ORIGINAL ARTICLE
DOI: https://doi.org/10.30932/1992-3252-2023-21-5-5

World of Transport and Transportation, 2023,
Vol. 21, Iss. 5 (108), pp. 204–210

Assessment of the Impact of Construction of Reinforced Soil Retaining Walls on Abutment Pile Group Foundation

Mikhail T. Zbryskiy
Moscow State University of Civil Engineering, Moscow, Russia.
✉ *Zmt.work@mail.ru.*

Mikhail T. ZBRYSKIY

ABSTRACT

Recently, reinforced soil retaining walls have been increasingly used for construction of abutment pile groups. But those two structures are designed separately from each other, often even by different organisations. The objective of this work was to determine the impact of construction of reinforced soil retaining walls on first-pier pile foundations. The main task was to determine the dependence of the height of the embankment on the growth of adverse effects, the influence of pile length, depth, a possibility to apply nonlinear models and types of installation.

Complex modelling in flat and spatial settings has shown the need to consider while designing pile foundations the negative impact of additional horizontal and vertical shifts, as well as of bending moments and longitudinal forces. The study recorded a factor of emergence of negative friction the mechanism of which requires separate study.

The main conclusion of the study related to the need to develop a comprehensive assessment of the impact of construction of reinforced soil retaining walls on pile foundations of abutments.

Keywords: *transport infrastructure construction, pile foundations, reinforced soil retaining walls, impact assessment, negative friction, calculation model, reinforced soil, abutment pile group.*

For citation: *Zbryskiy, M. T. Assessment of the Impact of Construction of Reinforced Soil Retaining Walls on Abutment Pile Group Foundation. World of Transport and Transportation, 2023, Vol. 21, Iss. 5 (108), pp. 204–210. DOI: https://doi.org/10.30932/1992-3252-2023-21-5-5.*

The text of the article originally written in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

From the point of view of construction technology, when constructing abutments with pile groups, it is rational to first drive piles and then erect a reinforced soil retaining wall (hereinafter referred to as RSRW).

Computation of RSRW design is often carried out by companies producing geosynthetic materials (e. g., Maccaferri, Tensar, Huesker, etc). For design, it is necessary to perform calculations to determine the required dimensions, the number of reinforcing elements and the optimal distance between them. After that, checks are made for external and internal stability, overturning, plane shear, and deformations [1, P. 168; 2, P. 70; 3, P. 57; 4, P. 146].

The design and calculation of abutment pile group foundation, in turn, is carried out without considering the active pressure of the embankment approaching the bridge or overpass.

Currently, these calculations are performed independently of each other, by different departments or organisations. This division excludes the possibility of a comprehensive assessment of the joint operation of the elements of the bridge structure. This has the most adverse effect on the foundations of the first pier, which in most cases are of pile type and are subject to horizontal and vertical shifts, as well as to the impact of additional forces.

The study performed joint «foundation-foundation soil» calculations related to the pile foundation of the abutment as well as to the reinforced soil embankment influencing it.

MATERIALS AND METHODS

According to the laws of soil mechanics, the design of foundations must be carried out considering the mutual influence of soils and foundations [1,2]. At the same time, current regulatory documents provide for that these checks (impact assessment) are reduced only to calculation of additional deformations of the existing buildings in the surroundings, the calculation of these deformations been limited to certain maximum values depending on the technical condition. In bridge construction, these limit values are not stipulated, except for high rigid structures and pipes; accordingly, it is not mandatory according to the standards to determine the impact of RSRW on an already existing pile foundation of the abutment.

Besides, the work [5, P. 19] indicates a possibility of negative friction occurring on the side surface of existing pile foundations caused by tangential stresses in the soil near the loading area. Such additional impacts on buildings and structures falling within the zone of influence of new construction are practically not considered in modern design practice.

N. M. Glotov and coauthors[3] [6, P. 90] draw attention to the emergence of additional horizontal stresses from construction of an approach embankment because of occurrence of vertical stresses in the soil from the weight of the embankment and propose a method for taking this phenomenon into account. Similar accounting is given in the current regulatory documents, but only for the approach embankment adjacent to the abutment[4]. Accordingly, if the embankment is not adjacent, then such checks are not required and thus not performed.

