Correction of soil design parameters for the calculation of the foundation based on the results of barrettes static load test

Correction des paramètres de conception du sol pour le calcul sur la base des résultats de test de barrettes de charge statique

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ABSTRACT: Geotechnical investigations and design works were being performed in 2008-2010 for the construction of Okhta-center high-rise tower in St. Petersburg. Unique static load tests of 80 m deep barrettes were performed in 2010 as part of design process. 3 barrettes were tested simultaneously as a group and two were tested individually. The tests were planned in such a way as to get the standard values of bearing capacity of barrettes, and to clarify the parameters of soil needed for the calculation of the barrette foundation.The comparison of the bearing capacity values with the values calculated using Russian and foreign building codes is provided. Limitations of currently used codes are shown.

RÉSUMÉ : Les études géotechniques et les travaux de conception ont été réalisées en 2008-2010 pour la construction du centre Okhta haute tour à Saint-Pétersbourg. Uniques essais de charge statique de 80 m de profondeur barrettes ont été réalisées en 2010 dans le cadre du processus de conception. 3 barrettes ont été testés simultanément en tant que groupe et deux ont été testés individuellement. Les tests ont été planifiés de manière à obtenir les valeurs standard de la capacité portante des barrettes, et de préciser les paramètres du sol nécessaires pour le calcul de la fondation barrette. La comparaison des valeurs de capacité portante avec les valeurs calculées à l'aide des codes de construction russes et étrangères est fournie. Limites des codes actuellement utilisés sont affichés.

KEYWORDS:piles, barrettes, static load test, shaft friction, FEM, bearing capacity, high-rise building.

1 INTRODUCTION

In recent decades, in Russia there is a steady increase in the number of tall buildings being built, of which a substantial part is the building higher than 150 m.

Building heigher then 150m need a special approach to design. Existing bulding codes in Russia and other countries as well, can not fulfill the requirements of modern day high-rise construction. For foundation constructions existing codes are limited by relatively small depth of ground investigation and testing loads.

In the current RF building codes plate loading test is considered as the reference method for soil Young modulus estimation. According to codes soil modulus determined by other methods should be adjusted to plate loading test modulus. It is not always possible, given the great depth of the soil used as the bearing layer of high-rise building foundation.

This paper discusses the engineering properties of Vendian clay as a bearing layer of Okhta tower high-rise building in St. Petersburg. According to building design it's pile foundation will be embedded in Vendian clay layer lying deeper then 45 m from ground surface.

Building design The project has a device for high-rise building with pile foundation bearing on Vendian clay layer, lying with a mark of -45 m B.S.V.

Laboratory tests on odometer and triaxial schemes were made during ground investigations to study the properties of Vendian clays. Given the depth of bearing layer pressuremeter test were selected as in-situ test method.

Laboratory testing of soil extracted from great depth usually complicated by disturbanceof soil samples, caused by stress relief and preparation of samples for testing, and by the complexity of high-precision measurements of deformation of the sample (especially true for high stiffness soils).

Pressuremeter test, in turn, has no alternatives for soil testing in-situ at greater depths. Design value of pressuremeter Young modulus needs to be adjusted to plate loading test modulus, and if that is not possible soil anisotropy factor needs to be determined for conversion of soil modulus in the horizontal direction to the modulus in the vertical direction.

Trial Barrette static test was scheduled as part of the pile foundation design process. Given the high testing load "Osterberg" method were considered economically effective. Given specifics of the method, in addition to pile bearing capacity assesment, one can provide design engineer with the possibility of making “deep plate loading test”.

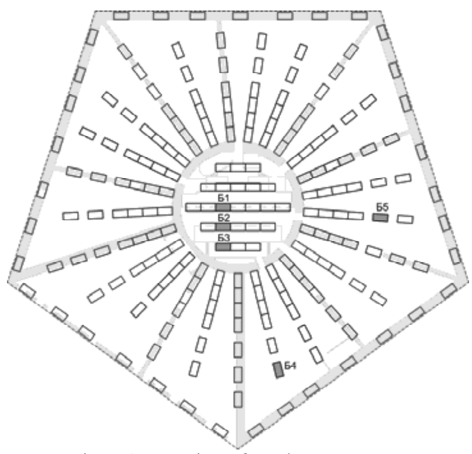

Figure1 .Location of test barretes.

