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Role of accuracy and quantity of field tests in engineering-geotechnical researches for construction

Key words: soil tests, accuracy (reliability) of tests, static sounding of soils, bearing capacity of piles, entropy, amount of information

Introduction

The engineering-geological and engineering-geotechnical surveys for the construction of buildings and structures are often associated with a large number of different soil tests (static sounding, dynamic testing of piles, dynamic sounding, static testing of piles "production" sizes, soil testing with a stamp and pressing meter, geophysical research, etc.). The results of such tests can vary significantly in their reliability and number (Trofimenkov, Matyashevich, Leshin & Khanin, 1983; Ryzhkov, 1995; Viana da Fonseca, 2010; Abu-Farsakh, Yoon & Tsai, 2014; Togliani, 2018). So it is difficult to generalize the data obtained, since the researcher has to deal with many particular values of the desired indicator which does not reflect the conditions of various points on the site only, but also the reliability of the tests themselves. Neither Russian nor foreign regulatory documents on geotechnical issues contain clear guidelines for the analysis of unequal tests, which in practice leads to a simplified approach when decisions are made based on the results of the most accurate method, and the results of other methods are considered as "safety net" and practically do not affect the decisions taken (Ryzhkov, 1995; Lunne, Powell & Robertson, 2004; Viana da Fonseca, 2010; Zhang et al., 2010; Zhao, Sun, Zhang & Li, 2012; Abu-Farsakh et al., 2014; Davies, 2015; Ryzhkov, Norshayan & Khamidullin, 2016; Xia, Xiong, Dong & Lu, 2017; Hu, Yuan, Mei, Qian & Ye, 2018; Lu & Zhang, 2018; Melnikov, Kalashnik & Kalashnik, 2018; Qiu,

Wang, Lai, Zhang & Wang, 2018; Khafizov et al., 2019). Such an underutilization of approximate test methods is characteristic not only of Russian, but also foreign research practice. This situation seems abnormal, since it takes a lot of time and material resources to conduct approximate tests, and their influence on the final result is minimal.

This situation occurs in surveys for the construction of objects on pile foundations, when the bearing capacity of piles becomes the desired indicator, and methods of varying accuracy are used in parallel to determine it. Such methods usually include static sounding of soils and static tests of full-scale piles (according to modern terminology "soil testing with piles") (Lunne et al., 2002; Ryzhkov & Isaev, 2016; Ryzhkov et al., 2016; SP 24.13330.2011). These are the most accurate methods for assessing the resistance of piles, but they differ significantly in many of their qualities, and therefore it is convenient to consider the role of approximate and "accurate" test methods in geotechnical surveys using their example (Mustafin et al., 2018; Khafizov et al., 2019).

Static sounding is a fast, cheap method for assessing the resistance of piles, which is widely used throughout the world (Lunne et al., 2002). By the reliability of the assessment of the resistance of piles, sounding is inferior to the static tests of full-scale piles, but the static tests are much more expensive and longer. Static sounding, conducted to a depth of 10–15 m allows (using the appropriate computer programs) in a few minutes to evaluate the resistance of piles of any length in the considered depth range (e.g. 3–15 m). But the "error" in determining the desired resistance of the pile is usually in the range of 30–35% "according to sounding data by Russian standards" (Trofimenkov et al., 1983; Ryzhkov & Isaev, 2016). Approximately the same reliability is in using the foreign methods for calculating the resistance of piles according to sounding data (Viana da Fonseca, 2010; Abu-Farsakh et al., 2014; Togliani, 2018).