Bridge construction widely uses the Fuss-Winkler elastic foundation model and its modifications [7, P. 42; 8, P. 49]. In this case, the soil is represented by a certain set of springs with proportional stiffness, while the piles are modelled as rod elements. Obviously, this model is not suitable for such a task. Solving problems in bridge construction is rarely performed in specialised geotechnical programs, such as PLAXIS, MIDAS GTS/FEA NX, Z-SOIL, etc.

To show the inapplicability of usual design principles, a MIDAS FEA NX software that implements the finite element method was selected. For structural elements with variable parameters (pile pitch, section size, etc.), it is recommended to use three-dimensional calculation schemes, which significantly complicates the modelling process and the engineer's labour costs.

In the work, numerical studies were carried out in the following variations:

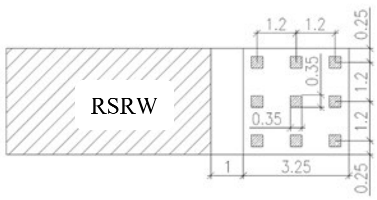
---

[1] Ukhov, S. B., Semenov, V. V., Znamensky, V. V. [et al]. Soil mechanics, basements, and foundations: Study guide. Moscow, Publishing House of the Association of Civil Engineering Universities 2005, 528 p., P. 129. ISBN 5-87829-003-0.

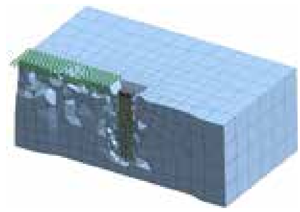
[2] Dalmatov, B. I., Bronin, V. N., Karlov, V. D., Mangushev, R. A[et al]. Basements and foundations. Part 2. Fundamentals of geotechnics: Textbook. Moscow, Publishing house ASV; SPbGASU, 2002, 392 p., P. 336. ISBN 5-93093-140-2.

[3] Glotov, N. M., Solovyov, G. P., Fainshtein, I. S. Basements and foundations of bridges: Handbook. Ed. by K. S. Silin. Moscow, Transport publ., 1990, 240 p. ISBN 5-277-00886-1.

[4] SP [Construction rules] 35.13330.2011 Bridges and pipes. Revised edition of SNiP 2.05.03–84. P. 233 [Electronic resource]: https://docs.cntd.ru/document/1200084849?ysclid=lmroclnplo408250369. Last accessed 17.05.2023.



a)



b)

Pic. 1. Finite-element model: a) diagram of a design case; b) spatial finite element diagram [developed by the author].

• Plane problem using the Mohr-Coulomb elastoplastic model.

• Plane problem using the elastoplastic model of hardening soil [9, P. 281; 10, P. 13].

• Volumetric problem using the Mohr-Coulomb elastoplastic model.

• Volumetric problem using the elastoplastic model of hardening soil.

In a two-dimensional setting, modelling piles with separate FE meshes (plane deformation elements) is possible only considering the reduced stiffness; the use of this method is not entirely correct. In view of this, special beam elements with a specified ultimate resistance along the lateral surface and under the heel of the piles were used.

In the three-dimensional model, the piles were modelled using solid finite elements, and the forces were obtained using a virtual beam, which integrates the stresses obtained in FE over the volume of the pile, and the interaction of the pile with the soil is taken into account by introducing interface elements [11, P. 34; 12, P. 19; 13, P. 26; 14, P. 36]. The finite element model is shown in Pic. 1 *b*.

Geological conditions are represented by one layer of sand of medium size, medium density, which has the following physical and mechanical parameters: p=19,5 kN/m^3; e=0,66; c=1 kPa; φ=35°; E=27 MPa; P_{ref}=100 KPa; ν_{ur}=0,28; E_{50}=15,7 MPa; E_{oed} =13,5MPa; E_{ur} =122,3 MPa; m=0,49; K_0^{nc} =0,4.

We assume that the RSRW design is stable and can be replaced by an equivalent design vertical load.

The specific gravity of the embankment soil is assumed to be 18 kN/m^3, the distance from the edge of the embankment to the edge of the grillage is 1 meter. It is obvious that the farther the retaining wall is located, the less impact the foundation will receive. It is also worth noting that there are projects in which the connection of RSRW to the cap is carried out almost end-to-end.

The height of the embankment varied from 6 to 13 meters; these heights are typical in similar projects. The cap measures 3,25 x 3,25 x 1,20 m and contains nine piles with a pitch of 1,2 m in the longitudinal and transverse directions (Pic. 1 *a*). The piles height varied from 7 to 15 meters with a section of 35 x 35 (C7.35-C15.35). Depth from surface level was up to 1,7 meters.