Trial Barrettes were made from the surface of the soil. The working part of a 65-m barrette was made of B40 grade reinforced concrete. Barrettes were constructed by the conventional technology - in the trenches, excavated under the protection of bentonite slurry.

2 GEOLOGICAL CONDITIONS

Geological conditions of the construction site can be described as unfavorable for civil engineering and especially for high-rise buildings. Weak water-saturated soils lies to the depth of 30 ... 35 m. Underneath these soils is a layer of moraine deposits of small thickness. From a depth of 45 m liesVendian clay. Rock, commonly used as a bearing stratum for high-rise buildings are located at depths of over 200 m. Considering the aforementioned facts Vendian clay was selected as the bearing layer for the Okhta tower pile foundation. Vendian clay is relatively strong soil and classified as hard clay and weak rock at the same time. Despite the relatively high strength properties Vendian clay exhibits long-term development of deformations in time under load. It should be noted that engineering properties of these soils in Saint-Petersburg is mostly unstudied.

3 TESTING SETUP

The test program was design in such a way as to achieve the following goals:Determination of the bearing capacity of barrette and it's individual fragments;Determination of load-settlement characteristics for "top-down" loading scheme;evaluation of the Young modulus for the underlying the barrette base;Evaluation of interface strength on the shaft of the barrette.

Three of the five tested group barrettes were equipped with loading device installed in two levels, two single piles in one level. Single-level and two-level testing scheme and barrette part nameingare shown in Fig. 2

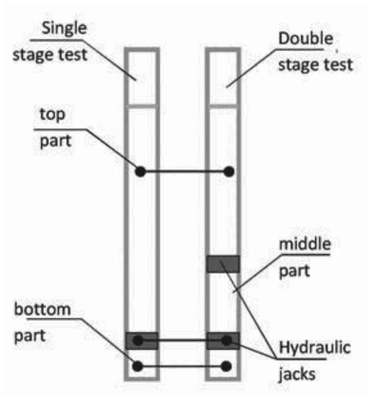

Figure2. Scheme of barrete parts namings

Barrettes with one level jacks were tested in one phase, the pile with two levels - in two stages. In the first stage the lower part of the pile is loaded with the lower level of the jack. In the second stage the upper jack level creates load on the middle part of barrette. During a first stage of testing upper level jacks are closed and load transfer through them is not different from a solid barrette section. During loading of the upper level, the hydraulic system of lower jacks is open into atmosphere, making them closing or opening freely. During the testing of the upper level when the lower level is open and jacks are retracted, the entire load of the upper level of loading is transmitted to the shaft of the barrette middle fragment. As the criteria for test advancement standard RF deformation stabilization criteria 0.1 mm/h was used. It is 2.5 times more rigorous then the standard European 0.25 mm/h. Results comparison with two different stabilization criteria showed, that application of the criterion of 0.25 mm/h underestimates the magnitude of barrete base displacement by 30%. Choice of stabilization criteria is especially important when the testing jack located near the barrette base in clay soils, as in this case, due to soil consolidation deformation process is much slower.

4 TEST RESULTS

4.1 Test of the lower parts of barrettes B1...B5.

The value of the load reached during first stage of testing was 40MN and 48 MN for second stage.

Bearing capacity of the lower parts of the test group barrette was 90% of the bearing capacity for a single barretes test, due to the group effect.

Load-settlement characteristics for barrettes B1…B5 shown on Figure 3 and shows that settlement of Barrette B2, located between Barrette B1 and B3 is 15% more than that of Barrette B1. This effect is referred to well-known concepts of group effect in pile groups. Pile settlement in the group always exceeds the settlement of single pile, and the settlement of central pile is highest. With the growth of the number of piles in the group this effect expected to increase. By means of mathematical modeling of group testing and achieving the same group effect, which was observed in the trial, one can confirm the accuracy of the model input parameters, and to validate its use for the calculation of the entire foundation.

