Experimental investigation of rheological properties of Permian claystones and sandstones

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ABSTRACT

The paper discusses the results of single pile and stamp tests on highly weathered and weathered claystones and sandstones. The following tasks were solved: 1) to describe the research technique; 2) to analyze the results of testing single piles and stamps on claystones and sandstones; 3) to describe the capabilities of the developed program for the calculation of settlement of pile; 4) to state conclusions. The experimental data were compared with the theoretical ones in order to expose similarities and adjust the existing theoretical solutions. The paper reveals a significant difference in the values and stabilization type of the stamp and pile settlement on highly weathered and weathered claystones and sandstones. Based on experimental results the authors developed an algorithm for the calculation of settlement of pile on highly weathered and weathered claystones and sandstones.

Keywords: rheological properties; claystone; sandstone; pile; foundation; settlement.

1 INTRODUCTION AND REVIEW OF PREVIOUS STUDIES

Many researchers have been involved in foundations on sandy and clay soils, including claystones and sandstones (Bartolomei and Ponomarev 2001, Zertsalov et al. 2018, Ter-Martirosyan et al. 2006, Shulyatyev 2014, Bond and Jardine, 1991, Lehane and Jardine, 1994). It was revealed that the type of a single pile – claystones and sandstones interaction differed from the type of a pile – dispersive soils interaction (Ponomarev and Sychkina 2018).

Rheological processes in claystones and sandstones do not stop with the completion of filtration consolidation and continue for a long time. When plastic-viscous flow of the soil occurs, damping creep is typical for loads not exceeding the limit values. A characteristic feature of creep curves is that 90 % of visco-elastic deformations develop in the first hours of loading, but then their growth slows down significantly, and the curves asymptotically tend to a certain limit which depends on the value of the load. O. Shulyatyev proved that the settlement of pile on Vendian clay increases twofold in 16 days (Shulyatiev 2014). It is necessary to predict the long-term interaction of a pile foundation and a soil base for bases with rheological properties.

In the works of M. Koltunov (1976) and A. Bartolomei (2001) it was proved that the most reliable theory that connected stress, deformation and time for viscous media was the phenomenological theory of hereditary creep. Based on the nonlinear theory of viscoelasticity, the relationship between load, settlement and time of load application was determined according to the expression:

$$S_t = S_0 \left\{ tg[bP(t)]^n + \int_0^t \frac{A\exp[-\beta(t-\tau)]}{(t-\tau)^{1-a}} tg[bP(\tau)]^n \, dt \right\} \quad (1)$$

where $0<a<1$, $\beta>0$, $A>0$ are core parameters by M. Koltunov; S_0 is the settlement occurred in 5 minutes after the load step application.

In a small loading range and the proportional dependence of the settlement on the load, the search for parameters included in the equation can be performed by M. Koltunov's graphic method, but this requires the data of the piles tests and the time-settlement graphs.

2 PURPOSE AND OBJECTIVES

The purpose of the study is to analyze the development of settlement in time under short-term testing of stamp and piles for highly weathered and weathered claystones and sandstones. The objectives are: 1) to describe the research technique; 2) to analyze the results of testing single piles and stamps on claystones and sandstones; 3) to describe the capabilities of the developed program for the calculation of settlement of pile; 4) to state conclusions.

3 RESEARCH TECHNIQUE

The study reviewed field test results of single piles on claystones and sandstones with different coefficients of weathering. The coefficient of weathering was determined in accordance with GOST 25100-2011. These soils can be described as highly weathered, weathered and softenable. The density of sandstones and claystones varies between 2.0 and 2.3 g/cm^3. On the test sites, these deposits are covered by a layer of modern sandy-clay deposits with a thickness of 5.0 to 13.0 m.

The study analyzed the settlements in time of full-scale driven and bored piles with claystone and sandstone bases. The dimensions of the piles were the following: the cross-section of driven piles was 0.3x0.3 m, the diameter of bored piles was 0.63 m. The penetration of the driven piles into claystones and sandstones ranged from 1.0 to 2.0 m, and that of the bored piles was from 2 to 6 m. The depth of the driven pile tests was 8–10 m, whereas the depth of the bored pile tests was 15–20 m.

