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PECULIARITIES OF THE CALCULATION AND DESIGNING OF FOUNDATIONS WITH COMPACTED BASE MICROPILES (CBM) FOR VERTICAL LOAD IN THE PRESENCE OF HORIZONTAL LOADS AND MOMENTA

ABSTRACT

The article presents the results of investigation of the interaction between the FWM and the compacted soil bases with the action of vertical load on the CBM in the presence of horizontal loads and momenta.
The CBMs have complex (hybrid) construction including the group (cluster) of 3 or 4 cone-shaped micropiles with the length of 1.0 m and uniting their common foundation framework with the height of 0.5 m.

The CBM construction technology provides for driving a special metal punch into and removal from the soil using the standard pile-driving equipment.

The metal well punch of the CBM consists of blockouts of the micro-piles and foundation framework, which are interconnected by a flexure link and driven into the subsoil in the following order: firstly, the blockouts of the micropiles and then the blockout of the foundation framework together with the blockouts of the micropiles. The blockouts are removed from soil in the reverse sequence.

The formed punched cavities (wells for the micropiles and pit for foundation framework) are filled with concrete with reinforcement.

During the construction of the CBM, the double compaction of the subsoil takes place due to driving the blockouts of the micropiles and foundation framework. The intensive compaction of the subsoil leads to high specific bearing capacity of the CBM reaching up to 3,000 kN per 1 m³ of the reinforced-concrete body of the CBM.

The long-term practice of application of the CBM as pier foundations (stand-alone and group ones) has revealed the disadvantages of the methods of their calculation and designing reflected in the technological regulations under the joint action of vertical and horizontal loads and momenta upon them, increasing their dimensions and cost and complicating the manufacturing technology due to enlargement of the CBM in the group (cluster) for the pedestal piers.

The article presents the refined (corrected) technique of calculation of the CBM together with the compacted subsoil under the joint action of vertical and horizontal loads and momenta with due account of three-dimensional nature of work of the CBM and plastic jamming of the CBM in the soil (pile-and-soil massive under the foundation framework and compacted filling around the foundation framework). The cost saving (material consumption and erection) is 30-100% depending on the kind of subsoils.

Keywords: foundation, micropiles, well punch, subsoils, compaction, joint work, loads, momentum, calculation.

INTRODUCTION

The foundations with CBM are an original development of Institute BelNIIS RUE protected with copyright certificates. They came into common use in the practice of civil engineering in the Republic of Belarus and were used in the Russian Federation and Ukraine. The CBM technology was purchased by the People's Republic of China and France. The appropriate technological regulations for the CBM calculation, designing and arrangement have been developed [1, 2].

The use of the CBM is the most efficient when erecting the buildings with three-hinged frame, where they are second-to-none as to both the cost and the erection rate [3].

Physically, the CBM is a cluster of three or four cone-shaped micropiles with the length of up to l = 1.0 m and of buried foundation framework in the punched pit with the plan dimensions $a \times b = (0.9 \div 1.4) \times (0.7 \div 1.1)$ m and height h = 0.5 m; here a is the length and b is the width of the foundation framework.

The CBM are manufactured by driving the well punch with the identical shape into the soil followed by concreting the micropile wells and pit of the buried foundation framework. Here, both single and ribbon CBM as well as clusters of two, three and four CBM can be made using a complete set of well punches [4].

The main advantage of the CBM lies in formation of a zone of double hardening (compaction) under the foundation during punching out the micropile wells and pit for the foundation framework. According to the investigations performed, it is the formation of the hardened (compacted) zone that ensures the high specific bearing capacity of CBM (including the filled-up ones) and allows liquidating the effect of fluctuation of the strength (density) of the top layer of natural bases as well as constructing on filled soils with the thickness of up to 3 m without their preliminary compaction [5].

Due to this, one of the highest bearing capacities (up to 3000 kN/m^3 of concrete) among all the kinds of foundations used at present in the construction engineering sector of Belarus is achieved.

Thus, the efficiency of CBM is ensured mainly due to maximum utilisation of the bearing capacity of the subsoil and, therefore, diminution (concrete, reinforcement) of the foundation construction (foundation body). The said development is protected with eight copyright certificates and patents [6 et al.].

The resistance of the CBM bases under the action of vertical loads is determined by [7]:

- the resistance of the compacted soil over the foot of the buried foundation framework (R_0);
- the resistance of the compacted soil over the tip (R) and side surface of the micropiles (R_{fi});
- the normal pressure of the compacted soil (side back pressure) over the side surface of the micropiles (R_i) caused by the conical shape of the micropiles.

The resistance of the CBM bases under the action of horizontal loads is determined by [5]:

- the forces of friction of the hardened soil over foot of the buried foundation framework determined by the value of the vertical counterweight (N) and angle of internal friction of hardened soil (j_y);
- the forces of cohesion (adhesion) between the foot of the buried foundation framework and the hardened soil determined by the area of the foot (A) of the buried foundation framework and specific cohesion of the hardened soil (C_y);
- the forces of the passive soil back force over the side surface of the buried foundation framework and of the micropiles.