The calculation was carried out considering the staged construction of the embankment with one meter of filling per stage. Stage deformations without the participation of additional load from RSRW were reset to zero.

The following parameters were changed during numerical calculations: the size of the calculation model, the length of the piles, buried and non-buried cap, the difference in the physical nonlinearity of soil models (the use of different mathematical models to describe the behaviour of soils).

The influence of the embankment on the foundation is manifested in the form of the following factors:

• Additional horizontal movements of the foundation.

• Additional vertical movements of the foundation.

• Additional bending moments in piles.

• Additional longitudinal forces in piles.

• The occurrence of negative friction on piles.

RESULTS

Based on the analysis, it was revealed that the main parameters influencing the results obtained are:

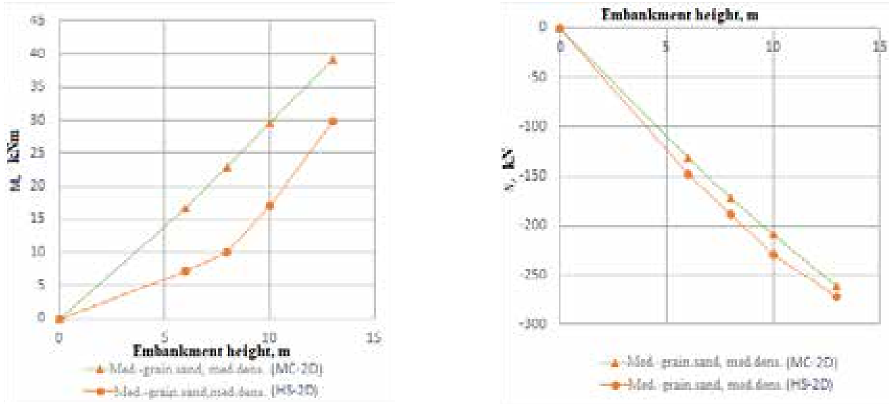
• Dimensions of the calculation area along the vertical axis.

• Pile length.

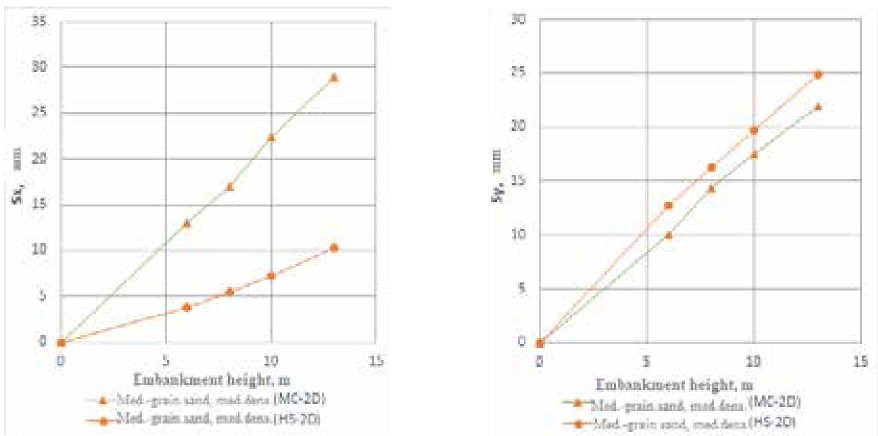
• Deepening of the cap.

• Type of setting (flat/spatial).

• Mathematical model describing the behaviour of soil (Coulomb-Mohr/ Hardening



Pic. 2. Additional internal forces in C15.35 piles [developed by the author].



Pic. 3. Additional movements in C15.35 piles [developed by the author].

Soil); the Hardening Soil model most correctly reflects the behaviour of soil when interacting with a pile[5].