In addition to testing the piles, the paper presents the results of stamp settlements in time. The stamp area was equal to 5000 cm^2. Four stamp tests were performed in weathered and highly weathered claystones and sandstones. The stamp tests were carried out for claystones occurring at a depth of 1.5-3.6 m, and for sandstones occurring at a depth of 4.0–5.5 m. The value of the steps of load was 0.05 MPa. Each step of load continued until reaching the speed of settlement of the stamp no more than 0.1 mm for 1 hour. The maximum load on the stamp was 0.40 MPa for claystone and 0.45 MPa for sandstone.

4 RESULTS AND DISCUSSION

4.1 Stamp tests

The graphs of the stamp settlement development in time for each load stage were constructed on the basis of test results (Fig. 1 and Fig. 2).

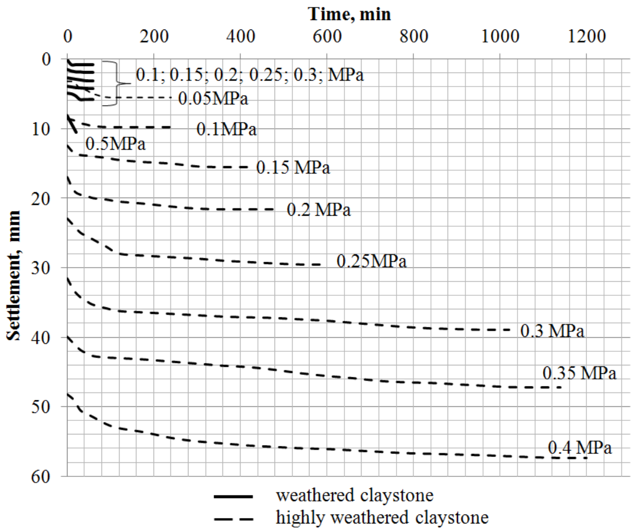

Fig. 1. Graphs of settlement in time for stamp testing of claystones.

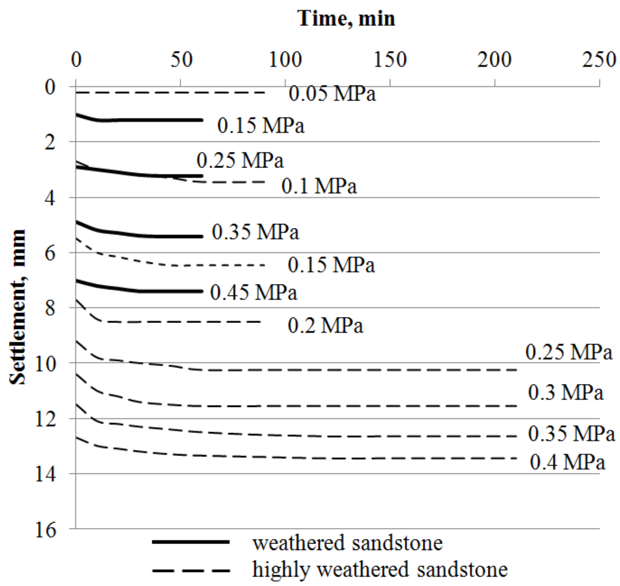

Fig. 2. Graphs of settlement in time for stamp testing of sandstones.

The duration of settlement stabilization for weathered claystones was 1 hour and 20 hours for highly weathered claystones, whereas for weathered sandstones it amounted to 1 hour and 3.5 hours for highly weathered sandstones. The curves have the form of damping creep, with the exception of the stamp testing of weathered claystones. A significant increase (by 20 %) in the stamp settlement in time on the weathered claystones was observed under the load of 0.5 MPa.

The stamp tests of claystones and sandstones showed that the deformations of highly weathered claystones under the load of 0.35 MPa were in 4.5 times higher than the deformations of the weathered claystones. The deformations of highly weathered sandstones with the load of 0.35 MPa were in 2.3 times greater than the deformations of weathered sandstones.

4.2 Single Pile Tests.

In the course of testing the piles, the bearing capacity of claystones and sandstones was not exhausted, but the ultimate strength of the pile material was reached. The obtained curves of all pile settlement in time were of damping creep. The rate of deformation and stabilization time for highly weathered claystones and sandstones were greater than those for weathered ones.