The elastic component of the Barrette B1 ... B5 base settlement is 13 ... 20%, and the residual inelastic component reaches 79 ... 87.6% (Fig. 3), i.e. much of the ground under the base of Barrette undergone plastic deformation.

In the analysis of Fig. 3 it may be seen that load-settlement characteristics can be divided into several stages. In the first phase, with a load values up to 5MN, load held by the shaft friction on the surface of Barrette part, and movement up to 1 mm recorded. At the 2nd stage of loading barrete part is moved and load being transferred to barrete base. Soil underneath the barrete disturbed by drilling began to compact under load. Settlement of barrete base increases linearly with load until 20…40 MN load value is reached. As the barrette part movement increases, shaft frictions on its side reaches a maximum value and remain constant to the rest of stage 1. Due to this effect further increment of load transferred directly to the barrette base. The final stage is characterized by an increase of settlement increment per unit increment of load, indicating that the transition of the ground under the base of barrette to the plastic state.

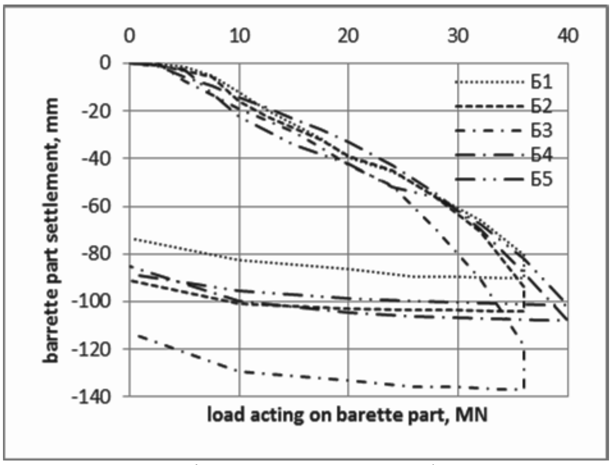

Figure 3. Stage 1 test results.

In order to clarify the shaft bearing capacity for bottom part of Barrette B4, the loading increments in the first stages of the load testing has been reduced from 5MN to 2.5 MN, which led to an increase in the number of stages in the load range of up to 20 MN from 4 to 8 . An interesting finding was the fact that, regardless of the number of stages loading time spent on testing barrette B4 and B5, was similar and was 277 and 259 hours, respectively.

Concluding the analysis of bottom level testing one can mention high repeatability of results, which indicates the homogeneity of the subsoil under the Barrette base and the good quality of their production.

4.2 Test of the middle parts of barrettes B1...B5.

At the end of the first stage of testing bottom level jacks are retracted, and their hydraulic system is open. In this configuration, the lower level of jacks do not transfer the load from a upper jacks level on the base. In this case, loading of the upper jack level resisted only by shaft resistance of the middle barrette part, allowing to accurately determine shaft friction value.

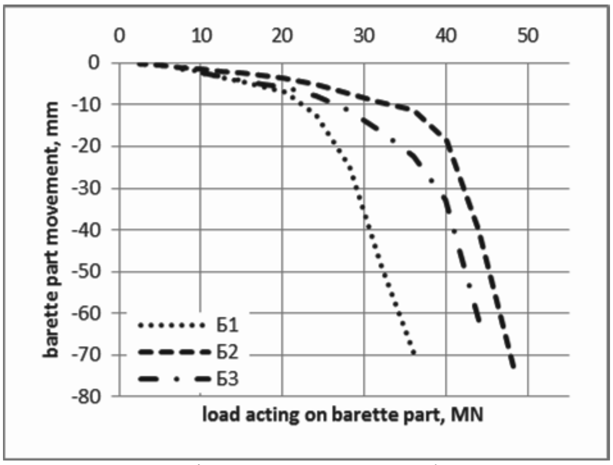

Figure 4. Stage 2 test results.