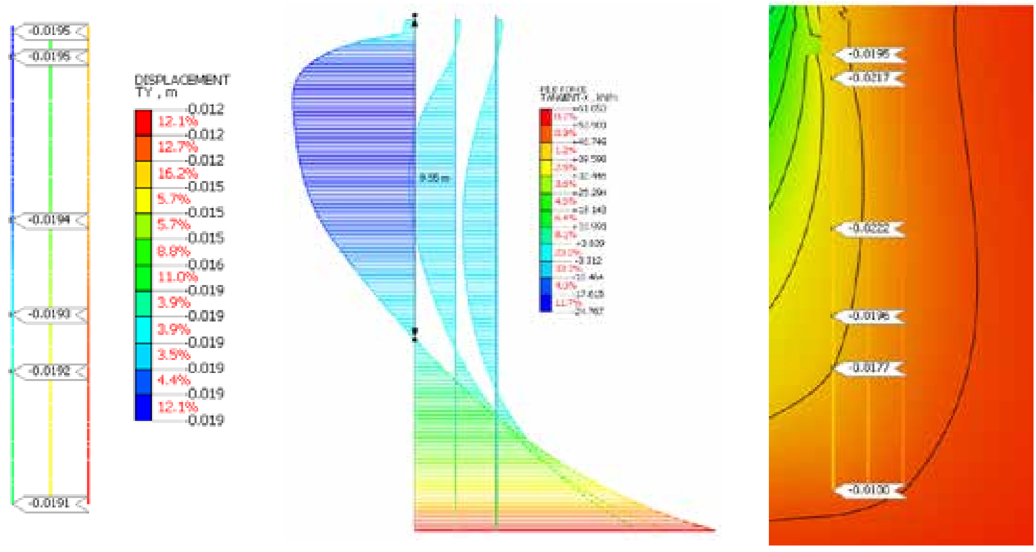
Analysis of Results in a Flat Setting

With the extension of the computational model, the absolute values of horizontal displacements increase, and the maximum value shifts lower to the edge of the computational model. The use of the elastoplastic model of Hardening Soil minimises this factor but does not eliminate it. The difference in additional bending moments can reach up to 40 %. In piles of shorter length, additional bending moments are greater and longitudinal forces are less. Due to the insignificant values of bending moments, it is worth paying more attention to longitudinal forces, which suggests that longer piles are subject to greater influence. As the depth of the cap increases, the pressure distribution on the cap and piles changes, resulting in a decrease in both moments and longitudinal forces. The resulting dependences of the displacements and forces in the piles on the soil model are shown in the graphs (Pics. 2 and 3).

The results obtained indicate that the elastoplastic model of hardening soil shows a noticeable decrease in bending moments and horizontal displacements compared to the Coulomb-Mohr model while longitudinal forces and additional subsidence remain within the same limits.

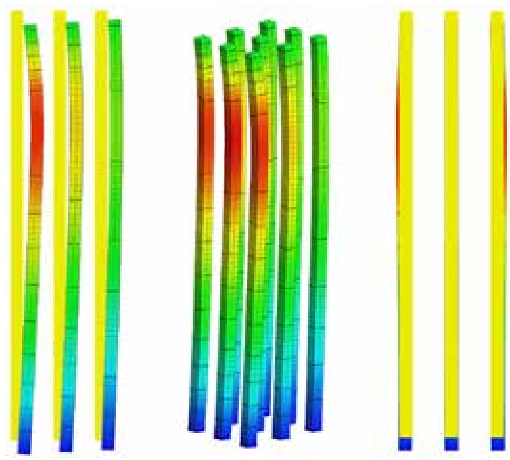
The study recorded the factor of the appearance of «negative friction» on the side surface of the bridge abutment piles. Negative friction occurs because the soil subsidence under the pile foundation under the influence of construction of RSRW is greater than the subsidence under the foundation itself (Pic. 4 *a, b, c*). In this case, the soil near the piles overhangs them, and the additional load is added to the external load

[5] Melnikov, R. V. Using the finite element method in geotechnics: Study guide. Moscow, Vologda, Infra-Engineering publ., 2021, 188 p. ISBN 978-5-9729-0697-0.



a) b) c)

Pic. 4. a) subsidence of the soil mass, b) subsidence of the pile foundation, c) shear stresses in pile interfaces [calculation results in MIDAS FEA NX environment, developed by the author].



Pic. 5. Deformed view of a pile foundation [calculation results in MIDAS FEA NX environment, developed by the author].

applied to the piles. According to the rules for calculating bearing capacity, tangential forces acting in the direction of settlement must be taken with the sign «–». This factor has a significant impact on the load-bearing capacity and leads to an increase in longitudinal forces [15, P. 1425; 16, P. 48; 17, P. 196]. Based on the nature of the diagram of tangential stresses in pile interfaces, it is clear that MIDAS FEA NX takes into account negative friction. Pic. 4 *c* shows that the negative friction from the embankment pressure acts only to a certain depth – a «neutral axis», the position of which can be determined from a numerical calculation. In specialised software systems, this phenomenon is considered automatically. In analytical calculations, or when using other solution methods, this factor must be specifically considered.

