UDC 624.15:692.115

TO THE ISSUE OF INCREASING THE RELIABILITY OF DETERMINING THE MECHANICAL CHARACTERISTICS OF SOILS

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Abstract
The problem of determining reliable characteristics of soils necessary for the design of foundations of buildings and structures is important and urgent. The main parameters determining the mechanical properties of soils are their strength and deformation characteristics, obtained, as a rule, by the results of static probing. Investigations of the process of probe immersion into the soil have allowed to identify a zone of fracture, within which shear deformations take place; a zone of elastic-plastic shear deformations and a zone of elastic deformations. This obviously leads to a change in the determined soil parameters around the probe. Comparing the interaction of the pile and the surrounding soil with the processes occurring during the probe immersion, the values of the obtained characteristics of sandy soils during probing are revealed with their values for the sands of natural composition, which allows to obtain more reliable values for the design of bases and foundations. The article examines the features of the interaction of the surrounding soil with piles and a probe during their immersion, associated with a change in the porosity coefficient.

Keywords: porosity coefficient, static soil probing, soil compaction, mechanical characteristics, soil compaction area.

К ВОПРОСУ ПОВЫШЕНИЯ ДОСТОВЕРНОСТИ ОПРЕДЕЛЕНИЯ МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК ГРУНТОВ

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Реферат
Проблема определения достоверных характеристик грунтов, необходимых для проектирования фундаментов зданий и сооружений, является важной и актуальной. Основные параметры, определяющие механические свойства грунтов – это их прочностные и деформационные характеристики, получаемые, как правило, по результатам статического зондирования. Исследования процесса погружения зонда в грунт позволили выявить зону разрушения, в пределах которой имеют место деформации сдвига, зону упругопластических деформаций сдвига и зону упругих деформаций. Это, очевидно, приводит к изменению определяемых параметров грунта вокруг зонда. Сопоставляя взаимодействие погружаемой сваи и окружающего ее грунта с процессами, происходящими при погружении зонда, выявлены значения получаемых характеристик песчаных грунтов при зондировании с их значениями для песков природного сложения, что позволяет получить более достоверные их значения для проектирования оснований и фундаментов. В статье рассмотрены особенности взаимодействия окружающего грунта со сваями и зондом при их погружении, связанные с изменением коэффициента пористости.

Ключевые слова: коэффициент пористости, статическое зондирование грунта, уплотнение грунтов, механические характеристики, область уплотнения грунта.

Introduction

The most important reserve for improving the quality of designing foundations and bases is the reliability of determining the physical and mechanical characteristics of soils. The main parameters of the mechanical properties of soils that determine the foundation bearing capacity and deformability of foundations are the valuesof strength and deformation characteristics: the internal friction angle, specific adhesion, deformation modulus. These parameters, with the same type of granulometric composition, plasticity number, vary in significant ranges depending on porosity coefficient values, fluidity index, etc. [1, 2, 3]. Therefore, obtaining objective reliable information on the soil properties located in the active zone of the foundation of the designed buildings and structures is a very important task of engineering and geological surveys which determine the feasibility and effectiveness of the decisions taken on the foundation type and design [15, 18–20].

In accordance with [2], when conducting engineering and geological surveys with the aim of determining soil strength and deformation characteristics for the design and construction of buildings and structures of II and III levels of responsibility, it is allowed to use statistical probing data.

Soil testing by probing is used in conjunction with other types of engineering and geological surveys or separately [11].

Theoretical analysis of the reliability of determining the mechanical characteristics of soils

Determinating the physical and mechanical characteristics of soils is carried out according to tables [2]. In this case, the porosity coefficient e of sandy soils should be taken from the table or from the correlation dependence

$$e = 0.815 - 0.104 \ln q_s ,$$

where q_s – specific soil resistance under the probe tip.

The value of e, in addition to q_s, is not affected by the genesis of sands, their granulometric composition, or humidity.

This statement is incorrect, since "Without studying the genesis and diagenesis of rocks, it is impossible to correctly estimate their physical and mechanical properties in space and depth, the nature and intensity of change under the influence of various factor, properties of a given rock in relation to the designed structure [13]".