Compared with the test of the first stage (lower jack level) results show significantly greater variation in the ultimate shaft friction values. Load-settlement curves for the second-stage tests are shown in Fig. 4.

Load-settlement curves shown on Fig. 3 characterized by initial almost flat part, with a slightly longer length for Barrette B2. The angle of the load-settlement curves for B1 and B3 began to increase after the load value of 20 ... 25 MN, and for B3 35 MN.

The presence of a longer horizontal part on load-settlement curve for B2 may be due to heterogeneity of soil conditions along the tested barrette part, or, more likely, due to its central position in the group.

4.3 Back-analysis of test results performed by FEM.

One of the most effective tools for the analysis of load test made by the Osterberg scheme is the reverse calculation method with regard to elastic-plastic soil properties by means of FEM.

The reverse calculation has several objectives: 1) Calibration of design parameters of adopted soil model 2) evaluation of the bearing capacity of single pile in the top down loading conditions 3) assessment of the applicability and adequacy of the chosen soil model.

The starting point for the reverse calculations is the soil properties obtained by laboratory testing. By varying individual soil model parameters one can identify the most important of them, and then achieve convergence between experimental and calculated results.

The first iteration of calculation based on laboratory determined soil properties showed that the calculated values of barrete upward movement is 6 times larger than the experimental values, and downward movement is overestimated by 2 times. This suggests that the characteristics of soils, provided through laboratory testing are very different from the characteristics of the soil in-situ.

Taking into account observed discrepancy the objective was to find such soil characteristics, which would have shown the best convergence of calculation with the experiment. Barrette movement and stress along its body were chosen as convergence criteria between the experimental and calculated values.

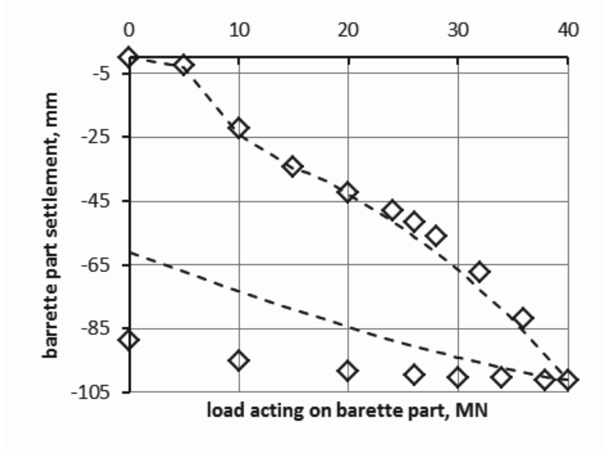

Figure 5. Comparative charts of data obtained from the experiment and the results of the calculation.

Comparison of modeling results with the experimental data shown in Figure 4. The graph shows the results of calculations with adjusted characteristics of soil is almost equal to the results of the test. It should be noted that non-compliance of Barrette behavior during unloading caused by incorrect rapid unloading procedure.

Table 1.Adjusted by FEM calculations soil properties.

GE number	Soil classification	Density, g/cm^3	E, MPa	Poisson ratio ν	φ, °	C, kPa
11	Hard clay	21.3	50	0.25	17	150
12	Hard clay	22.2	200	0.2	25	330
12a	Hard clay	21.1	105	0.22	18	200
13	Hard clay	22.3	252	0.18	27	491

5 COMPARISON OF OBTAINED SHAFT UNIT FRICTION WITH BASIC CALCULATION METHOD RESULTS.

The main purpose of the second phase of the test was to determine the specific shaft resistance values for middle parts of Barrette B1 ... B3. Resistance value is determined by dividing the applied load on the shaft surface area of the middle part of barrette.