At the same time, a static test of piles ("soil test of piles") lasts several days, and before this, it is required to manufacture these piles, deliver these piles (test and anchor) to the place of testing, drive the piles and leave them for two or three weeks in the soil ("rest" of piles). All this takes about a month. Although the reliability of the result of such an assessment of pile resistance is high ("errors" of less than ±5%), its cost is about 20–30 times higher than the cost of determining according to sounding data, and the time spent (taking into account driving and "rest") is tens and even hundreds of times more than when using static sounding. For these reasons, static tests are usually carried out in rare cases (during the construction of high importance or in difficult soil conditions) and sounding is used everywhere (especially in foreign practice). At the same time, geotechnical experts all over the world consider the results of static tests of piles as conditionally "accurate", and the results of calculations based on sounding data as "close".

Methods

For a theoretical assessment of the information content of any approximate method, it is necessary to establish

quantitative criteria for the reliability of its results. These are usually data from the previous experience, in the form of a comparison of "accurate" and approximate indicators. When considering the reliability of determining the resistance of piles from sounding data, it is necessary to compare the resistance of piles determined by this method with the resistances taken as a standard, i.e. according to the results of static tests of natural piles (Ryzhkov & Isaev, 2016) in the period 1960s–1980s. Static sounding was performed by installation C-832 (heavy CPT rig of the USSR-Russ; the tensometric cone penetrometer).

The resistance calculations of piles were conducted according to the method described in the Russian regulatory documents in force at that time, i.e. SNiP II-17-77, SNiP 2.02.03-85 (the calculation procedure has remained unchanged to date). The engineering and geological conditions of the sites on which the comparison was carried out were characterized mainly by alluvial, deluvial deposits, mainly clay, but in some cases, sites with other deposits (fluvioglacial, moraine, etc.) were found. The sites were located in the European and West Siberian parts of the former USSR (Ufa, Sterlitamak, Salavat, Neftekamsk, Perm, Tyumen, Samara, Tobolsk, Nizhnevartovsk, Ryazan, Moscow, St. Petersburg, Astrakhan, etc.). The tests were associated with industrial and civil buildings' construction in the period 60–80 years of the twentieth century. Soviet normative documents carried out probing and static testing of the piles. The method of testing and processing the obtained data did not fundamentally differ from the modern Russian rules. The test results of 504 piles with a cross section from 0.2 × 0.2 to 0.4 × 0.4 m (mainly 0.3 × × 0.3 m) and 3–18 m length were used. The tests were carried out in accordance with the requirements of the valid standards for static testing of piles, i.e. State standards GOST 5686-51, GOST 5686-78 (the criteria for assessing the ultimate resistance of piles did not differ significantly from the criteria currently adopted according to the State standard GOST 5686-2012. During static tests of piles, the load at which the draft was 2 cm was taken as the ultimate resistance "which corresponded to Soviet standards (during this period, the requirements of regulatory documents in the USSR were mandatory)".

Similar results for other approximate tests were obtained in the 1980s by the specialists of the Foundation Project Institute (Ryzhkov et al., 2016).