The parameters of the hardening zones of subsoils of the CBM and characteristics of hardened soils within these zones have been determined by an experiment and normalized [5].

The compaction zone has the shape of an ellipsoid of rotation. In particular, the maximum dimensions of the zone of compaction of mean-size sandy soils depending on the width b of the buried foundation framework are:

– for dense sands:

width: 4b,

depth: 1.6b;

– for mean-density sands:

width: 2.8b;

depth: 1.8b;

– for loose sands:
width: 2.2b;
depth: 2.9b;

The values of the transition coefficients for determining the geometrical parameters of the zone of hardening (compaction) in comparison with the respective parameters of the mean-size soils are:
– 1.30 for coarse sands;
– 0.80 for fine sands;
– 0.70 for dusty sands and 0.60 with taking into account the occurrence of thixotropic properties.

CORRECTED CALCULATION TECHNIQUE

The calculation of the CBM as regards the vertical load (in the presence of moments) according to the deformations is performed with determining the maximum and minimum edge pressures under the foot of the buried foundation framework [5], which corresponds to the obliquely compressed state of the CBM foundation framework.

In this case, the following conditions shall be met:

$$\sigma_{max} \le 1,2R_y; \quad (1)$$

$$\sigma_{min} \ge 0; \quad (2)$$

$$\sigma_{avr} \le R_y, \quad (3)$$

where R is the design resistance of the compacted soil under the foot of the buried foundation framework;

σ_{max}, σ_{min} are the maximum and minimum edge pressure over the foot of the buried foundation framework, respectively;

σ_{avr} is determined as an average value between the σ_{max} and σ_{min}.

However, the practice of application of the CBM, especially as pier foundations has shown that this calculation underestimates the values of the instant loads, which can be perceived by the CBM. It is associated with the fact that neither spatial nature of work of the CBM nor the plastic jamming of the CBM in the soil (pile-and-soil massive under the foundation framework and compacted filling around the foundation framework) are taken into account.

To consider the peculiarities of the joint work of the CBM with the compacted subsoils under the joint action of the vertical and horizontal loads and momenta, the technique applicable for calculating the foundations in the rammed pits was used [7].

The calculation of the edge pressures σ_{max} and σ_{min} are is performed in accordance with the calculation diagram shown in the figure from the formulae:

$$\sigma^{max}_{min} = (N + G)/A_m \pm (\Sigma M - 0,5 f_h b_m h^2)/W, \quad (4)$$

$$\sigma_{max} \le 1,2R_{(1,2)}, \quad (5)$$

$$\sigma_{min} \ge 0, \quad (6)$$

where N is the vertical component of the resultant of the forces acting upon the foundation kN;

G is the dead weight of the foundation and weight of the soil acting upon the edge of the foundation (see the figure) that is equal to $G = \gamma_m d_0$ (here: γ_m = 20 kN/m^3, d_0 is the thickness of the soil and floor, m), kN;

A_m is the foundation area at the depth of 0.5h(d_p), m^2 (see the figure);

ΣM is the sum of moments including also those of shear (horizontal) forces, kNm;

f_h is the horizontal component of the reactive back pressure of the soil with due account of compaction of the sand blanket with the thickness of h_b equal to the lesser value of the two values:

$f_h = a + b\sigma_m$ (here: a = 100 kPa; b = 0.4; σ_m is the mean vertical stress at the depth of 0.5h, m), kN/m^2;

$f_h = E_p$ (see item Г.2.2 of the Reference Book П19–04), kN/m^2 [5];

$R_{(1,2)}$ is the calculated resistance of soil resistance under the foot of the CBM $R_{(1)}$ and calculated resistance under the equivalent foundation $R_{(2)}$ (under the micropiles) (see Tables 5.6 and 5.7 of the Reference Book П19–04 and the Figure) [5], kN/m^2;

W is the foundation framework section moment at the depth of $0.5d_p$(h), m^3.