Thus, the value of the porosity coefficient is affected only by the specific resistance of the soil under the probe tip. Consequently, the obtained value of e should correspond to the soil natural density. However, the density values which are obtained in this way are of a purely preliminary, forecasting, nature [4, 5, 19].

Driving the probe into the soil results in its displacement into the area surrounding the probe.

The trajectory of the soil particle movement, its resistance when a conical tip is driven into it from the action of a static load, can be considered as the interaction of the surrounding soil and the pile driven into the soil "in the area" of its tip. When driving a pile, a so-called internal uplift appears under the tip of the pile, which forms a plastic zone around the pile. Further on, in the volume adjacent to this zone, the soil passes into an elastic state (Figure 1). The size of the elastic-plastic area, within which the soil is in a compacted state versus its natural state, depends on the strength characteristics. This is confirmed by natural and model studies of pile driving into various soils [6, 8, 9].

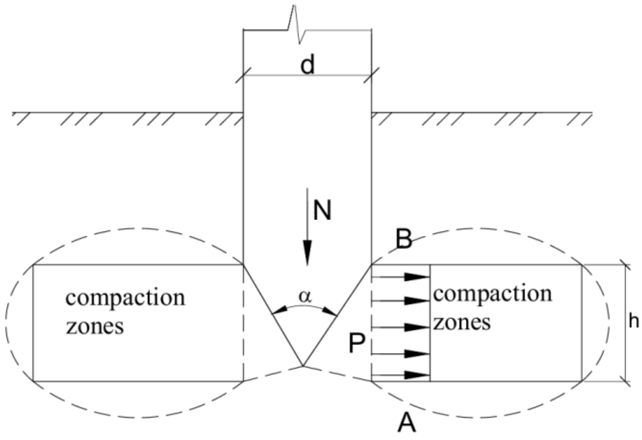


Figure 1 – Diagram of soil compaction when immersing a probe

Field studies by the Krasnodar PromstroyNIIproekt showed that when driving piles into clay soil, the compaction zones around the pile have the shape of a cylinder with a diameter of about (7–8)d (d – the diameter of the pile) [6].

The annular sand zones displaced by the pile around its shaft d = 10,7 cm have an average width of 1,9 cm along the entire height. The area of this annular zone in the horizontal section is 1,84 times greater than the cross-sectional area of the pile. Thus, all the soil in the volume of the pile was squeezed out to the sides with its simultaneous compaction. The decrease in the initial soil porosity in this zone is 16 %.

A compacted soil core is also formed under the lower end of the probe during its immersion, which has a great influence on the nature of the formation of the surrounding massif [8, 9].

A number of studies of the interaction of the driven pile and the surrounding soil confirm the formation of areas of horizontal displacement of soil particles and its compaction around the ring piles in a radius of 2 to 10,0d [6, 7, 8]. Some of the latest studies of the process of continuous immersion of the probe into the soil [14, 16, 17] made it possible to identify the following zones of its deformation as it moves away from the probe:

– destruction zone, in which the soil shear deformations reached and exceeded the ultimate strength values;

– zone of elastic-plastic shear deformations that did not reach the ultimate value;

– zone of minor elastic shear deformations, soil compression.

The sizes of these zones change proportionally to the initial soil density.

Thus, the experimental studies conducted with various soils on the models allowed us to establish compaction zones below the tip (compacted core) and deformation zones, mainly in the horizontal direction.

The elastic part of the compacted core causes the formation of a compaction zone. When the soil is displaced in the radial direction, compression pressure P occurs on the probe contour, causing the movement of soil particles in the plastic area, i.e. causing its compaction (Figure 2). This means that when the probe is driven in, the soil natural density changes: loose soil is compressed, and dense soil is loosened. Besides, a similarity in the nature of the deformation of the base during the immersion of the probe and pile models into the soil was revealed, which makes it possible to mutually extrapolate the analytical and numerical solutions obtained for both problems.