Displayed on Figure 1 data allow to evaluate the accuracy of individual (single or generalized) values of the resistance of piles. But in practice there is usually a situation where it is necessary to assess not individual resistance values, but of the site as a whole, including finding out the location of its sections with different pile resistances. In other words, it may be necessary to evaluate the numerical "image of the site" in the form of a cartogram of the distribution (in terms of) of the resistance of piles. If such a cartogram is constructed according to approximate data, it will inevitably contain distortions of the true "image". A similar problem arises when constructing a geological-lithological (or numerical) section from approximate initial data. With inaccurate source data, such a section will also be distorted.
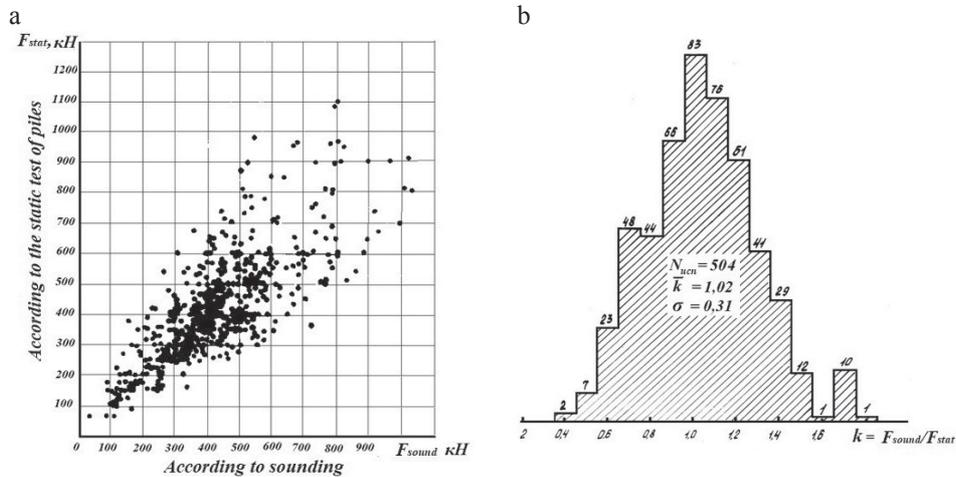
FIGURE 1. Results of comparison of ultimate resistance of driven prismatic piles, calculated according to sounding data, F_{sound} with the resistance obtained by their static tests, F_{stat}: a – scattering diagram of F_{stat}–F_{sound}; b – histogram of the distribution of relations F_{sound} / F_{sound}, constructed according to the same data

For a theoretical analysis of the influence of the accuracy of the source data on the resulting cartograms, it is necessary to introduce some quantitative criteria.

Figure 2 shows a site of arbitrary shape, divided into n small sections, within which the ultimate resistance of piles can be considered the same. In practice, this is possible, for example, with plot sizes of 10–20 m². Each section will be characterized by its ultimate resistance of the piles (F_i), so that the entire site can be represented in the form of a cartogram of these resistances. As already been noted, depending on the reliability of the method for assessing the F_i, this cartogram will differ to some
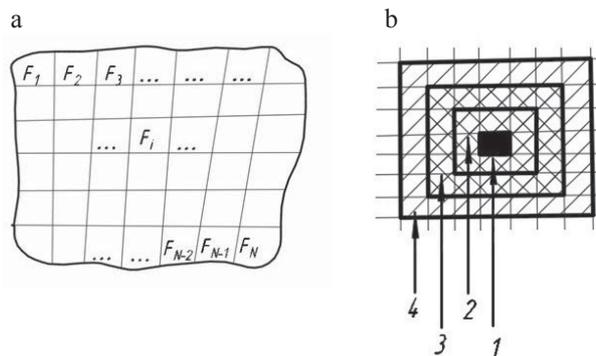

FIGURE 2. Scheme of dividing the site into sections and the scheme taking into account the heterogeneity of the soil when extrapolating the test results outside the test site: a – site plan (cartogram of ultimate resistance of piles F_i); b – zones of extrapolation of test results: 1 – "absolutely" heterogeneous soil; 2 – high heterogeneity; 3 – medium heterogeneity; 4 – almost homogeneous soil

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extent from the true distribution of these resistances. The described approach was used by us earlier, but the methodological methods used now seem somewhat outdated (Shennon, 1963).

Let us consider this in more detail from a modern perspective. The number of possible "site images" (N) is very large, it should be

$$N = m^n \qquad (1)$$

where:
m – number of possible values of piles resistance (most often they are in the range of 100–250 kH, which with an accuracy of ±10 kH corresponds to $m = 10$–25);
n – number of sites into which the site is divided.

For objects of medium size (1,000–2,000 m^2), with an accuracy of estimating the resistance of piles of ±10 kH, the number of "site images" will be expressed with a value of two to three dozen digits.

Before testing, complete uncertainty is assumed, i.e., all possible values of F_i are assumed to be equally probable. The number of "site images" (N), as noted, should be equal to m^n. After any tests are performed at the site, the uncertainty will decrease, and this decrease should depend on the accuracy of the tests and their number (more precisely, the number of sites on which they were carried out).

