Analysis of the relationship between the bearing capacity and diameter of piles in sands

Variation de la force portante des pieux en fonction du diamètre en milieux sableux

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SYNOPSIS Load testing of instrumented piles 73-325 mm in diameter driven in sands have been carried out. The portion of the load carried by the point and by the shaft was measured during pile loading. The relationship between the bearing capacity and diameter of piles was determined. This permits the bearing capacity of production piles to be accurately estimated by the tests of small diameter sectional steel piles driven to the predetermined depth.

The reliable data on the bearing capacity of piles can be derived by the results of static load tests. But these tests are very laborious. During site investigations it is much easier to drive and load test small diameter sectional steel piles of the same length as presupposed production piles.

To evaluate the expediency of the use of these piles, the test results of steel instrumented piles of 73 to 325 mm in diameter were compared. The toe of these piles was equipped with a cone and an electric strain gauge to measure point loads. The strain gauges were also placed along the pile shaft to measure the distribution of skin friction.

The tests of piles of equal length and of 4 different diameters provided data for evaluation of the change of the bearing capacity of piles with the diameter.

Correlations made earlier (Trofimenkov, et al., 1983) showed that in clayey soils the bearing capacity of piles of equal length is directly proportional to diameter of the piles. In sand soils such a relationship is not observed.

Comparison of the bearing capacity of production piles in clays and in sands determined by the load tests (Q_t) and by compution from the results of the load tests of small piles (Q_c) assuming that bearing capacity is directly proportional to the pile diameter is given in Fig. I. The results of both determinations are close in clays and differ in sands. This departure from linear proportionality in sands is the result of a significant role of base load of a pile on its bearing capacity. Therefore the distribution of the load along the pile shaft and pile base was analyzed.

The tests were carried out in alluvial medium sand of medium density with the following characteristics at the level of pile point: unit weight - 18.5 kN/m^3, angle of internal friction -35°, modulus of deformation - 30 MPa, cone penetration resistance, q_c, 7 MPa

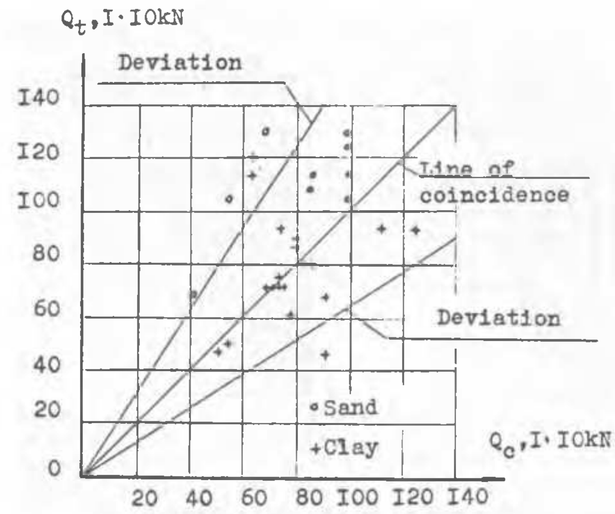

Fig. I Comparison of the bearing capacity determined by tests of production piles and pile of small diameter.

The length of tested piles - 6 m. In Fig 2 the load-settlement diagrams of the test piles of four different diameters are presented. In these diagrams each curve is a mean of the two tests. The distribution of force along the pile shaft is shown in Fig. 3. In this figure it is seen that the part of the total load taken by pile base changes in the process of loading and constitutes more than 40 percent. All the date on results of the tests are given in Table I. As not all load - settlement curves show a definite peak load, the ultimate load was defined as the load causing total pile settlement equal to 10 percent of the radius.