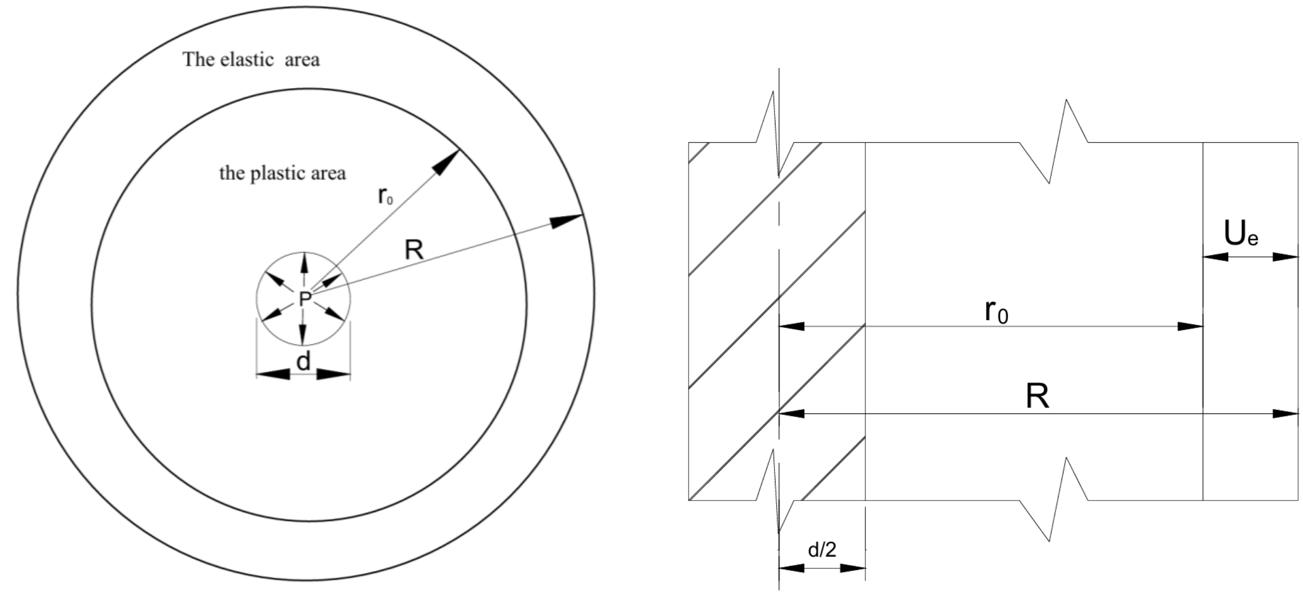


Figure 2 – Calculation scheme

The identified peculiarities of the interaction of the surrounding soil with the piles and the probe during their immersion are connected with a change in the porosity coefficient compared to its natural value.

The porosity coefficient for sandy soils is one of the main classification indicators, according to which sands are divided into varieties by density. The value of this indicator is affected by the dispersion of the sandy soil and its natural composition density, humidity, which determines the value of mechanical characteristics.

Consequently, the issues of the reliability of determining the natural density and mechanical characteristics of soil are very important.

Let us designate the porosity coefficient of natural soil as e, and the porosity coefficient of compacted soil as e_c. Taking into account that soil compaction occurs mainly within the plastic area (Figure 2), since the value of U_e is usually insignificant compared to the plastic area, then e_c is characteristic as the average coefficient of soil porosity in this area. Supposing that all solid particles in the probe volrme are displaced into the soil volume limited by the radius r_o, the equation will look

$$e_c = e - \frac{d^2}{4r_o^2}(1+e).$$

Hence

$$e = \frac{r_o^2(1+e_c)}{r_o^2 - 0,25d^2} - 1.$$

In accordance with [9], the radius of the soil maximum state zone in the plane passing through the tip of the cone is determined by the formula

$$r_0 = \frac{d}{2}\left[1 + \frac{\sqrt{2}\cdot e\left(\frac{\pi}{2} - \frac{\varphi}{2}\right)tg\varphi}{sin\left(\frac{\pi}{2} + \frac{\varphi}{2}\right)}\right].$$

Denoting the expression in square brackets D, we obtain

$$r_0 = D\cdot\frac{d}{2}.$$

Then

$$e = \frac{D^2(1+e_c)}{D^2 - 1} - 1.$$

Obviously, in the plastic area and when the cone is immersed, the change in the porosity coefficient of the compacted soil depends on the distance from the probe edge, where the density will be maximum and as it moves away from the probe, it will decrease to the natural one.