Time-settlement graphs for testing bored piles on claystones, driven piles on claystones and sandstones are presented in Fig. 3-5, respectively.

The settlement of piles on claystones and sandstones in time can be divided into two parts. The settlement under load dominates in the first phase for about 1 hour for the weathered and 3 hours for the highly weathered claystones and sandstones. Then creep deformations develop, under which the pile settlement velocity varies from 0.023 mm/min and tends to zero for highly weathered claystones and sandstones, whereas for weathered claystones and sandstones it is from 0.01 mm/min and tends to zero.

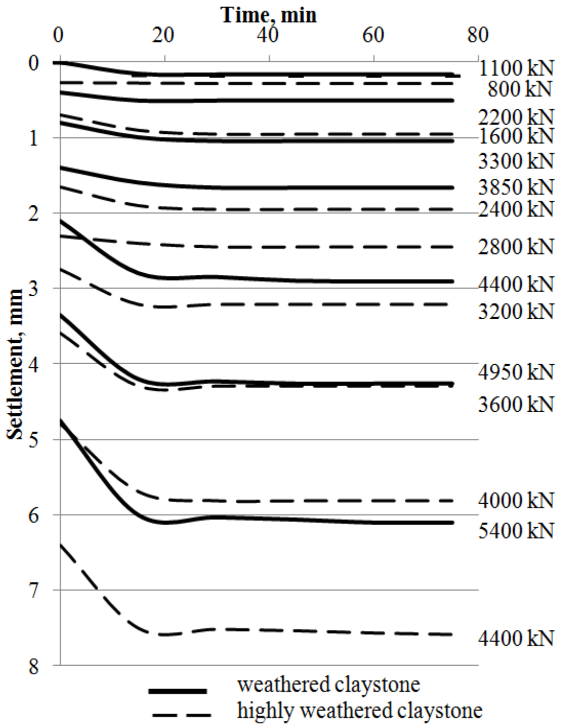

Fig. 3. Settlement of a bored pile on claystones in time.

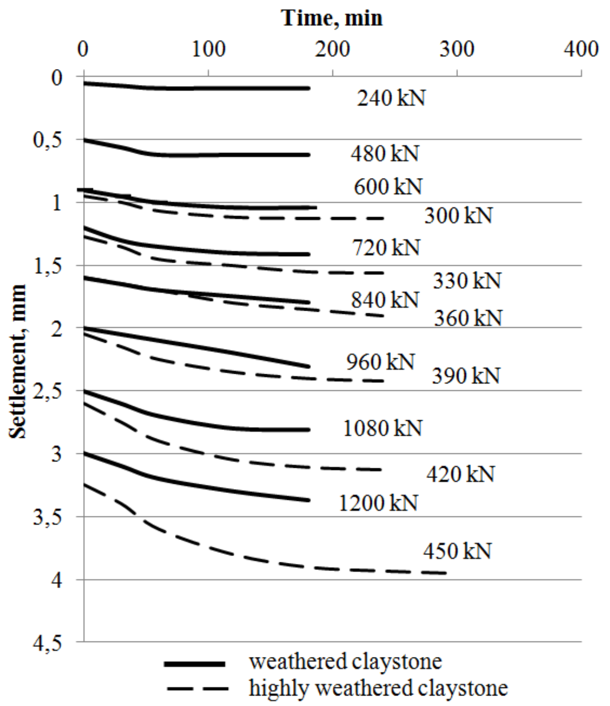

Fig. 4. Settlement of a driven pile on claystones in time.