As it is seen from the Table I : the ultimate load, Q_u is increased by 8.3 when the diameter of a pile is increased by 4.4; the ratio of the point load Q_p to the cross section area

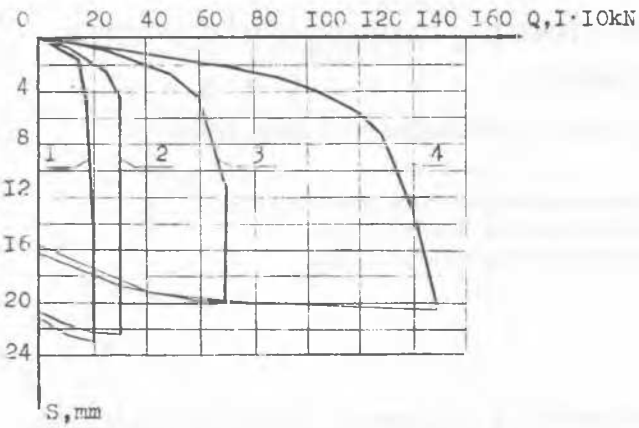

Fig. 2 Load - settlement diagrams of the test piles
I. Dia. 73mm 2. Dia. II4 mm
3. Dia. 2I9mm 4. Dia. 325 mm

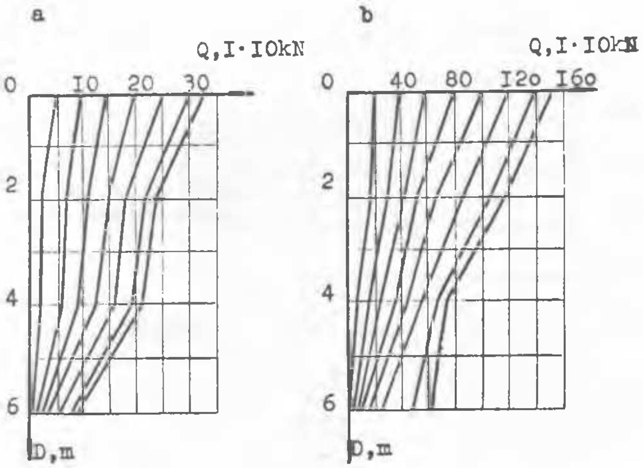

Fig. 3 Distribution of load along a pile shaft
a - pile II4 mm in diameter
b - pile 325 mm in diameter

is approximately constant and does not depend on the pile diameter.
For the determination of the relationship between the bearing capacity and dimensions (length and diameter) of a pile, equation (I) may be written following the technique of dimensional analysis:

$$\frac{Q}{q_c r s} = f\,(L/r) \qquad (I)$$

where Q - load on a pile, kN;
q_c - cone resistance, MPa;
r - radius of a pile, cm;
s - pile settlement, cm;
L - pile length, cm;

TABLE I

Results of Pile Testing

Description	Unit	Pile diameter, mm 73	II4	2I9	325
Pile radius (r)	cm	3.65	5.7	I0.95	I6.25
Ratio of pile Length (L) to pile radius (r)	-	I64	I0.5	55	37
Ultimate load (Q_u)	kN	I70	300	690	I420
Point Load (Q_p)	kN	30	80	290	600
Ratio Q_p/Q_u	-	0.I75	0.267	0.420	0.423
Unit base resistance (q_o)	MPa	7.07	7.7I	7.60	7.08
Unit skin resistance (f)	MPa	0.I00	0.I46	0.095	0.I32
Value for function 0.I f(L/r) by Eq. 2		I8.2	I3.2	8.2	7.7

As was indicated above ultimate load corresponds to settlement equal to 0.I r. In this case

$$\frac{Q_u}{q_c r^2} = 0.I\, f\left(\frac{L}{r}\right) \qquad (2)$$

Value for function 0.I f (L/r) calculated by equation (2) is given in Table I and the graph of this function is shown in Fig. 4. As it is seen in the graph all the experimental points are practical on a straight line. The equation of this line is:

$$0.I\, f\,(L/r) = 0.09I5\,(L/r) + 3.I6 \qquad (3)$$

As a result the following formula is obtained

$$Q_u = q_c r^2 \left(0.09I5 \frac{L}{r} + 3.I6 \right) \qquad (4)$$

After some transformations the formula (4) may be expressed as

$$Q_u = A_s \frac{q_c}{70} + A_b\, q_c \qquad (5)$$

where A_s; A_b - the bearing areas of a pile skin base, respectively.
This expression shows that the unit resistance under a pile point for all diameters is equal to cone resistance divided by 70.

