Experimental study of bearing capacity of cast-in-situ hollow piles

Recherches expérimentales de capacité portante des pilotis vides

B. V. BAKHOLDIN, Cand. Techn. Sci., NIIOSP, Moscow, USSR
V. I. BERMAN, Cand. Techn. Sci., VNIIGS, Kiev, USSR

SYNOPSIS The paper gives the results and analysis of field test studies of bearing capacity of bore hollow cast-in-situ piles, underreamed and smooth, subjected to compression or pull-out loads. Comparison is made with similar data for solid piles.

In the USSR bore hollow cast-in-situ piles produced by vibro-compaction technique are used. The bearing capacity of such piles was studied at the test-sites.

The piles of 12 m in length incorporated cavity of 530 mm dia at its upper part and of 430 mm dia at its lower part.

Diameter of the piles was 800 mm while their lengths ranged from 11 to 16 m. Some bore cast shell-piles were underreamed with 1.2 - 1.6 m dia bulbs.

Conventional piles were also erected and tested nearby at the site along with the shell-piles with the same outer dimensions as the latter ones(Fig.1).

The piles were erected in stable soils without casing. They cut through loess soils and penetrated stiff clays 2-4 m deep (Table I).

To measure forces along the shaft length string transducers were welded on the reinforcement cage to feed data to a special remote periodometer on the form of electric frequences.

The load acting on the tip and on the bulb was registered by soil contact string sensors whose operation is based on the change of the natural frequency of the string resonator under the load. Not less than 2 sensors were installed on the tip and 3 sensors were installed on the bulb. The settlements of the pile heads were measured by 2 deflectometers with the accuracy of 0.01 mm.

The piles were tested by loads increasing stepwise. There were 15 steps for compression on 10 steps for pull-out tests. Each subsequent step was applied after the settlements stabilized i.e. achieved 0.1 mm settlement increase per 30 min. in compression and 0.1 mm per 120 min. in pull-out. Some tests

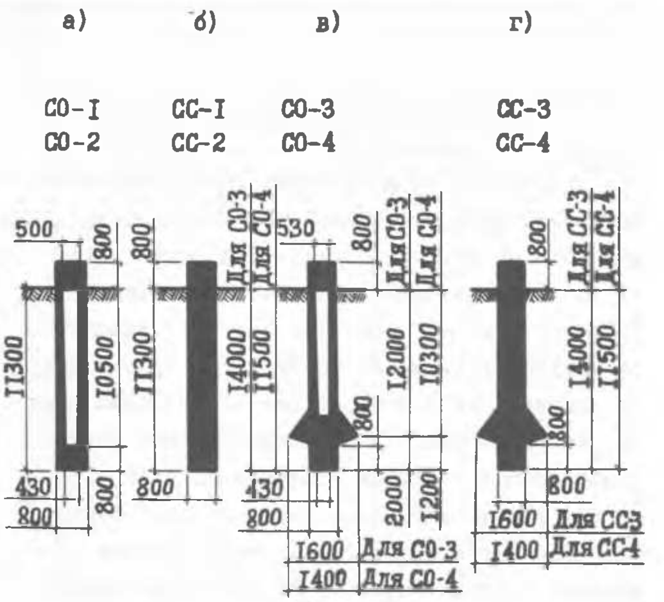

Fig. 1 Identification of Tested Piles

a),b)- shell-piles and solid piles without bulbs

c),d)- shell-piles and solid piles with bulbs

TABLE I

Item to be measured	Kind of soil	
	Loess-sandy loam	Clay
Natural water content, w	0.09	0,21
Natural water content at the plastic limit, w_p	0.18	0.23
Natural water content at the liquid limit, w_L	0.23	0.40
Liquidity index, I_L	-1.80	-0.10
Water content ratio, S_r	0.27	0.87
Specific weight of soil, γ , kN/m^3	15.80	19.50
Specific weight of dry soil, γ_d , kN/m^3	14.50	15.90
Void ratio, e	0.84	0.71
Deformation modulus, E , MPa	30.0	25.0
Angle of internal friction, φ , degree	18	21
Cohesion, c , MPa	0.01	0.11

were stopped due to the repture of reinforcement of an anchor or of a tested pile.

The analysis of consolidated load settlement graphs of cast bore shell-piles both with and without bulbs and cast bore solid piles of the same geometry subjected to compression (Fig. 2) showed that the bearing capacity of hollow piles produced by vibro-compaction of concrete is 1.3-1.5 times higher than that of the piles produced by conventional technique from the liquid concrete mix.