The change in the porosity coefficient e_r within the compacted area is accepted, taking into account the logarithmic nature of the development of shear deformations [10], according to the formula

$$e_r = e\cdot e_н^{-\frac{r}{a}},$$

where $e_н$ is the base of the natural logarithm.

r is the distance from the compaction boundary to the point under consideration,

a is a certain coefficient.

Analysis of the change in the porosity coefficient in the direction from the probe to the boundary of the plastic area shows that at the probe surface e has the lowest value and when approaching the edge of the plastic area e increases. The difference in soil density between these characteristic points is about 14 %.

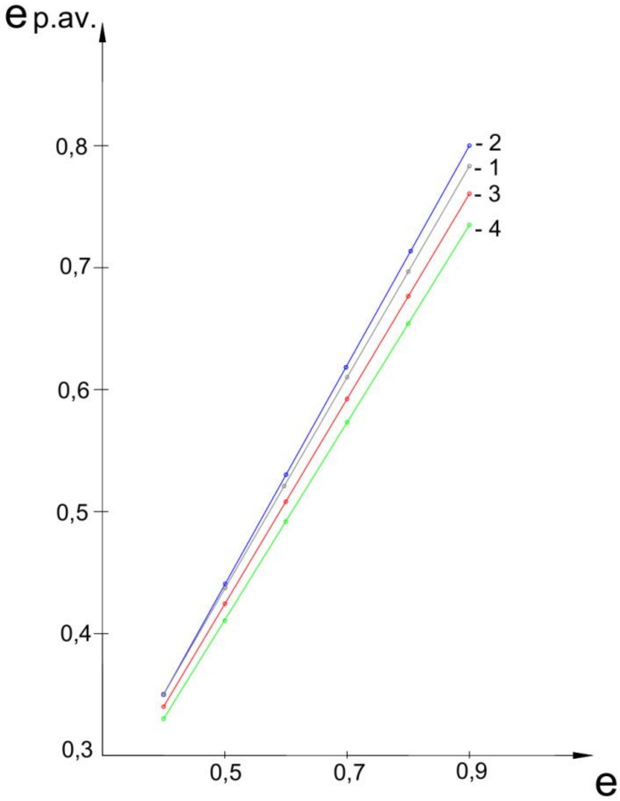
At $r = 0$; $e_r = e$; if $r = r_0 - \frac{d}{2}$; $e_r = e_p$ is the porosity coefficient of the soil at the probe surface.

The most intense change in the porosity coefficient is observed in the section from the probe surface to 0,25d. It is obvious that the maximum soil density during probing tests will be in the area adjacent to the probe surface. Taking into account the results of testing models of piles driven into sandy soils, and also guided by the need to determine the most reliable characteristics of the soils, we will determine the value of $e_{p.av}$ within the range of 0,30d. Then the value of $e_{p.av}$ will be equal to

$$e_{p.av} = e\cdot e_н^{\frac{-(r_o - 0,3d)}{a}}.$$

Calculations show that within the 0,2d area, the change in the porosity coefficient does not exceed 10 %. Figure 3 shows the change in the porosity coefficient of natural soil composition in the 0,3d area depending on the average porosity coefficient when the probe is immersed. There is a clear linear relationship between $e_{p.av}$ and e for sandy soils of different coarseness. The angle of inclination of the line to the abscissa axis depends on the angle of internal friction of the soil. The greater the value of φ, the smaller the angle of inclination α. This indicates that for the same value of $e_{p.av}$, the value of e for different soils is different in density: with a larger sand coarseness of the determining fraction, the natural density of the soil is higher.

Conversely, for the same natural density of the soil, the average value of $e_{p.av}$ is higher for fine and dusty sands than for coarse and gravelly sands; the higher is the value of e, the greater is this difference.



1 – $e_{p.av}$ within 0,3d; 2 – $e_{p.av}$ at φ = 24°; 3 – $e_{p.av}$ at φ = 36°; 4 – $e_{p.av}$ at φ = 42°.

