Comparison analysis of pile foundations on the modern and ancient clays

Analyse comparative du fonctionnement des fondations sur pieux à la base des argiles anciennes et récentes

Andrey Ponomaryov, Evgeniya Sychkina
Construction Technology and Geotechnics Department, Perm National Research Polytechnic University, Russia, spstf@pstu.ru

ABSTRACT: Numerous studies have shown that the different ages soils interact with foundations of buildings and constructions in different ways. The purpose of this paper is comparison analysis of the characteristics of pile foundations work on modern and ancient clays. To achieve this purpose the following tasks were solved during the study: 1. Existing works on settlement precipitation and bearing capacity of piles on the modern and ancient clay are analyzed. 2. Characteristics of experimental sites and methods of field research are described (full-scale pile test, cone penetration test). 3. The experimental data are compared with the calculation results. 4. Based on these results recommendations for forecast piles behavior on ancient clay in comparison with modern clays and cone penetration test data interpretation in different ages clays are presented.

RÉSUMÉ : Selon les résultats de nombreuses études, les sols formés aux époques différentes se portent différement par rapport aux fondements des édifices et des bâtiments. Le but de notre travail comme l'analyse comparative des particularités du fonctionnement des fondations sur pieux à la base des argiles anciennes et récentes. Aux cours de nos recherchers nous avons résolu les taches suivantes: 1. On a fait l'analyse des recherches menées concernant les pronostiques de l'affaissement du sol et de la capacité portante du pieu à la base des argiles anciennes et récentes. 2. On a présenté les caracteristiques des terrains experimentaux, on a décrit la méthode des recherches (les pieux étalonnés, exploration statique). 3. Les données experimentales sont comparées à celles reçues par les méthodes de calcul. 4. Les résultats des recherches ont permis de formuler les récommandations sur les pronostiques du fonctionnement des pieux sur argiles anciennes par rapport aux argiles récentes, et sur les interprétations des données de l'exploration statique des argiles anciennes et récentes.

KEYWORDS: pile, settlement, bearing capacity, clay, claystone, cone penetration test.

1 INTRODUCTION.

Numerous studies and practice of soil mechanics show that the different age soils interact with foundations of buildings and constructions in different ways. The main reason is microstructure of the soil. The microstructure is formed as a result of long interaction of various processes: sedimentation, compression and decompression, dehydration, weathering.

The development of urban infrastructure, the availability of social, transport, environmental and economic problems is typical for modern cities. It leads to the necessity of development of underground space and deep pile foundations.

Large areas in Russia (Ponomaryov and Sychkina, 2015; Kuznetsova and Makhova, 2016), Europe (Bond and Jardine, 1991; Cooke et al., 1989; Zhang et al., 2010), North America and Canada (De Ruiter and Beringen 1979), China (Suxin et al., 2006) and many other countries are characterized by the spread of ancient soil deposits. These deposits can be represented by claystones, sandstones, siltstones, limestones, marl; and their varieties weathered to a state of clay, loam, sand and crushed stone. These ancient deposits often do not have access to the surface and lie under the modern deposits. However, modern sand and clay deposits very often have low values of mechanical properties. Accordingly, ancient soils are increasingly being used as the basis for the pile and the pile-plate foundations of heavily loaded buildings and constructions.

Most methods of calculating pile bearing capacity were developed in the 80s and 90s of the last century. Existing researches of settlement and bearing capacity corrected the information about the pile behavior on modern sand and clay deposits and increased the accuracy of pile foundation calculations. The most reliable and the most common methods for determining the pile bearing capacity are full-scale pile tests and cone penetration tests. At the same time, a number of questions for pile bearing capacity and cone penetration tests interpretation were not resolved for the ancient soils.

The main difference between European methods of calculation bearing capacity and Russian methods is determining coefficients from the cone to the pile. It may be noted among the most common European methods of pile bearing capacity calculation for cone penetration tests in stiff clay: Schmertmann and Nottingham method (Schmertmann 1978, Fellenius 2014); de Ruiter and Beringen method, «Dutch method" or "European method" (Fellenius 2014); Bustamante and Gianeeselli method, «LCPC» method or the "French method" (Bustamante and Gianeeselli 1982); Prince and Wardle method (Price and Wardle 1982).

The following methods can be used for the pile bearing capacity calculation for cone penetration tests in soft soil (Ponomaryov et al. 2015): Schmertmann and Nottingham method (Schmertmann 1978, Fellenius 2014); de Ruiter and Beringen method, «Dutch method" or "European method" (De Ruiter and Beringen 1979); Bustamante and Gianeeselli method, «LCPC» method or the "French method" (Bustamante and Gianeeselli 1982); Tumay and Fakhroo method (Tumay and Fakhroo 1982); Aoki and De Alencar method (Aoki and De Alencar 1975); Eslami and Fellenius method (Fellenius 2014).