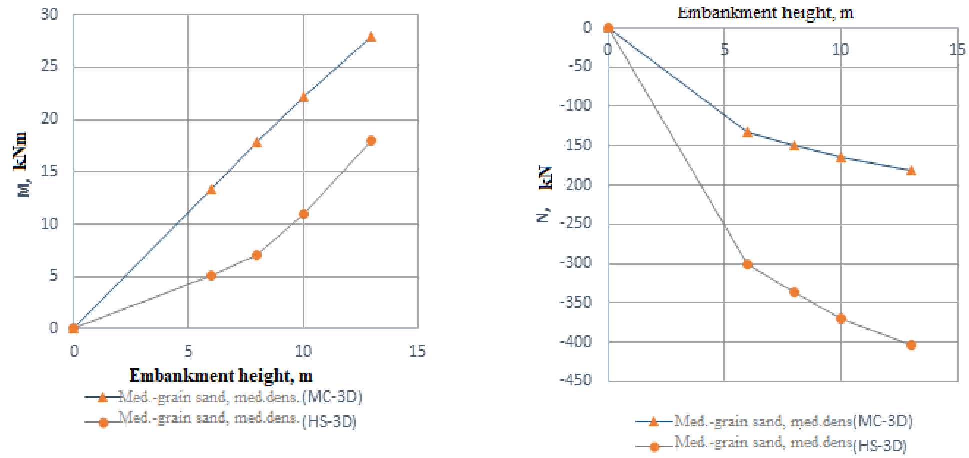
Analysis of Results in a Spatial Setting

Following numerical experiments carried out in a three-dimensional setting it was found that the behaviour of a pile foundation under the influence of the construction of RSRW is much more complex and requires careful analysis in each individual case. Pic. 5 shows the deformations of the pile foundation. Pics. 6 and 7 show the obtained dependences of the displacements and forces in the piles on the soil model in a spatial setting.

It is clearly seen that additional bending is observed only at 1/3 of the length of a pile, while the piles of the front row are subject to greater bending, which is intuitively understandable based on the distribution of additional stresses in the soil mass. The movement of the soil mass in the space in-between the piles leads to bending of the outermost piles in a different projection, which indicates a complex stress-strain state of the support foundation.

The obtained dependencies demonstrate a significant discrepancy in the results between the soil behaviour depending on the models used, which requires a separate study.

In a spatial setting, changing the height of the calculation model does not have a significant



Pic. 6. Additional internal forces in C15.35 piles [developed by the author].

effect on the results obtained. The bending moment values are reduced compared to the plane setting of the problem.

Longitudinal forces, on the contrary, increase. This effect can be explained by the fact that the behaviour of piles along the lateral surface is more accurately described, since the entire solid volume is modelled, and the software package automatically determines the tangential forces applied along the lateral surface. The absolute values of displacements decreased.

DISCUSSION AND CONCLUSIONS

The results of experiments can be summarised and suggested for discussion as the conclusions that follow.

1. The impact on the abutment pile foundation of the construction of RSRW is expressed in additional bending moments, longitudinal forces, vertical and horizontal displacements.

