# Analysis of pile foundation behavior on modern and ancient clay bases

A.B. Ponomaryov & E.N. Sychkina
*Perm National Research Polytechnic University, Perm, Russia*

ABSTRACT: Large areas in many countries are characterized by the spread of ancient deposits. The purpose of this paper is comparison analysis of the characteristics of pile foundations behavior on modern and ancient clays. The following tasks were solved during the study: 1) The analysis of existing works on settlement and bearing capacity of piles on the modern and ancient clay are summarized. 2) Characteristics of experimental sites and methods of field research are described. 3) The experimental data are compared with the results of analytical methods calculations. 4) Based on these results recommendations for forecast piles work on ancient clay in comparison with modern clays and cone penetration test data interpretation in different ages clays are presented.
Key words: Pile, Foundation, Clay, Settlement, Bearing capacity.

## 1 INTRODUCTION

### 1.1 *Review of existing researches*

Numerous studies have shown that the soils of different ages interact with foundations of buildings and constructions in different ways. It is caused by the features the microstructure of the soil, formed as a result of long interaction of various processes: sedimentation, compression and decompression, dehydration, weathering. Large areas in many countries are characterized by the spread of ancient deposits. For example, Vendian clay, Permian and Sochi Formation claystones of European part of Russia (Ponomaryov & Sychkina 2015), the overconsolidation clay and sandstone of Europe (Cooke et al. 1989, Bond & Jardine 1991), North America and Canada (De Ruiter & Beringen 1979, Lehane & Jardine 1994), Japan (Matsumoto et al. 1995). These ancient deposits often lie under the modern sand-clay deposits. However, because of the low values of mechanical properties of modern sand-clay deposits, ancient soils are increasingly being used as the basis for the pile and the pile-plate foundation of heavily loaded buildings and constructions. Existing researches of settlement and bearing capacity corrected the information about the pile behavior on modern sand-clay deposits and increased the accuracy of foundation calculations. However, for the ancient soil a number of questions were not resolved.

Most methods of calculating pile bearing capacity were developed in the 80s and 90s of the last century. The main difference between European methods of calculation 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:

1. Schmertmann and Nottingham method (Schmertmann 1978, Fellenius 2014);
2. de Ruiter and Beringen method, «Dutch method" or "European method" (Fellenius 2014);
3. Bustamante and Gianeeselli method, «LCPC» method or the "French method" (Bustamante & Gianeeselli 1982);
4. Prince and Wardle method (Price & Wardle 1982).

The main difference between methods is the determining soil resistance under the pile tip and on the lateral surface of the pile.

### 1.2 *The research aim, object and tasks*

The purpose of this paper is comparison analysis of the characteristics of pile foundations behavior on modern and ancient clays. Object of the research are Early Permian age ($P_1$) claystones and Quaternary age ($Q_{IV}$) lean clays.

The following tasks were solved during the study: 1) the analysis of existing works on settlement precipitation and bearing capacity of piles on the modern and ancient clay are summarized. 2) characteristics of experimental sites and methods of field research are described. 3) experimental data are compared with the results of analytical methods calculations. 4) based on these results recommendations for forecast piles work on ancient clay in comparison with modern clays and cone penetration test data interpretation in different ages clays are presented.