The purpose of research was analysis of pile foundations behavior on modern and ancient clay bases.

The following tasks were solved:

1) Characteristics of experimental sites and methods of field research are described (full-scale pile test, cone penetration test);

2) Comparison of character and value of pile settlement on modern and ancient clays was performed;

3) Experimental bearing capacity data were compared with the results of calculations based on cone penetration test data;

4) Recommendations for the pile behavior on ancient and modern clay were presented.

The authors believe that the proposed recommendations for forecast of pile behavior on layered clay and claystone can be used in similar geological conditions. The recommendations and calculations are presented for examination and verification in other geological conditions and for driven piles group.

2 METHODOLOGY OF INVESTIGATION

2 .1 *Characteristics of experimental sites and field tests*

In this research four experimental sites in Perm city (Russia) are reviewed. Geological conditions of all sites are composed of Early Permian age claystones (P_1), which are covered by the modern sand and clay deposits (Q_{IV}). The Permian claystone is a weathered soft clay rock that consists of clay particles consolidated by means of the cement of ferrous and carbonate composition (Ponomaryov and Sychkina, 2015).

The typical soil profile one of the experimental sites is presented in Figure 1.

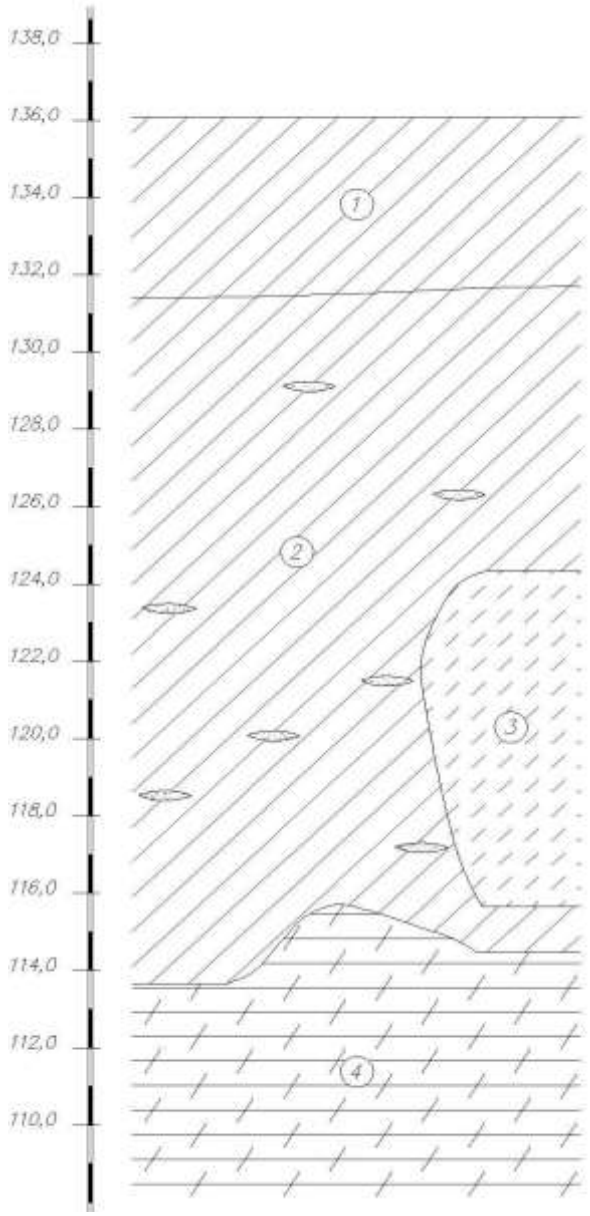

Figure 1. Experimental sites typical soil profile. Herein: 1 – soft loam and clay, 2 - soft clay and loam, with areas of gravel, 3 - loamy sand; 4 – claystone

The Table 1 shows some values of the physical characteristics of soft, stiff clays and claystone on experimental sites.

Table 1. The average values of physical properties of claystones (P_1) and clays (Q_{IV}).

Parameter	Claystone	Stiff clay	Soft clay
Density (g/cm³)	2.01	1.98	1.91
Moisture (%)	20	19	27
Consistency index (%)	8	5	34
Void ratio (%)	65	72	76
Water saturation (%)	83	73	95

Pile settlement was determined by the results of full-scale static load pile test. Pile settlement during unloading period was measured for evaluating elastic and inelastic strains. The results of the pile load tests are presented in the graphical form.