A quantitative analysis of such situations allows us to obtain a number of interesting regularities given below.

Results

The need for operations with large quantities is eliminated when using the concepts and representations of informa-tion theory as mathematical models. So, for a quantitative assessment of the degree of uncertainty of information about the resistance of piles on the site, it is advisable to use the fundamental concept of information theory – entropy (Shennon, 1963; Yaglom & Yaglom, 1973). In the general case, the entropy (H) is understood as the quantity (Shennon, 1963)

$$H = \sum_{i=1}^{N} p_i \log_2 p_i \qquad (2)$$

with:
p_i – probability,
i – that state of the system (in the given case i – that "site image"),
N – number of states of the system (in this case, the number of possible "site images").

Since before the tests all the values F_i are taken equally probable, the probability of each of the considered options ("site images") before the tests will be the same and equal to $p_i = 1 / (m^n)$. If we evaluate the uncertainty of such a situation by the value of entropy (H), it will be maximum and equal (in bits) (Yaglom & Yaglom, 1973):

$$H = -N \log_2 \left(\frac{1}{N} \right) \qquad (3)$$

With the accuracy of determining the piles resistance ±10 kH and the range of possible values $F_i = 0$–2,500 kH, i.e. at $m = 250$ (250 possible values of F_i), the entropy will be 8 bits in each section before testing.

After the first test in any site, this uncertainty will decrease. Suppose that a test was performed at the k-th site and the result F_k was obtained. The equal-

ity of probability is broken. On the test site (zone 1, shaded in black in Fig. 2b), the value of the sought indicator corresponding to the test result F_k will have the maximum probability. The closest possible values of F_{t-1} and F_{t+1} will have a lower probability, more distant (F_{t-2} and F_{t+2}) even less, etc. In adjacent sections, probabilities can be taken by interpolation between the values in the test section and outside the extrapolation zone. The distribution of F_k (in the k-th section) will depend on the accuracy of the test. It should correspond to the distribution of possible "errors", which is considered known for this method (from a statistical analysis of data from previous experience). For statistical sounding, such a distribution is shown in Figure 1a.

The change in the probabilities in the k-th section will entail a decrease in the entropy (H_k), which will also affect the overall entropy of the site (H), since according to the ideas of information theory, the entropy of the components of the system is equal to the sum of the entropies of these components. In this case, the total entropy of the values of F_i over the entire site is equal to the sum of the entropies of individual sections.

$$H = H_1 + H_2 + H_3 + ... + H_k + ... + H_n \tag{4}$$

This decrease in H will be the more significant, the more accurate the test. If, for example, the test had a zero error, the uncertainty in the k-th section would completely disappear: the probability of the value of F_k would become equal to 1, i.e. $p(F_k) = 1$, and the entropy in the k-th section (H_k) would become equal zero ($H_k = 1 \log 1 = 0$). Thus, if we take into account the result on the k-th site,

the total entropy would become 8 bits less.

If the test result is partially extended to neighboring sites, the decrease in H will be even greater. Obviously, the possibility of such an extrapolation of the results will depend on the heterogeneity of the soil of the site. We conditionally distinguish four cases of site heterogeneity (Fig. 2b):

– "maximum" heterogeneity, which does not allow any extrapolation of the results outside the test site;
– high heterogeneity, allowing extrapolation of the results to only one row, that is, to the nearest sections directly adjacent to the test site;
– average heterogeneity allowing extrapolation to two rows in all directions;
– homogeneous soil, allowing extrapolation to three rows in each direction.

Testing in any other part of the site would cause a similar decrease in entropy in this site, which also depends on the accuracy of the test. This would further reduce the overall entropy of the site. Thus, each new test will reduce the uncertainty of our ideas about the values of F_i within the site, i.e. reduce the entropy.

