Libina, L. Mariupolsky and V. Shwej carried out these investigations under the direction of A. Mihalchuk and L. Vorabkov.

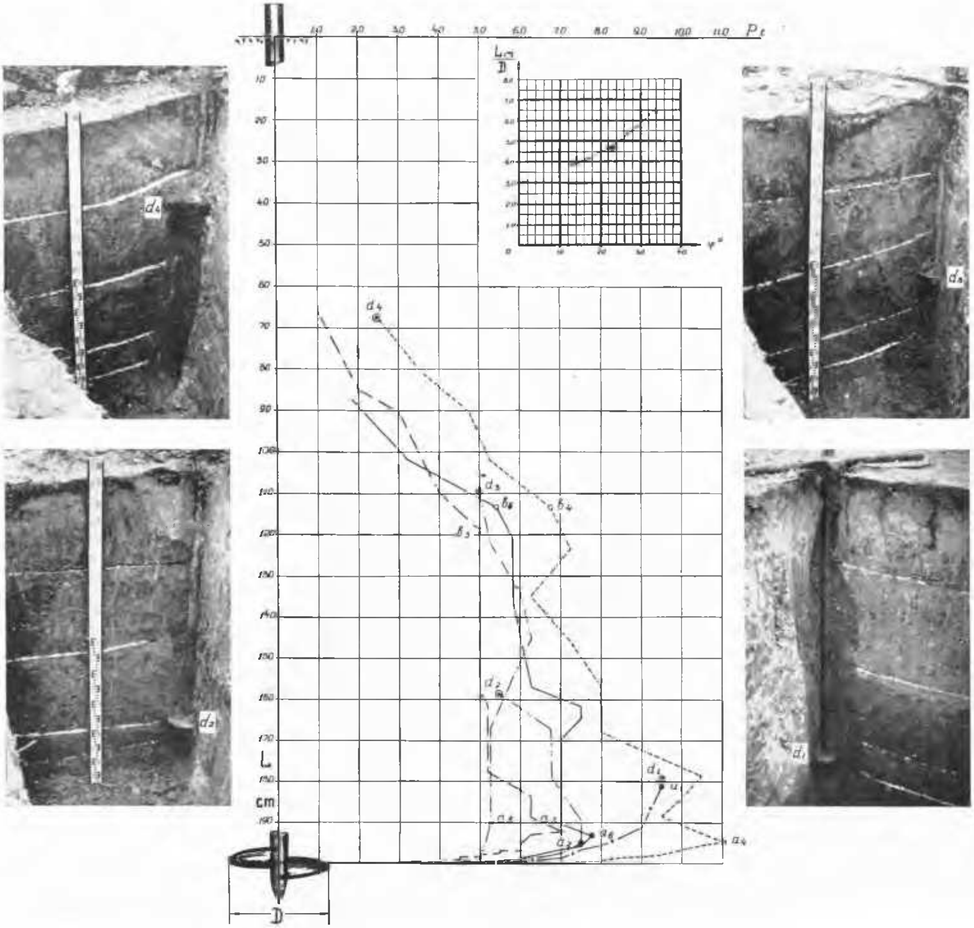

Fig. 6 Results on extraction tests on screw piles in moraine loams and the dependence of $\frac{L_{cr}}{D}$ on φ°.

Graphique des essais de pieux à vis à l'arrachement dans les limons morainiques et graphique de la fonction $\frac{L_{cr}}{D}$ de φ°.

ing show that these loams are comparatively uniform. However, the presence of inclusions peculiar to glacial deposits caused some irregular changes in pulling resistance of the pile.

On the test diagrams the points (a) corresponding to the beginning of the cutting of the soil and the points (b) when failure spreads to the surface are clearly visible. Points (d) correspond to the end of these tests after which the shafts shown in Fig. 6 were dug.

The value of critical depth (L_{cr}) according to the average data of 32 tests carried out in clays, loams and sands is from $4D$ to $6{\cdot}5D$. It is shown in the top right diagram. Deformations at the beginning of rupture of the soil were in average : in sands — $0{\cdot}15D$, in clays — $0{\cdot}25D$ — $0{\cdot}30D$.