The bearing capacity of pile was determined by the results of the full-scale static load pile tests and cone penetration tests on mentioned experimental sites in Perm. The type of cone - II.

The comparison of settlement and bearing capacity of piles on claystones and lean clays with low plasticity on piles was presented in this paper.

2.2 *Description of methodology pile bearing capacity calculation*

The cone penetration tests results in soft modern clays on this experimental site were taken according to Ponomaryov and Bezgodov 2015. The authors (Ponomaryov et al. 2015) analyzed the results of the calculation of the bearing capacity of single pile on soft clays according to the methodology:

1) Schmertmann and Nottingham;
2) de Ruiter and Beringen ("European" or "Dutch" method);
3) Bustamante and Gianeeselli (LCPC or "French method");
4) Tumay and Fakhro method;
5) Aoki and De Alencar method;
6) Eslami and Fellenius method.

The calculation pile bearing capacity on claystone was performed by the cone penetration test data according to:

1) Russian standard document SP 24.13330.2011;
2) Schmertmann and Nottingham method;
3) de Ruiter and Beringen method;
4) Bustamante and Gianeeselli method;
5) Prince and Wardle method.

The calculated results were compared with the results of pile tests on the described experimental sites.

3 RESULTS OF INVESTIGATION

3 .1 Pile settlement on different age clay bases

Figure 2 shows the character of single pile settlement on three varieties of clays.

Piles settlement on soft clays significantly increased for loads of 250 - 450 kN. The maximum value of pile settlement on soft clays was 26.10 - 38.31 mm.

The pile settlement on stiff clays and claystones had character closest to linear on the entire range of the pile loading. Maximum pile settlement on stiff clays was 4.58 - 5.28 mm for load 1050 kN. The maximum pile settlement on claystones was

2.17 - 3.37 mm for load 1100 - 1200 kN. Thus, the minimum settlements were noted for piles on claystones.

The elastic component of pile settlement on modern soft clay and loam was 5 – 12 % of the total pile settlement. On modern stiff clay and loam this value was in the range 97 – 99 %.

For claystone elastic deformations were in the range 46 – 69 % of the total pile settlement. In this way, inelastic strain for claystones was higher than the inelastic strain for stiff clays in the range 30 – 50 %.

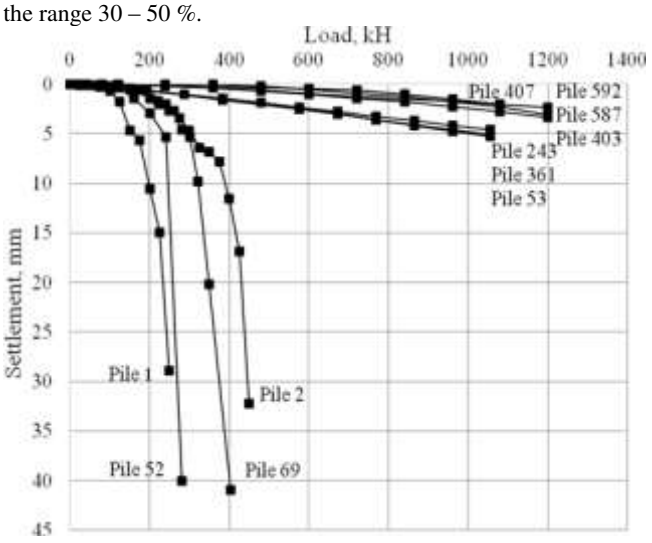

Figure 2. The pile settlement on soft clays (Pile №№ 1, 2, 52, 69), stiff clays (Pile №№ 53, 243, 361) and claystones (Pile №№ 403, 407, 587, 592).

According to authors, it is caused by the cementation bonds between soil particles in claystones. These bonds are not able to recover after the failure from pile load and produce residual strains.

3 .2 Pile bearing capacity on different age clay bases

Obtained results of bearing capacity from full-scale static load pile tests and calculated bearing capacity from cone penetration tests in soft clay are presented in Figure 3.