Let us consider the idealized example mentioned above, when the entropy became equal to 0 in the test site. The dimensions of the sites were taken to be the same and equal to 3×3 m. In this case, in a homogeneous soil, the test results can be spread by 10.5 m in each direction, and the entropy value there will be 4 bits in this zone (interpolation between 0 and 8 bits). With medium heterogeneity, the test results can be spread

over 7.5 m, and the entropy value in this zone will be 4 bits, as in the previous case. With high heterogeneity, distribution is possible at 4.5 m (entropy is also 4 bits) at maximum at 1.5 m (i.e. within the test site, entropy should be assumed to be 0, beyond it 8 bits).

Obviously, the decrease in the total entropy (H) will be the more significant the more homogeneous the soil.

The difference in entropy before and after the test characterizes the amount of information (Shennon, 1963; Yaglom & Yaglom, 1973)

$$I = H_0 - H_1 \qquad (5)$$

with H_0 and H_1 the entropy before and after the test, respectively.

The second test at another section of the same site, as already noted, will lead to a similar decrease in the entropy of N. The third test will additionally also reduce the entropy, etc. The difference between the previous and subsequent entropy values will each time give the amount of information about the site (in bits) introduced by the new test.

This technique allows to evaluate the total amount of information contained in the results of any test group for any accuracy and heterogeneity of the soil.

Let us consider the question of how much information this or that method of determining the piles resistance can bring depending on the reliability of its results and the number of points on the site at which such a determination was made.

Figure 3 shows the curves of the same amount of information on the piles resistance obtained by two independent types of tests of different accuracy for a different number of such tests. In Figure 3a, we examined static sounding and static tests of piles. In Figure 1b, the dynamic tests of piles (calculations of "failures" during driving) and static sounding were compared.

The solid lines show the "equivalent" informative volumes of work, the dashed lines represent the same duration of field work. The shaded areas correspond to situations where the time spent on testing the piles (without preparatory
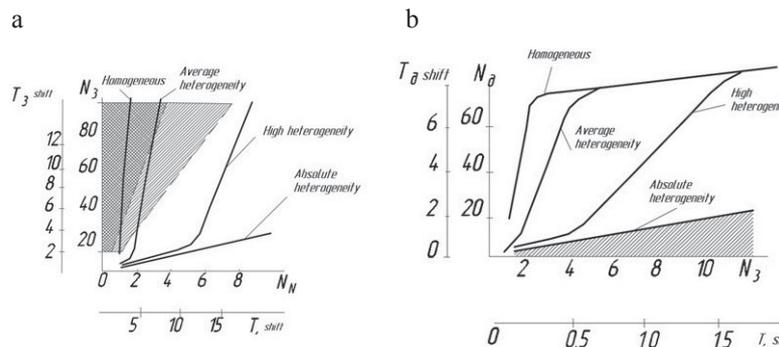
a   b

FIGURE 3. Lines of "equivalent" in their informative content quantities of soil tests of different reliability (i.e. introducing the same amount of information about the piles resistance): a – comparison of static sounding with tests of piles with static load; b – the same with dynamic tests of piles. N_3, N_u, N_{∂} are the numbers of tests, respectively, by sounding, static loads, and dynamic tests; T_3, T_u, T_{∂} the duration of the test complex, respectively, by sounding, static load, dynamic tests

and auxiliary works) is less than the time spent on the sounding during single-shift (single hatching) or two-shift (double hatching) work.

At the first glance the calculation results shown on Figure 3 reveal a paradoxical result: the amount of information from a sufficiently large number of approximate tests may (due to heterogeneity of the soil) exceed the amount of information from small exact tests. In this case, the concept of "test inaccuracy" conditionally includes the insufficient adequacy of the design scheme used.