This difference is even more pronounced for pull-out tests. This fact shows that the greater bearing capacity of cast bore shell-piles without bulbs results from the increased resistance along the shaft.

The analysis of friction distribution (f) along the shaft length (e) in pull-out (P) tests yields the fact that friction changes negligibly along the lower third, friction along the upper portion achieves maximum rather quickly while the middle portion exhibits the most intensive change of friction (Fig. 3).

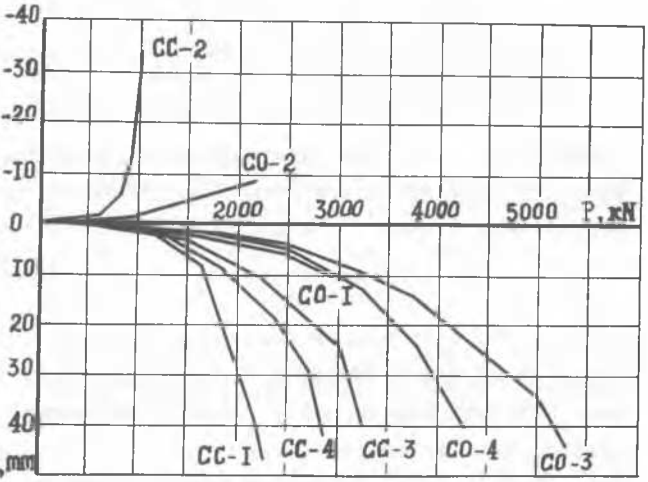

Fig. 2 Settlement-Compression Load Curves for CO-1, CO-3, CO-4, CC-1, CC-3, CC-4 Piles and Upheave-Pullout Load Curves for CO-2 and CC-2

E.g., when the pull-out force grows twofold friction along the middle portion of the shaft increases 3-6 fold.

Theoretical values of friction are represented on the graph by the dotted curve. Side friction (F) in compression (P) tests grows more continuously and is proportional to the applied load until the lower tip is activated then their growth rate lowers (Fig. 4).

The tip of the piles without bulbs endures great loads only after the side friction achieves 60-80% of its maximum value. Notably, even for short piles (l/d=1/14) the tip resistance amounts only to 30% of the total strength of solid piles and 20% of the cast bore shell-piles. This high side friction results from the fact that the piles cut through dry loess soils at all the test-sites.

The lower tip (bulb and heel) of underreamed piles is activated more intensively than that

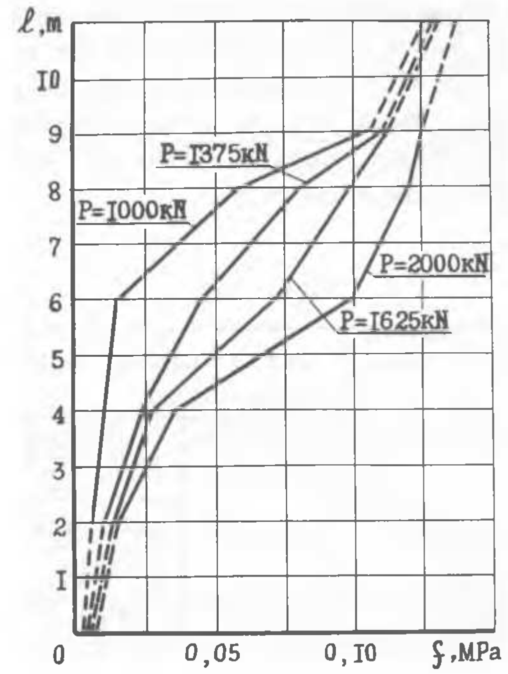

Fig. 3 Friction Distribution Along the Shaft of CO-2 Pile Versus Various Pull-out Loads

of smooth piles while the interaction of resistances at the tip and at the shaft becomes more complicated; the greater is the load applied to the tip the less is the side friction growth which even alternates its direction and then stabilizes. The tip load is the sum of loads applied to the bulb and to the heel.

The bulb is activated much earlier. The pressure applied by the bulb to the soil depends on its diameter to a low extent.

Table II displays data on distribution of loads between the bulb and the heel for piles CO-3 and CO-4 and variation of pressures under them versus pile load growth.