The method for determining the bearing capacity of a screw pile when the penetration exceeds the critical value, suggested by J. Trofimenkov is based on extraction tests on single piles. In this case, before the ground is cut ultimate equilibrium with no notable deformations or cracks in adjoining soil appears. Above the screw appears a compact soil cone moving with the screw. The value of the angle at the conical base has not yet been precisely determined

(ψ). Some tests revealed the reduction of this angle, while φ increases. Therefore ψ is assumed to be as follows :

$$\psi = \frac{\pi}{4} - \frac{\varphi}{2}$$

The slip surface is assumed to spread from the top of the cone to the level of the screw blade.

As the blade area is small, in the derivation of the slip line equation the stresses on the blade surface are reduced to one resultant force applied to the blade centre. The angle between the tangent to the slip line and the major principal stress is $\frac{\pi}{4} - \frac{\varphi}{2}$

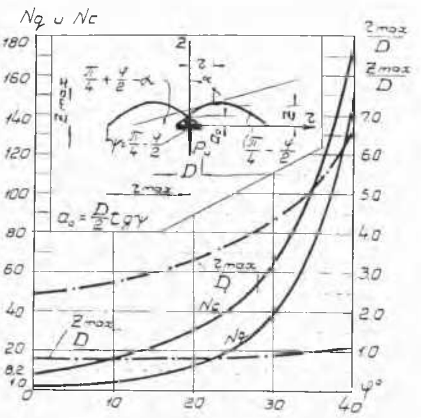

Fig. 7 Design scheme and diagram of values $N_q, N_c, \frac{r_{max}}{D}, \frac{z_{max}}{D}$.

Schéma des calculs et diagramme des valeurs $N_q, N_c, \frac{r_{max}}{D}, \frac{z_{max}}{D}$.

Therefore (see Fig. 7)

$$\frac{dz}{dr} = \operatorname{tg}\left(\frac{\pi}{4} + \frac{\varphi}{2} - \alpha\right)$$

Solving this equation we obtain coordinates of the slip curve :

$$z = a_0 \cos\alpha \, e^{\operatorname{tg}\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\alpha}$$

$$r = a_0 \sin\alpha \, e^{\operatorname{tg}\left(\frac{\pi}{4}+\frac{\varphi}{2}\right)\alpha}$$

To determine the value of the sliding zone Fig. 7 gives :

$$\frac{z_{max}}{D} \text{ and } \frac{r_{max}}{D}$$

Using the slip line equation and the differential equation of limit equilibrium for axial-symmetrical conditions suggested by Berezanzev we obtain the ultimate bearing capacity above the blade :

$$q_u = \gamma L N_q + C N_c$$

where,

$$N_q = \frac{(1 + \sin\varphi + \sin\varphi \cdot \sin 2\psi \sin\psi)(2 + e^{2\sin\varphi})}{3(1 - \sin\varphi)\cos\psi} e^{\pi \operatorname{tg}\varphi}$$

$$N_c = \frac{\operatorname{ctg}\varphi}{\cos\psi}(N_q \cos\psi - 1)$$

L : the penetration of the screw;

γ : soil unit weight.

Fig. 7 gives the diagrams N_q and N_c when

$$\psi = \frac{\pi}{4} - \frac{\varphi}{2}$$

The ultimate pile resistance is

$$P_u = q_u A$$

in which A — is the blade area.

The difference between the calculated bearing capacity of the pile and the one obtained by tests is ± 25 pour cent. A factor of safety of 3 is recommended. When the load was equal to $\frac{P_u}{3}$ the rise of the pile in all tests was less than $0{\cdot}01D$.

The extraction tests on groups consisting of 3 screw piles aligned at a distance from $1{\cdot}5D$ to $5D$ showed no difference between the bearing capacity of a pile in a group of piles and that of a single pile when the penetration of the screw is more than the critical.