The calculation performed for the idealized conditions described above shows that on a site divided into 100 sections in homogeneous soils (according to the criteria adopted above), 20 approximate tests with a unit test error of ±30% characterize the site in much the same way as one "exact" test with an error of ±5%. With medium heterogeneity, the same number of approximate tests is equivalent to two exact ones, with high heterogeneity – to five ones (with two exact tests equivalent to six–eight approximate ones), and with "maximum" heterogeneity nine (two exact tests are equivalent to five approximate ones). The accepted separation of soil heterogeneity levels in this mathematical model is taken for reasons of convenience. It is of no fundamental importance, i.e. taking any other division, we get about the same result.

A similar conclusion is drawn from a consideration of the average values of the desired characteristic $\overline{F}$. In this case, it is more convenient to use the standard deviation of the test results (σ) or its relative value – the coefficient of variation ($v = \sigma / F$) (Gmurman, 2000). The very

consideration of average characteristics also deserves attention, since the averaging of test results is one of the stages in establishing the calculated characteristics (according to the standard ISO 2394:2015 and the national standards of many states, including Russia).

The value of the coefficient of variation v should be $v = \sqrt{v_1^2 + v_2^2}$, where v_1 and v_2 are the coefficients of variation due to the inaccuracy of the test and the heterogeneity of the soil, respectively. The coefficient of variation v_2 for homogeneous soils can be taken equal to 0.025, with an average heterogeneity of 0.1, with a high heterogeneity of 0.2. Non-accuracy of tests can be characterized by coefficients of variation of 0.2 (approximate test) and 0.025 ("accurate"). Naturally, the coefficients of variation adopted for the example are not of fundamental importance, since they are only an illustration of the laws under consideration.

Relative test errors should be equal in accordance with the rules of error theory:

$$\Delta = t_\alpha \, v \qquad (6)$$

where:
t_α – Student's coefficient, depending on the accepted confidence probability (α) and the number of test results.

The calculations of the errors of the average test results of various accuracy also confirmed the prevailing effect of soil heterogeneity. For example, the error of the average result from two exact tests turns out to be the same as the average of 15 approximate ones – in homogeneous soils; six approximate – in soils of medium heterogeneity; and only

three approximate ones – with high heterogeneity.

Obviously, all of the above does not apply to the site as a whole only, but also to any part of it, to a separate engineering-geological element.

Thus, the heterogeneity of the soil significantly reduces the value of "accurate" tests. It makes the results of such tests seem less representative. If, for example, we assume that at some point on the site an "exact" test revealed the ultimate resistance of a pile of 600 kH, is there a guarantee that at 15–20 m from this point the ultimate resistance will not be one and a half times lower if neither sounding, nor drilling was carried out in this part of the site? Obviously, the answer is negative. For this reason, an insufficient number of tests may in some cases turn out to be more dangerous than their insufficient accuracy. At the same time, "accurate" tests, as already noted, are very expensive, complex, and time consuming. Complex and expensive methods cannot be applied in volumes that allow taking into account the actual heterogeneity of the soil. The use of such a simple method as static sensing completely solves the mentioned problem.

However, it should be noted that in addition to random errors, the results of any tests may contain a systematic error, which is not eliminated by increasing the number of tests. Such an error can be eliminated only by comparing a part of the approximate results with the "exact" ones taken as a standard. The works by Ryzhkov (1995), Ryzhkov and Isaev (2016), and Ryzhkov et al. (2016) describe the method used in Bashkortostan for sharing approximate and "accurate" methods for determining various geotechnical parameters, including the bearing capacity of piles. Its essence is that the whole territory of the studied site is estimated by the approximate method ("express method"), and in the most typical place or in several places called key sites, "exact" tests are carried out, according to which the adjustment is made to the approximate estimates. The adjustment involves the refinement of the calculation reliability coefficient (γ_k) as applied to the conditions of a particular site.