## 2 METHODOLOGY OF INVESTIGATION

### 2.1 *Characteristics of experimental sites*

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

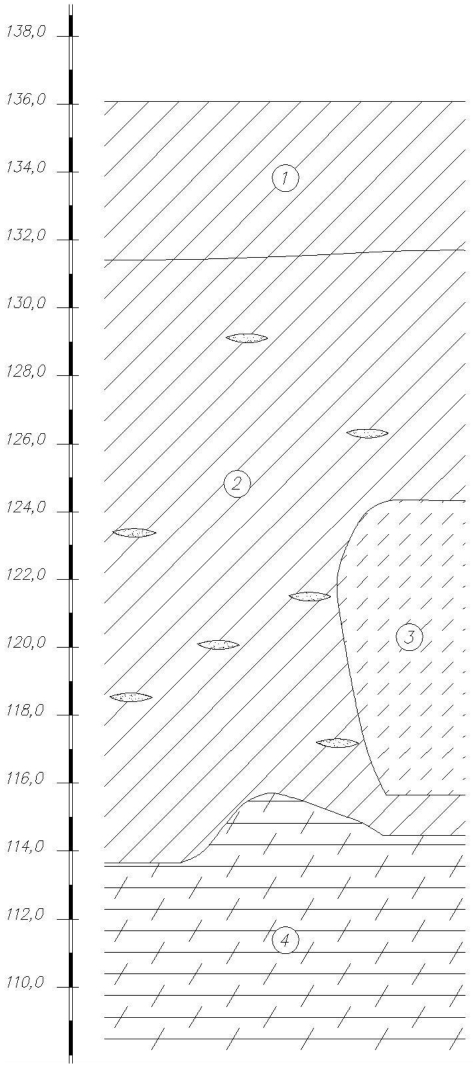


Figure 1. Experimental sites typical soil profile. Herein: 1 – soft loam and clay, 2 - soft clay and loam, with areas of gravel, 3 - loamy sand; 4 – claystone.

The detailed stratigraphy of the soil layers on Figure 1 are given below:

Layer 1: soft, clay and loam clay ($Q_{IV}$).

Layer 2: p soft clay and loam clay, with areas of gravel up to 25-35% ($Q_{IV}$).

Layer 3: sandy and gravel, from soft to stiff loamy sand ($Q_{IV}$).

Layer 4: weathered claystone ($P_1$).

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

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

| Soil type | density | moisture | consistency index |
|---|---|---|---|
| | g/cm$^3$ | % | % |
| Claystone ($P_1$) | 2.01 | 20 | 8 |
| Stiff clay ($Q_{IV}$) | 1.98 | 19 | 5 |
| Soft clay ($Q_{IV}$) | 1.91 | 27 | 34 |

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

Much attention is given to the static load tests of driven piles. Pile size was 0,3m x 0,3m. Settlement of pile was determined by the results of full-scale static load pile test according to Russian standard documents. Settlement of piles during unloading period was measured for evaluating elastic and inelastic strains.

In the article eleven piles on a different clay deposits are discussed. Including:

- on modern soft clay and loam ($Q_{IV}$) 4 piles are tested (Pile №№ 1, 2, 52, 69).
- on modern stiff clay and loam ($Q_{IV}$) 3 piles are tested (Pile №№ 53, 243, 361);
- on Permian claystones ($P_1$) 4 piles are tested (Pile №№ 403, 407, 587, 592).

Tests for soft clays and loams were performed at 90 days (Pile 1), 96 days (Pile 2), 22 days (Pile 52) and 43 days (Pile 69) after pile driving.

Tests for stiff clays and loams were performed at 19 days (Pile 52), 17 days (Pile 243) and 17 days (Pile 361) after pile driving.

### 2.2 *Description of methodology*

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

Much attention is given to the static load tests of piles. Pile size was 0.3 m x 0.3 m. Settlement of pile was determined by the results of full-scale static load pile test. Settlement of piles during unloading period was measured for evaluating elastic and inelastic strains. In the paper eleven piles on a different clay deposits are discussed. Including:

- on modern soft clay and loam ($Q_{IV}$) 4 piles are tested (Pile №№ 1, 2, 52, 69).
- on modern stiff clay and loam ($Q_{IV}$) 3 piles are tested (Pile №№ 53, 243, 361);
- on Permian claystones ($P_1$) 4 piles are tested (Pile №№ 403, 407, 587, 592).

Tests for soft clays and loams were performed at 90 days (Pile 1), 96 days (Pile 2), 22 days (Pile 52) and 43 days (Pile 69) after pile driving. Tests for stiff clays and loams were performed at 19 days (Pile 52), 17 days (Pile 243) and 17 days (Pile 361) after pile driving. Pile tests on claystones were performed at 32 days (Pile 403), 20 days (Pile 407), 14 days (Pile 587) and 9 days (Pile 592) after pile driving.

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

The cone penetration tests results in soft modern clays on this experimental site were taken according to Ponomaryov et al. 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: Schmertmann and Nottingham; de Ruiter and Beringen ("European" or "Dutch" method); Bustamante and Gianeeselli (LCPC or "French method"); Tumay and Fakhro; Aoki and De Alencar and method Eslami and Fellenius.