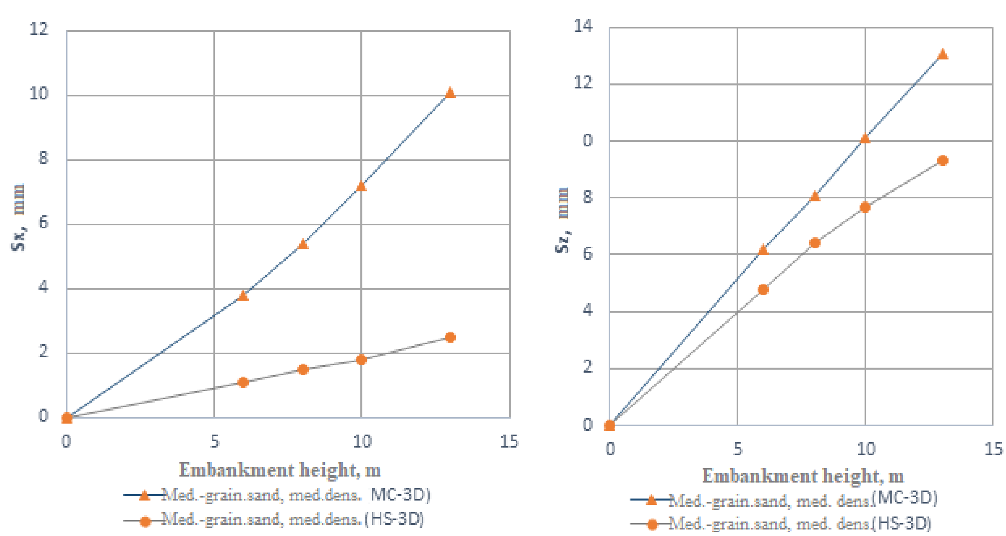
2. When building a high-height RSRW next to a pile foundation, negative friction may occur on the side surface of the piles, which can lead to a decrease in the load-bearing capacity of the piles regarding the soil.

3. Beam finite elements are idealised models, and their cross-section is not considered entirely correctly, thus the longitudinal forces may not be determined correctly.

4. Additional internal forces depend on the soil behaviour model used.

5. The height of the calculation model affects the results obtained in a flat setting and has virtually no effect in a spatial setting.

6. When designing an abutment with pile groups, it is necessary to jointly calculate and



Pic. 7. Additional displacements in C15.35 piles [developed by the author].

design the RSRW and the foundation of the abutment.

Performing two independent calculations may lead to incorrect results and future damage to foundations, which will significantly reduce safety and reliability of the bridge structure. To avoid such problems, during design phase it is necessary to consider the influence of retaining walls on pile foundations. To solve this problem, it is necessary to ensure coordination between specialists involved in calculations of the foundation of the abutment and RSRW.

In general, proper design of foundations and retaining walls is one of the most important aspects in creating reliable and safe structures. So, it is necessary to consider all possible influencing factors while proceeding with the design.

REFERENCES

1. Sokolov, A. D. Reinforced soil systems of highway bridges and transport interchanges: Monograph [*Armogruntovie systemy avtodorozhnykh mostov i transportnykh razvyazok: Monografiya*]. St. Petersburg, LLC Industry Media Corporation «Derzhava», 2013, 504 p. ISBN 978-5-7937-0901-0.

2. Tarasov, A. A. Design of bridge abutments from reinforced soil [*Proektirovanie mostovykh ustoev iz armirovannogo grunta*]. *Stroitelnaya mekhanika i konstruktsii*, 2012, Iss. 2 (5), pp. 70–76. EDN: PJEPYR.

3. Zernina, E. V. Calculation of a reinforced soil retaining wall to ensure slope stability [*Raschet armogruntovoi podpornoi stenki dlya obespecheniya ustoichivosti sklona*]. *Modern technologies in construction. Theory and practice*, 2019, Vol. 1, pp. 57–64. EDN: QGVUDT.

4. Shapiro, D. M., Tarasov, A. A. Calculation of stability of abutments and cones of bridge structures [*Raschet ustoichivosti ustoev i konusov mostovykh sooruhenii*]. *Scientific Bulletin of Voronezh State University of Architecture and Civil Engineering. Construction and architecture*, 2012, Iss. 2 (26), pp. 146–153. EDN: OXPZDT.

5. Sotnikov, S. N., Simagin, V. G., Vershinin, V. P. Design and construction of foundations near existing structures [*Proektirovanie i vozvedenie fundamentov vblizi sushchestvuyushchikh sooruzhenii*]. Ed. by S. N. Sotnikov. Moscow, Stroyizdat publ., 1986, 96 p. [Electronic resource]: https://djvu.online/file/QJwy7yYkzzFgH?ysclid=lmronkdpaf472884850. Last accessed 18.05.2023.

6. Glotov, N. M., Luga, A. A., Silin, K. S., Zavriev, K. S. Pile foundations [*Svainie fundamenty*]. Moscow, Transport publ., 1975, 432 p. [Electronic resource]: https://elima.ru/books/?id=1982&ysclid=lmro8al8w147138415. Last accessed 18.05.2023.