The theoretical basis for this adjustment is the "Bayesian" approach to sharing data obtained directly on the study site, and as a result of a statistical analysis of data from previous experience. The Bayesian formula is used, which allows to estimate the probabilities of various assumptions ("a priori hypotheses") again after obtaining any specific data about the studied object (Kay, 1977; Ryzhkov & Isaev, 2016). The role of "a priori hypotheses" is played by statistically processed data from previous experience. In this case, these are the probabilities of the possible values of the bearing capacity of piles. It should be noted that domestic specialists usually use discrete distributions without taking into account the analytical distribution law, while the foreign ones prefer continuous distributions.

In the process of practical application of the obtained results we revealed certain inaccuracies and unnecessary complications that were eliminated, and their modern interpretation is given below (Djamaev, 2018).

The reliability coefficient (γ_k) is proposed to be determined by the formula (Abu-Farsakh et al., 2014):

$$\gamma_k = \overline{\left(\frac{F_{u,sound}}{F_{u,full}} \right)} + \Delta_{sl} \qquad (7)$$

where:

$\overline{\left(\dfrac{F_{u,sound}}{F_{u,full}} \right)}$ – average ratio of $\left(\dfrac{F_{u,sound}}{F_{u,full}} \right)$ in key areas,

Δ_r – an amendment that reflects the impact of random events, determined by Table 1 and correction reflecting the influence of random, determined by Tables 1 and 2,

$F_{u,sound}$, $F_{u,full}$ – limit resistances of piles based on probing data and static tests.

Obviously, the number of results of "accurate" tests can be very insignificant and static sounding allows it to be reduced to values that are economically optimal.

In some cases, the corrective information may be the data of previous surveys, including that in neighboring territories, similar in terms of engineering and geological conditions. The above considerations show that it is advisable to consider the approximate methods of soil testing such as static sounding as a necessary element of research, complementing more accurate tests. Small exact tests, no matter how thoroughly they

TABLE 1. Values of Δ_r at one key site (one static pile test)

$k^{,}$	≤ 0.7	0.8	0.9	1.0	1.1	1.2	1.25
Δ_r	0.12	0.11	0.10	0.10	0.08	0.03	0.00

TABLE 2. Values of Δ_r for two key sections (two static tests of piles)

$k^{,}_1$	Δ_r value at $k^{,}_2$ equal						
	≤ 0.7	0.8	0.9	1.0	1.1	1.2	1.25
0.7	0.11	0.10	0.07	0.05	0.03	0.01	–
0.8	0.10	0.10	0.09	0.07	0.05	0.03	0.04
0.9	0.07	0.08	0.09	0.08	0.07	0.06	0.04
1.0	0.05	0.07	008	0.07	0.07	0.06	0.05
1.1	0.03	0.05	0.07	0.07	0.06	0.06	0.05
1.2	0.01	0.03	0.06	0.06	0.06	0.03	0.03
1.25	–	0.04	0.04	0.05	0.05	0.03	0.00

As practice has shown, the coefficients $k^{,}_1$ and $k^{,}_2$ should be limited to 0.8 and 1.25, i.e. for values $k^{,}_1$ or $k^{,}_2$ less than 0.8, take 0.8, for $k^{,}_1$ or $k^{,}_2$ more than 1.25, take 1.25. In addition, it was proposed not to take the reliability coefficient γ_k less than 0.95, i.e. upon receipt of the values $\gamma_k < 0.95$, the acceptor is $\gamma_k = 0.95$.

were carried out, without the use of "express methods", which can be "probed" the entire site, characterize only those areas where they were carried out.