The results of calculation bearing capacity of pile on claystone according to the calculation methodology in Russian standard document SP 24.13330.2011 (p. 7.2.); and with cone penetration test data according Russian standard document SP 24.13330.2011; Schmertmann and Nottingham method; de Ruiter and Beringen method; Bustamante and Gianeeselli method; Prince and Wardle method are analyzed.

## 3 RESEARCH RESULTS

### 3.1 *Pile settlement on different age clay bases*

Figure 2 shows the character of single pile settlement on three varieties of clays: soft clay and loam (Pile №№ 1, 2, 52, 69), stiff clay (Pile №№ 53, 243, 361) and claystone (Pile №№ 403, 407, 587, 592).

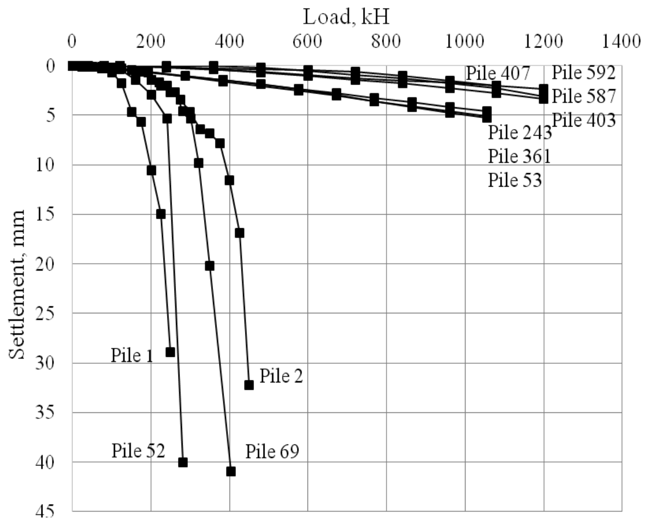


Figure 2. The pile settlement on soft clays, stiff clays and claystones

Settlement of piles on soft clays significantly increased even for loads of 250 - 450 kN, the maximum value of piles settlement was 26.10 - 38.31 mm. Maximum pile settlement on stiff clays was 4.58 - 5.28 mm for load of 1056 kN. The maximum pile settlements on claystones were still less than for stiff modern clay and amounted 2.17 - 3.37 mm for load on the pile of 1100-1200 kN. 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.

According to authors, it is caused by the cementation bonds in claystones. These bonds are not able to recover after the failure from pile load. Inelastic strain for claystones higher than the inelastic strain for stiff clays without cementation bonds at 30 – 50 %.

### 3.2 *Pile bearing capacity on different age clay bases*

As noted by Ponomaryov et al. 2015, the most reliable among the bearing capacity calculation methods based on the results of the cone penetration tests in weak clay is the calculation method SP 24.13330.2011 with cone penetration test data from cone type II, method Schmertmann and Nottingham, de Ruiter and Beringen, method Eslami and Fellenius (accuracy within 25% with static testing piles).

The Figure 3 shows the bearing capacity of piles on claystones determined by different methods.

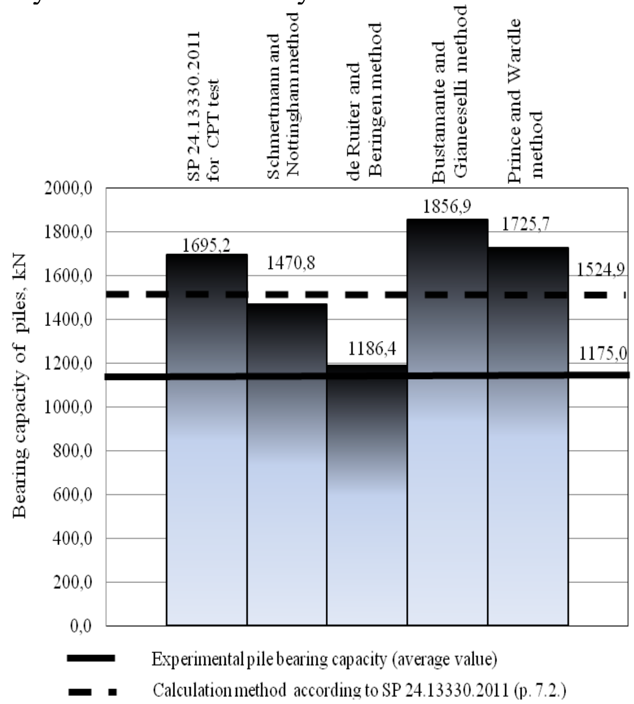

Figure 3. The average values of the calculated and experimental pile bearing capacity on claystones