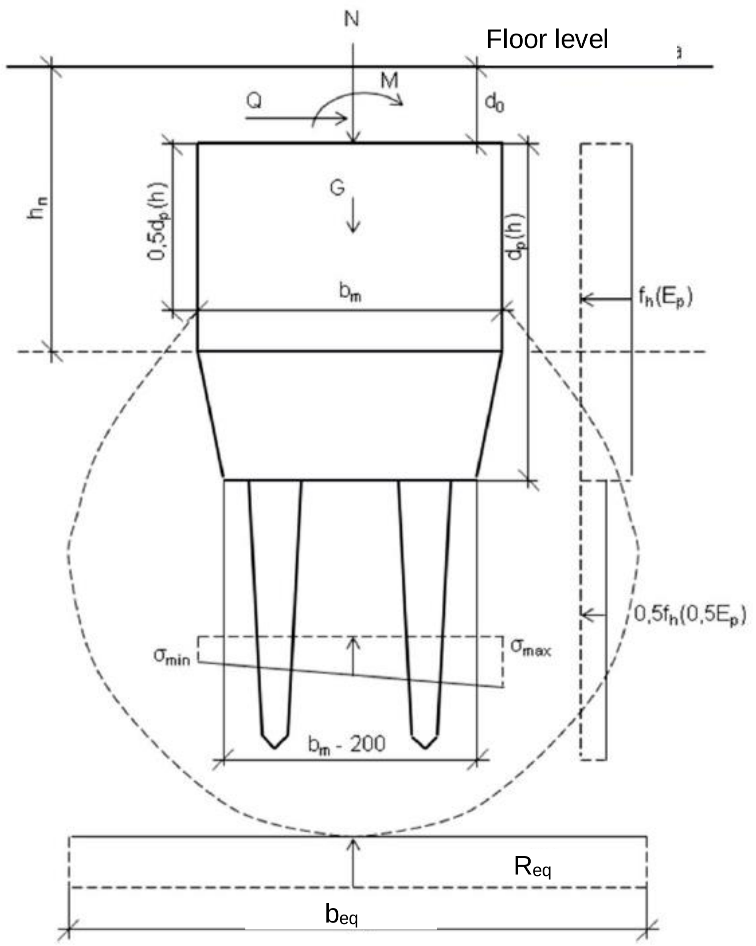

Figure. Analytical model

The value of the mean vertical stress σ_m, kN/m^2 at the depth of 0.5h, m is determined from the formula:

$$\sigma_m = (N + G)/A_m, \quad (7)$$

where N, G, A_m are the same as formula (4).

The values $R_{(1,2)}$ are taken from tables 5.6 and 5.7 of the Reference Book П19–04 [5] with due account for the distance from the calculated surface of the soil to the middle of the layer under consideration, namely:

- the value $R_{(1)}$ at the distance (depth) is 0.5 m in all cases;
- the value $R_{(2)}$ at the distance (depth) is 1.5 m in all cases with the coefficient of 0.6;

In this case, the value $R_{(2)}$ shall not exceed that of the calculated soil resistance (R_{eq}) under the foot of the equivalent foundation (see the figure) with the width of b_{eq} determined for the natural-texture soil according to the data of the engineering and geophysical surveys.

The corrected calculation technique of the CBM under the joint action of the vertical and horizontal forces and momentum was used in designing the pedestal piers consisting of CBM for the columns at the site of the “Sports-and-fitness complex and shopping-and-recreation centre at the intersection of the Kazimirovskaya and Kamennogorskaya St. in the Minsk City” (site 1) as well as in designing the CBM for the manufacturing and storage building near the Sosnovy Bor Settlement of the Myasota Village Council (site 2).

Tables 1 and 2 present the worst-case combination of vertical, horizontal and moment loads as well as results of calculations for site 1.

Table 1

Loads on CBM-1, -2, -3, -4

Name of the CBM	Location of the CBM (building axis)	CBM top elevation, m	Loads		
			Vertical, N, kN	Horizontal, Q, kN	Moment, M, kNm
CBM-1	“Ф”-“5”	(–1.00)	196.34	13.97	68.76
CBM-2	“B”-“11”	(–0.50)	163.71	0.32	144.84
CBM-3	“U-F”-“1”	(–1.70)	271.70	4.42	76.63
CBM-4	“U”-“3”	(–0.50)	786.27	1.48	45.83
CBM-4	“G”-“12”	(–0.50)	1041.88	0.92	78.84

Table 2

Results of calculations of the CBM-1, -2, -3, -4

Name of the CBM	Location of the CBM (building axis)	CBM top elevation, m	CBM driving elevation, m	Calculated resistance of soil $R_{(1)}$ (1,2 $R_{(1)}$), kPa	Edge pressures, σ, kPa	
					max	min
CBM-1	“F”-“5”	(–1.00)	(–1.60)	650 (780)	334.2	3.85
CBM-2	“B”-“11”	(–0.50)	(–1.30)	650 (780)	248.35	62.29
CBM-3	“U-F”-“1”	(–1.70)	(–2.00)	650 (780)	321.19	180.81
CBM-4	“U”-“3”	(–0.50)	(–1.30)	650 (780)	599.25	593.71
CBM-4	“G”-“12”	(–0.50)	(–1.30)	650 (780)	773.1	770.3

When using the standard calculation technique (see conditions 1–3), the plan dimensions of the CBM (according to Tables 1 and 2) increase 1.5÷2.0 times.

CONCLUSION

The corrected calculation technique of the CBM under the joint action of the vertical, horizontal and moment loads was presented, with due account for spatial work of the CBM jointly with the compacted soil basis and plastic jamming of the CBM in the compacted soil.

The cost saving (material consumption and erection) is 30-100% depending on the kind of subsoils.

The proposed corrected calculation technique of the CBM has been applied in designing two real construction sites and will be introduced into the technological regulations [5] as amendments and addenda when revising them after appropriate approbation at other constriction sites.

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