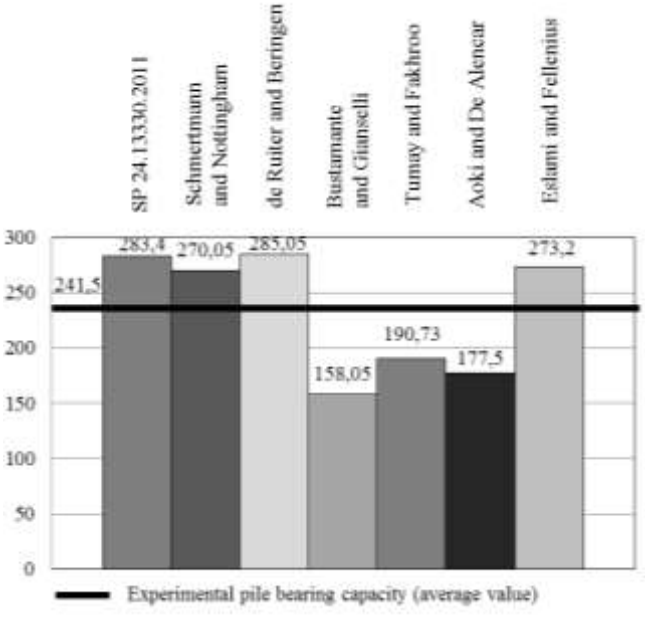

Figure 3. The average values of pile bearing capacity on soft clays

According to Figure 3, the most reliable among the bearing capacity calculation methods based on the results of the cone penetration tests in soft clay were the calculation method SP 24.13330.2011, method Schmertmann and Nottingham, de Ruiter and Beringen, method Eslami and Fellenius (accuracy within 25 % with pile tests).

The Figure 4 shows calculated and experimental pile bearing capacity on claystones.

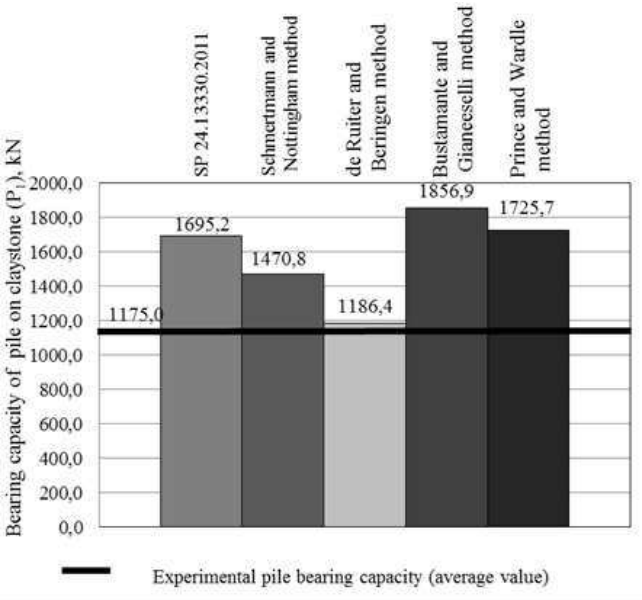

Figure 4. The average values of pile bearing capacity on claystones

According to Figure 4, the calculation by de Ruiter and Beringen method, Schmertmann and Nottingham method showed the closest results to experimental pile bearing capacity on claystone (accuracy within 25 % with pile tests).

In this way, the most reliable among the bearing capacity calculation methods are based on the results of the cone penetration tests were de Ruiter and Beringen method, method Schmertmann and Nottingham for piles on modern clays and claystones. These methods can be called versatile and suitable both for hard and soft clay.

4. RECOMMENDATION AND CONCLUSIONS

The pile behavior on claystone was close to pile behavior on stiff clay and stiff loam. In summary it can be noted, that the Permian claystone has compressibility less than the modern stiff clay.

The elastic component of pile settlement on soft clay and loam was 5 – 12 % of the total pile settlement, on stiff clay and loam this value was in the range 97 – 99 %.

For claystones elastic deformations were in the range 46 – 69 % of the total pile settlement. It is caused by the cementation bonds in claystones, which are not restored after loading. Permian claystone can be a reliable low-compressibility base and it is able to take a significant load from the pile foundation.

The most reliable among the bearing capacity calculation methods based on the results of the cone penetration tests in soft clay were the calculation method SP 24.13330.2011, method Schmertmann and Nottingham, de Ruiter and Beringen, method Eslami and Fellenius (accuracy within 25 % with pile tests).

The calculation by de Ruiter and Beringen method, Schmertmann and Nottingham method showed the closest results to experimental pile bearing capacity on claystone (accuracy within 25 % with pile tests).

In this way, Schmertmann and Nottingham method, de Ruiter and Beringen method for determination pile bearing

capacity show good agreement with static load pile tests on different age clay bases. These methods can be applied for soft, stiff clays and loams, claystones.

Represented conclusions are true for experimental sites and should be verified and evaluated in other experimental sites with layered clays and claystones. Increase the accuracy of calculations and description of the driven single pile and pile group behavior can ultimately reduces the costs of special reinforcement, material consumption and labor input measures of the pile foundations and provides their safety and durability.

According to authors, this line of research is promising for further study because of widespread of ancient clay bases for buildings and constructions foundations in many countries of the world.

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