The heel is intensively activated when the load achieves 2/3 of the pile strength. Although the area of the heel is 2-3 fold less than that of the bulb, the load endured by the heel is greater than that endured by the bulb when the pile achieves its ultimate state. This fact demonstrates the low specific effeciency of the bulb. The shares of loads endured by the shaft anf by the tip of the shell-pile with

TABLE II

Pile load, kN	Pressure under bulb, MPa		Load on bulb, kN		Pressure under heel, MPa		Load on heel kN	
	for CO-4	for CO-3	for CO-4	for CO-3	for CO-4	for CO-3	for CO-4	for CO-3
500	0.023	-	24	-	-	-	-	-
1000	0.050	-	52	-	0.032	-	16	-
1500	0.083	-	86	-	0.037	-	19	-
1750	0.108	-	112	-	0.038	-	29	-
2000	0.167	0.043	173	64	0.097	-	49	-
2250	0.240	-	249	-	0.127	-	64	-
2500	0.297	0.200	308	350	0.130	0.015	65	7.5
2750	0.373	-	387	-	0.163	-	82	-
3000	0.464	0.510	481	765	0.462	0.200	232	100
3250	0.581	0.585	602	878	0.880	0.340	442	170
3500	0.651	0.660	675	990	1.630	1.050	820	525
3750	0.682	0.730	707	1100	1.925	1.730	968	871
4000	0.730	0.795	757	1193	2.170	2.400	1092	1200
4250	0.768	0.835	796	1253	2.300	2.815	1157	1408
4500	-	0.870	-	1305	-	3.140	-	1570

1.5 d bulb relate as 1.3:1, they are almost equal to each other for 1.75 d bulb and relate as 1:1.5 for 2.0 d bulb.

To investigate the geometry of the pile shafts and the quality of concrete the soil around 32 piles was excavated down to 6-8 m depth and then the piles were cut off. The measurements showed that the technique of piling did not affect their outer diameters while the concrete-soil adhesion for shell-piles was much higher than that of solid cast bore piles. The concrete moulded by vibro-compaction had denser structure than that of solid piles. The thickness of the shell-pile shaft varied less than 15% in the same cross-section and amounted to 17 cm in the middle portion of the pile.

Thus the strength of soil around cast bore piles without bulbs as compared to that of identical solid piles cast from liquid concrete mix is greater due, mainly, to the side friction increase that results from better concrete-soil adhesion as well as from vibro-compaction of soil mass during casting.

The increase of soil bearing capacity of underreamed cast bore piles is also linked up with side friction growth. This, however, is strongly connected with vibro-compaction of concrete in the bulb and of the soil paste in the heel which is not compacted to such an extent when the shaft is filled with liquid concrete mix.

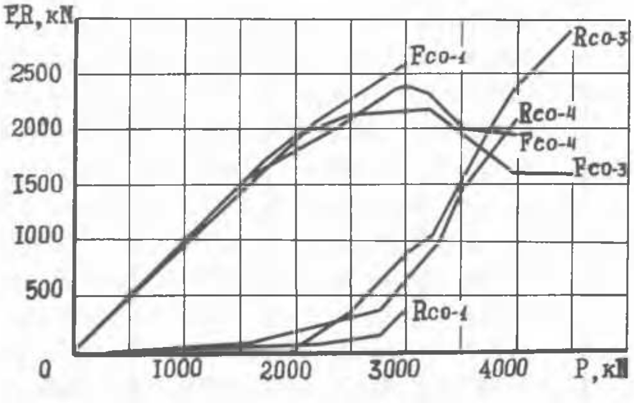

Fig. 4 Side (F) and Heel (R) Resistance Versus Loads Applied to the Pile (P)

Table III displays the specific bearing capacity values of various shell-piles and solid piles per 1 m^3 of concrete as well as the efficiency which is equal to the ratio of specific bearing capacity of the shell-pile to that of the solid pile.

TABLE III

Kind of piles	Specific bearing capacity value, kN/m^3			
	Pile without bulb	Underreamed pile with the bulb dia equal to		
		1.5d	1.75d	2d
Shell-pile	890	844	816	786
Solid pile	318	361	365	351
Efficiency	2.80	2.34	2.24	2.24

The studies has shown that the efficiency of consumption of concrete in the cast bore shell-pile both with and without bulbs is more than 2 fold higher as compared with that of the solid piles made of liquid concrete mix.