7. Nuzhdin, L. V., Mikhailov, V. S. Methods for constructing models and calculating the «pile foundation soil foundation» system in SCAD Office and Smath Studio [*Metody postroeniya modelei i rascheta sistemy «svainiy fundament –gruntovoe osnovanie*]. *News of higher educational institutions. Construction*, 2020, Iss. 5 (737). – C. 42–52. DOI: 10.32683/0536-1052-2020-737-5-42-52.

8. Shapiro, D. M. Theory and design models of foundations and geotechnical objects: Monograph [*Teoriya i raschetnie modeli osnovanii i obektov geotekhniki: Monografiya*]. Voronezh, IPC «Scientific Book», 2012, 164 c. ISBN 978-5-905654-70-1.

9. Sharma, V. J., Vasanvala, S. A., Solanki, C. H. Behaviour of Load-Bearing Components of a Cushioned Composite Piled Raft Foundation Under Axial Loading. *Slovak Journal of Civil Engineering*, 2014. Vol. 22, Iss. 4, pp. 25–34. DOI: 10.2478/sjce-2014-0020.

10. Schanz, T., Vermeer, P. A., Bonnier, P. G. The hardening soil model: Formulation and verification. In: Beyond 2000 in Computational Geotechnics. Balkema, Rotterdam, 1999, pp. 281–296. DOI: 10.1201/9781315138206-27.

11. Zakharova, T. M., Cherepanov, B. M. Review of the Midas GTS NX and PLAXIS 3D software systems for solving design problems when calculating pile foundations [*Obzor programmnykh kompleksov Midas GTS NX i PLAXIS 3D dlya resheniya proektnykh zadach pri raschete svainykh fundamentov*]. *Polzunovsky almanac*, 2023, Iss. 1, pp. 34–37. EDN: IHOQLI.

12. Kupchikova, N. V., Sychkov, A. N. Results of numerical analysis of the «building – pile foundation – soil foundation» system using «MIDAS GTS NX» [*Rezultaty chislennogo analiza sistemy «zdanie – svainiy fundament – gruntovoe osnovanie» s pomoshchyu «MIDAS GTS NX»*]. *Engineering and Construction Bulletin of the Caspian Region*, 2021, Iss. 1 (35), pp. 19–24. EDN: SZIVGB.

13. Fadeev, A. B. Parameters of the hardening soil model in Plaxis software. In: Numerical methods of calculations in practical geotechnics: Collection of articles of international scientific and technical conference. St. Petersburg, SPbGASU publ., 2012, 398 p., pp. 13–20. ISBN 978-5-9227-0318-5.

14. Alekhin, V. S. Interaction of piles in groups and determination of the ultimate resistance of the foundation. Ph.D. (Eng) thesis [*Vzaimodeistvie svai v sostave grupp i opredelenie predelnogo soprotivleniya. Diss…kand.tekh. nauk*]. Moscow, RUT publ., 2020, 147 p.

15. Znamenskii, V. V., Hegazy, O. M. A comparative study of ordinary piles and superlong piles in consolidating soil. *Journal of Physics: Conference Series*, 2019, Vol. 1425, Iss. 1, art. 012071. DOI: 10.1088/1742-6596/1425/1/012071.

16. Akopyan, V. F., Kondrik, I. V., Samsonov, O. V. Modeling of negative friction forces during implementation of subsidence properties of soil [*Modelirovanie otritsatelnykh sil treniya pri realizatsii prosadochnykh svoistv grunta*]. *Engineering Bulletin of the Don*, 2018, Iss. 1, pp. 48–54. [Electronic resource]: http://www.ivdon.ru/uploads/article/pdf/IVD_40_akopyan_kondrik_samsonov.pdf_aa673c493e.pdf. Last accessed 29.07.2023.

17. Znamensky, V. V., Le Thuy Duong. The influence of the water drawdown process on the development of negative friction forces on the side surface of the pile. *Innovations and investments,* 2022, Iss. 4. [Electronic resource]: https://www.innovazia.ru/upload/iblock/f3b/se3tpz3oxz7i2tm8uat40hz9mee9c1lu/%E2 %84 %964 %20 2022 %20 %D0 %98 %D0 %B8 %D0 %98.pdf [full issue]. Last accessed 29.07.2023.

Information about the authors:

Zbryskiy, Mikhail T., *master's student at the Department of Soil Mechanics and Geotechnics of Moscow State University of Civil Engineering, Moscow, Russia, Zmt.work@mail.ru.*

Article received 13.06.2023, approved 13.10.2023, accepted 15.11.2023.