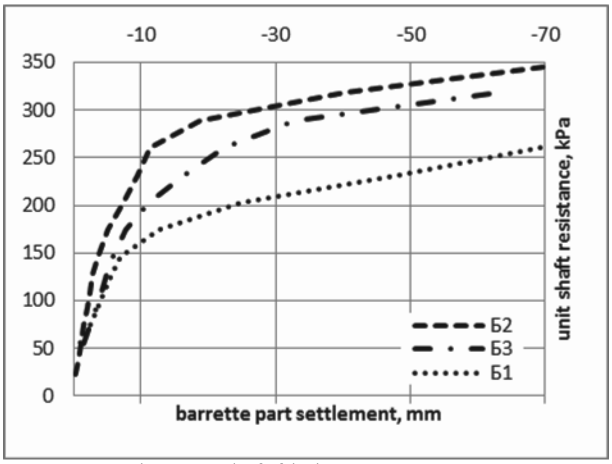

Figure 6. Shaft friction-movement curves.

As can be seen from Fig. 5, for barrette movements of up to 20 mm shaft friction increasing drastically to 190 ... 290 kPa. A further increase in displacement to 60 mm results in a small (about 60 kPa) monotonic increment of resistance. The peak (maximum) value of the shaft resistance was not clearly observed as the resistance monotonically increases up to 100 mm movement. By analyzing the obtained movements-resistance curves it can be noted that values of shaft resistance for Vendian clays can be taken as corresponding barrette shaft resistance for 40 mm (according to RF building codes) movement.

Design shaft resistance values provided for assessment of pile bearing capacity by SP24.13330.2011 at depths greater than 40 m are assumed constant and equal to 50 kPa, which is 4.6 ... 6.4 times less than the values obtained in static Barrette test. For comparison, ultimate values of shat friction were also calculated for the most common approaches worldwide: the α-method (Skempton 1959) using undrained strength parameters and Mohr-Coulomb law. In calculation with the alpha method lower (α=0.3) and upper bound (α=0.6) values of alpha were examined. Resulting specific values of shaft friction values were 250 and 500 kPa respectively. For calculation by Mohr-Columb earth pressure at rest coefficient K_0 were taken for non-consolidated soil by well-known Jaky equation and as for overconsolidated soil with OCR=2,5. Resulting K_0 values were 0.66 and 0.99 respectively. Factor of 0.5 for interface strength also applied according to SP24.13330.2011. Specific shaft friction values obtained by this calculation method were 270 kPa for K_0=0.66 and 460 kPa for K_0=0.99.

Thus, the lower limit of the specific shaft friction, calculated using the mechanical properties of soils were within the values obtained by the results of static Barrette tests, and the upper limit value – was higher on average of 1.7 times. One of the reasons for this discrepancy may be that the central parts of barrette during the first stage of test (lower part testing) has the 5...7 mm upward movement, during which partial mobilization of shaft friction forces in opposite direction were observed.

6 CONCLUSIONS

Trial works confirmed the technical feasibility of barrettes construction with cross-section of 1.5 x 3.0 m length of 85 m by the standard "slurry wall" technology in difficult sub-soil conditions of St. Petersburg.

It is advised to implement Osterberg testing technique (by cast in pile submerged jack) for the deep foundation of high-rise buildings. The method allows to use pile parts as an anchor system and to clearly determine the values of unit shaft friction and base resistance. It is recommended to install two levels of jacks in a pile: one near the base of the pile, and the second in the middle of the main bearing layer. It is critical to install several levels of strain gauges in the pile along its length.

Pile testing at construction site should be seen not only as method to determine pile bearing capacity but as an effective method to calibrate design parameters of adopted soil model, and to assess its applicability and adequacy. Soil parameters provided by ground investigation can by checked and adjusted if necessary. During design process of tower foundation, obtained results of unit shaft friction and base resistance should be used as the control values, against which the calculation results are checked.

The calculations made on the basis of experimental data showed what the values of the mechanical properties of soils determined by the laboratory testing has severely underestimated soil strength and deformability parameters due to sample disturbance, the influence of the scale factor & etc.

As a result of the tests it was found that the Vendian clays can provide high values of shaft friction and base resistance. The experimental values of shaft friction and base resistance exceed the ultimate values provided by codes by 4 ... 6 and 1.6 timesrespectively.

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