From the formula (5) the relationship between the ultimate loads of piles with different slenderness ratio (L/r) may be found

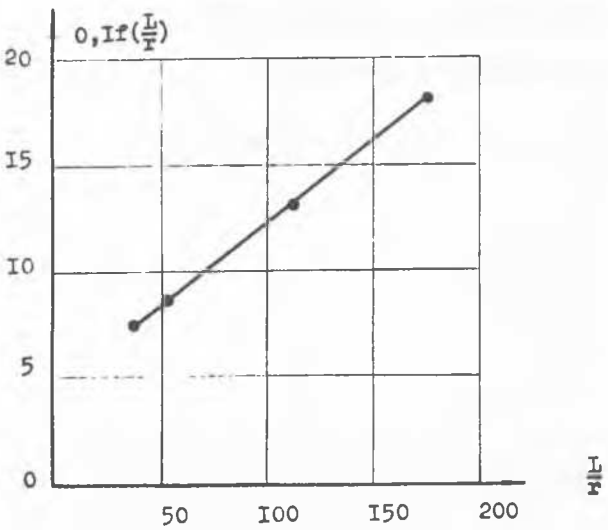

Fig. 4 Value of function 0.I f (L/r)

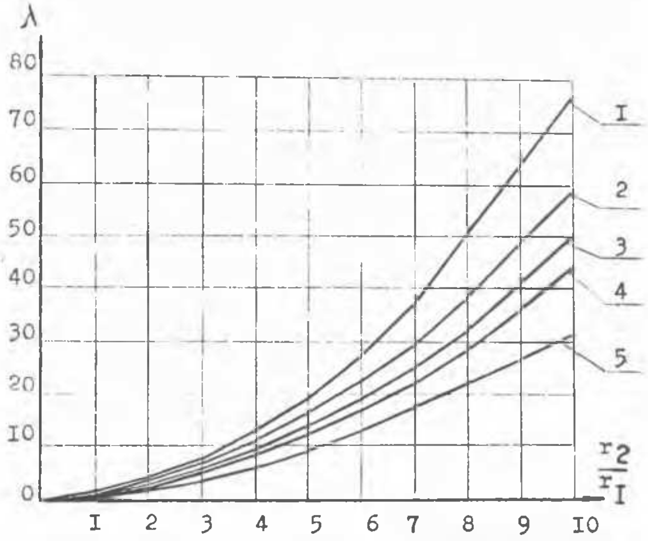

Fig. 5 Variation of λ with r_2/r_I and L/r_I

I. $L/r_I = 20$ 2. $L/r_I = 50$ 3. $L/r_I = 75$
4. $L/r_I = 100$ 5. $L/r_I = 200$

$$\lambda = \frac{r_2}{r_I} \times \frac{I + 35\,\frac{r_2}{L}}{I + 35\,\frac{r_I}{L}} \qquad (6)$$

The variation of λ with r_2/r_1 and L/r_I is shown in Fig. 5

From the formula (6) and the graph in Fig. 5, it is seen that the bearing capacity of a pile in sand is increasing not proportional to the diameter but much more rapidly as it was indicated above on the basis of the tests. The fraction of the load taken by the base is (from Eq. 5)

$$\frac{Q_b}{Q_u} = \frac{I}{I + \frac{L/r}{35}} \qquad (7)$$

In Table II the comparison of the ratio Q_b/Q_u determined experimentally and by Eq. 7 is given.

Table II

Fraction of the load taken by pile base

Q_b/Q_u \ r_{cm}	3.65	5.70	I0.95	I6.25
experimentally	0.I76	0.27	0.42	0.42
by Eq. 7	0.I75	0.25	0.39	0.48

The obtained relationship between the bearing capacity and the slenderness ratio of piles enabled to widely use sectional steel piles of II4 mm in diameter for the determination of the bearing capacity of production piles.

Reference

Trofimenkov, Yu. G., Matjeshevich, I.A., Leshin, G.M., Khanin, R.E., (I983). Reliability of different methods for determination of bearing capacity of driven piles. Foundations and soil mechanics N I, pp. I5-I7, Moscow (in Russian).