The conducted studies contribute to the alternative to the approach established in the survey practice to establish estimated geotechnical indicators. The adoption as the calculated indicator of

the result of the most accurate test or simply the minimum result does not fully take into account the test conditions and the specifics of a particular site. Nevertheless, despite the absence of objections to the presented ideas, the "Bayesian" methods for adjusting the approximate results are not considered by most of engineers. Apparently, the informational concepts that are so familiar with the use of computers are too unusual in theoretical questions of geological methods. More than 40 years have passed since the publication of the article by Kay (1977) on the application of the Bayesian approach to choosing the permissible load on a pile; nevertheless, practically no one develops this direction except for a narrow circle of Russian geological specialists. The Bayesian approach is mentioned neither in the Western European, nor in the Russian regulatory documents (Doc, 1990; EN 1997-1:2004; EN 1997-2:2007; GOST 5686-78; GOST 5686-2012; ISO 22475-2:2005; ISO 22475-4:2005; ISO 22475-1:2017; SP 47.13330.2012), nor in the textbooks on the foundations. Nevertheless, its application allows (without reducing the reliability of the foundation) to take the load on piles 5–10% higher than the current regulatory documents recommend (Ryzhkov & Isaev, 2016).

Conclusions

Approximate tests performed on the studied site in a sufficiently large amount can carry more information than the small number of "accurate" tests. This is due to the fact that under conditions of real heterogeneity of the soil, the accuracy of a particular test does not guarantee the representativeness of the result obtained (i.e. its type for a given site).

Due to the fact that an increase in the number of measurements does not reduce "systematic errors", it is optimal to use static sounding in combination with a few "accurate" tests, which can be used to correct the sounding results, minimizing systematic (for this site) errors. An updated methodology for correcting approximate determinations of the piles resistance with the data of static sounding and statistical tests of piles is proposed.

Using this technique allows to make more economical (5–10%) and more reliable decisions when choosing pile lengths. Inaccuracies in determining the piles resistance are compensated by a special reliability factor, adopted individually for each particular site. This coefficient is established by comparing the approximate values of the piles resistance (according to the sounding data) with the values taken as a standard (i.e. the results of tests of full-scale piles with a static load directly on the study site). This approach is acceptable for the correction of any approximate indicators (not necessarily according to sounding data), and the calculation of particular values of such indicators can be carried out according to the norms of any country. It is only necessary to clarify the corrections reflecting the influence of random factors (see Δ_r values in Tables 1 and 2) depending on the accuracy of the calculations used. With the accuracy of determination corresponding to the scattering diagram in Figure 1, you can use Tables 1 and 2.

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Summary

Role of accuracy and quantity of field tests in engineering-geotechnical researches for construction. The aim of this work is to summarize previously conducted studies on the optimization of the unequal geotechnical testing program and on the selection of the desired calculation indicator based on the results of such tests. The approximate, but quick and cheap tests ("express methods") are recommended to be performed on a large scale and considered as a means of assessing the geotechnical structure of the site as a whole. It is proposed to carry out expensive "accurate" tests in a reduced volume and to use them as a means of correcting approximate tests. In the article, these issues are considered by the example of determining the bearing capacity of piles according to the data of static sounding (cone penetration testing – CPT), dynamic and static tests of full-scale piles. We propose the mathematical model for evaluating the informative content of the test complex, based on the concepts of information theory. The site is mentally divided into several sections, each of which is characterized by one of the possible values of the ultimate resistance of piles of a certain length. All variants of "placement in the plan" of possible values of pile resistances ("site images") are considered. Initially, when nothing is known about the true value of the pile resistances in each section, all possible values of the pile resistances are assumed to be equally probable, i.e. the uncertainty of the situation is maximum. In the theory of information, such uncertainty is quantified by the value called entropy. When any test is performed at the site, the uncer-

tainty decreases, and the more accurate the test the more significant is the decrease. The difference in entropy before and after the test represents the amount of information (in bits) that these tests carry. The calculations using this model showed that the information content of a large number of approximate tests can (due to heterogeneity of the soil) exceed the information content of small exact tests. Only one approximate test method can lead to the systematic error (overestimation or underestimation of the average value of the desired indicator). It is necessary to carry out control "exact" tests and approximate tests to eliminate such a danger. A technique is proposed for adjusting approximate estimates based on data from "accurate" tests, which ensures optimal "safety margins" in decisions being made.

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