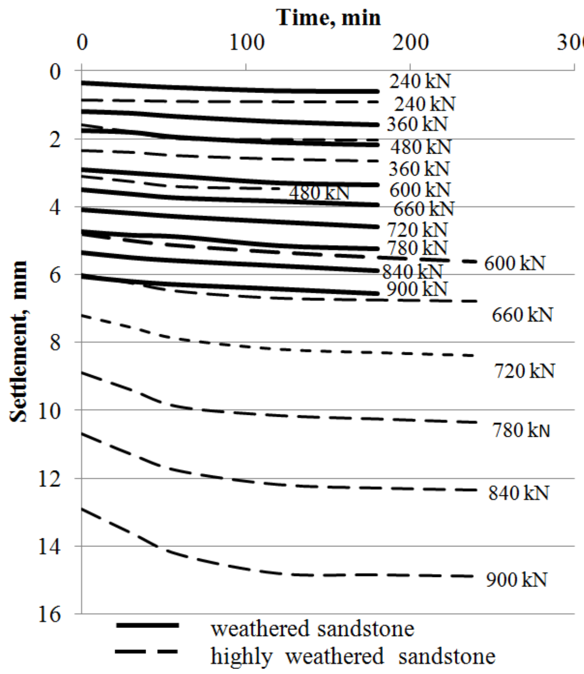

Fig. 5. Settlement of a driven pile on sandstones in time.

The graphs in Fig.3-5 show that the settlements of driven and bored piles on highly weathered claystones and sandstones exceed their settlements on weathered claystones and sandstones. For example, with the load of 900 kN on a pile on the weathered sandstones, the settlement was equal to 6.57 mm, but on highly weathered sandstone it was 14.88 mm. With the load of 450 kN on a pile on the weathered claystones the settlement of 0.62 mm was obtained, and on highly weathered claystone it was 3.95 mm. Thus, it was 6.4 time difference for claystones, and 2.3 time difference for sandstones. It corresponded to the results obtained during the stamp tests.

When the foundation was set on claystones and sandstones, sandstones appeared to be the less deformable base. Even if the foundation rested on the highly weathered sandstones, the settlements were 3.7 times less than the deformations of the highly weathered claystones under a similar load.

5 PRACTICAL APPLICATION OF THE RESULTS

The obtained experimental time-settlement curves were compared with the theoretical ones constructed by M. Koltunov (1976) in order to expose similarities and adjust the existing theoretical solutions.

The authors used the expression for the calculation of settlement of single pile proposed by M. Koltunov (1976) for nonlinear relations of the theory of creep:

$$S(t) = \psi(\sigma_k)\cdot(1+\int_0^t K(t)dt) \qquad (2)$$

where: $\psi(\sigma_k)$ is the similarity coefficient, $K(t)dt$ is the function of influence (core by M. Koltunov).

The process of finding the coefficient of similarity was automated. The authors developed an algorithm for the calculation of pile settlement in Microsoft Visual Basic. The sequence of actions in the developed algorithm:

1) time and values of settlements for short-term tests of piles or stamps are entered as input parameters;

2) the search for a theoretical curve similar to the experimental one and the calculation of the deviations of the experimental values from the theoretical ones are performed;

3) determination of core parameters by M. Koltunov (α, β, A) is performed;

4) results in the form of curves "time - long-term settlement" and "load - long-term settlement" are shown.

This algorithm makes it possible to perform the calculation of long-term settlements of piles on weathered and highly weathered claystones and sandstones. Data from widely used field tests of piles and stamps are applied as input. The authors believe that the application of this design scheme is a simple and effective way to improve the accuracy of calculation of long-term settlement of the pile.

6 CONCLUSION

1) The obtained results are important for predicting the settlement of the pile on claystones and sandstones. The authors developed an algorithm for the calculation of pile settlement in Microsoft Visual Basic. Data from widely used field tests of piles and stamps are applied as input. The developed algorithm can provides reasonable estimates of vertical displacements of the single pile on claystones and sandstones.

2) It was investigated that in the case of foundation support on claystones and sandstones, sandstone appeared to be the less deformable base.

3) The authors presented time-settlement graphs based on the experimental tests of stamps and piles on claystones and sandstones with different degrees of weathering. When testing stamps and piles on highly weathered varieties of claystones and sandstones, it was found that deformations under identical loads had large values for highly weathered claystones and sandstones. The difference in stamp settlements on highly weathered and weathered varieties of claystones was 6.4 times, and 2.3 times on sandstones. The difference in pile settlements on highly weathered and weathered varieties of claystones was 4.5 times, and 2.3 times on sandstones.

The authors plan to continue research for forecast settlement and bearing capacity not only for a single pile, but also for a pile foundation. However, the authors emphasize that the transfer of the foundation behavior observed on one site to other sites or to general statements needs careful discussion.

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