According to Figure 3, the closest results to experimental pile bearing capacity on claystone the calculation by de Ruiter and Beringen method (difference was less than 1 %), by Schmertmann and Nottingham method (difference was 25.2 %), and calculation method SP 24.13330.2011 p.7.2 (difference was about 30 %) showed. Calculation by the method Bustamante and Gianselli, method Prince and Wardle showed overestimated value of pile bearing capacity to 44.3 – 58 % as compared with pile tests on claystones.

The most reliable among the bearing capacity calculation methods is based on the results of the cone penetration tests in claystones de Ruiter and Beringen method, method Schmertmann and Nottingham.

## 4 RECOMMENDATION AND CONCLUSIONS

The behavior of pile on claystone is close to the behavior of pile on stiff clay and loam. It can be concluded, that the Permian claystones have compressibility less than 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. Character of the interaction between claystone and pile shows that pile under load act as end bearing pile. In summarizing Permian claystone can be a reliable low-compressibility base and 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 is the calculation method SP 24.13330.2011 for cone type II, method Schmertmann and Nottingham, de Ruiter and Beringen.

The most reliable among the bearing capacity calculation methods based on the results of the cone penetration tests in claystones is de Ruiter and Beringen method, method Schmertmann and Nottingham. The calculation method SP 24.13330.2011 p.7.2 is also a reliable method.

In summarizing method Schmertmann and Nottingham, method de Ruiter and Beringen for determination bearing capacity shows good agreement with static load pile tests on different age clay bases. These methods can be applied for soft, stiff clays and loams, claystones.

The obtained results can be used to forecast bearing capacity and settlement of piles on clay bases with appropriate justification. According to the authors, this line of research is promising for further study because of the widespread of non-quarter age bases and using them as bases for foundations of buildings and constructions in many countries.

## 5 REFERENCES


Bond, A.J, Jardine, R.J. 1991. Effects of installing displacement piles in high OCR clay. *Geotechnique* 41: 341 - 363.

Bustamante, M., Gianeeselli, L. 1982. Pile bearing capacity predictions by means of static penetrometer CPT. *Proceedings of the 2nd European Symposium on Penetration Testing, ESOPT-II.* Amsterdam 2: 493 - 500.

Cooke, R.W., Price, G., Tarr, K. 1979. Jacked piles in London Clay: a study of load transfer and settlement under working conditions. *Geotechnique* 29: 113 - 147.

De Ruiter, J., Beringen, F.L. 1979. Pile foundations for large north sea structures. *Marine Geotechnology* 3: 267 - 314.

Fellenius, H. 2014. *Basics of Foundation Design*. Revised Electronic Edition. Sidney, Canada.

Lehane, B.M., Jardine, R.J. 1994. Displacement pile behaviour in glacial clay. *Canadian Geotechnial Journal* 31: 79 - 90.

Matsumoto, T., Michi, Y., Hirano, T. 1995. Performance of axially loaded steel pipe piles driven in soft rock. *Journal of geotechnical and geoenvironmental engineering* 121 (4): 305 – 315.

Ponomaryov, A.B., Bezgodov, M.A., Bezgodov, P.A. 2015. Comparison of methods for determination of the bearing capacity of driven piles using the cone penetration test in soft clay. *Herald of Perm National Research Polytechnic University, Construction and architecture* 2: 24-39.

Ponomaryov, A., Sychkina, E. 2015. Analysis of strain anisotropy and hydroscopic property of clay and claystone. *Applied Clay Science* 114: 61 - 169.

Price, G., Wardle, I.F. 1982. A comparison between conep test results and the performance of small diameter instrumented piles in stiff clay. *Proceedings, the 2nd European Symposium on Penetration Testing*. Amsterdam 2: 775 - 780.

Schmertmann, J.H. 1978. *Guidelines for cone penetration test, performance and design*. U.S. Department of Transportation, Report No. FHWA-TS-78-209, Washington, D.C.