Figure 3 – Change in $e_{p.av}$ for sandy soils of different densities

Figure 4 shows the graphs of the change in the specific soil resistance under the probe tip q_s depending on e. The graphs show that for any given value q_s, the actual value of e is less than the determined by [2].

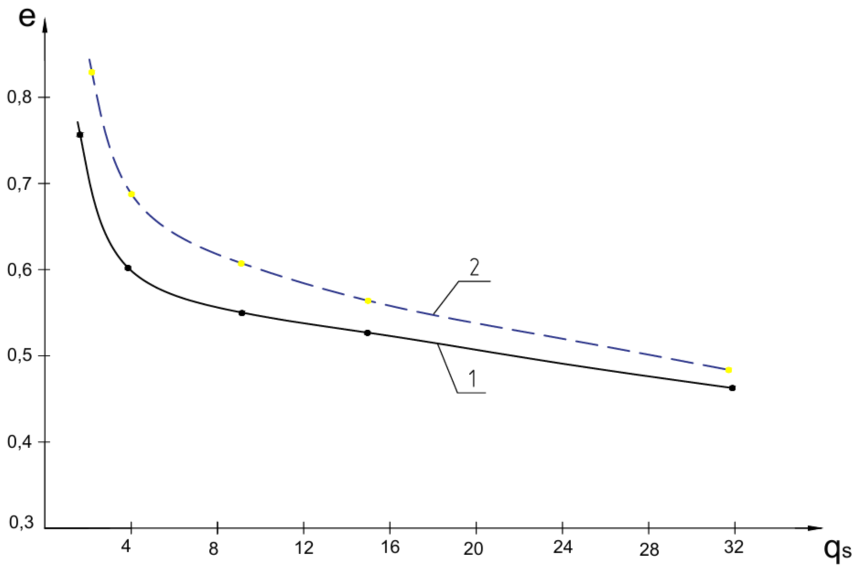
And this, as is obvious, affects the value of mechanical characteristics determined according to [11–13]. The comparison of the deformation modulus for coarse sands according to the proposed procedure and in compliance with [11–13] shows this difference of up to 17 %.

Conclusions

1. When the cone is immersed into the soil, the soil is displaced in the radial direction, which causes its additional compaction.

2. The determination of the soil porosity coefficient, its strength and deformation characteristics should be carried out taking into account the presence of a zone of additional soil compaction "in the area" of the immersed probe.

https://doi.org/10.36773/1818-1112-2024-135-3-64-67



1 – according to [2]; 2 – by formula (1).

Figure 4 – Change in q_s depending on e

References

1. Grunty. Klassifikaciya : GOST 25100-2020. – Vzamen GOST 25100-2011 ; vved. 01.01.2021. – Moskva : Standartinform, 2020. – 38 s.
2. Prochnostnye i deformacionnye harakteristiki gruntov po dannym staticheskogo zondirovaniya i penetracionnogo karotazha. Pravila opredeleniya = Tryvalasnyya i defarmacyjnyya haraktarystyki gruntoý pa dannyh statychnaga zandziravannya i penetracyjnaga karatazhu. Pravily vyznachennya: TKP 45-5.01-15-2005 (02250). – Vved. 01.07.2006. – Minsk : Minstrojarhitektury Respubliki Belarus': Minsktipproekt, 2006. – III, 21 s.
3. Inzhenernye izyskanie dlya stroitel'stva = Inzhynernyya vyshukanni dlya budaýnictva : SN 1.02.01-2019. – Vved. 26.12.2019. – Minsk : Minstrojarhitektury, 2020. – 109 s.
4. Kurilovich, A. E. K voprosu ob opredelenii fizicheskih svojstv peschanyh gruntov po dannym staticheskogo zondirovaniya / A. E. Kurilovich // Vestnik VGU. Seriya Geologiya. – 2013. – № 2. – S. 184–187.
5. Inzhenerno-geologicheskie izyskaniya dlya stroitel'stva. CHast' 1. Obshchie pravila proizvodstva rabot : SP 11-102-97. – Vved. 15.08.1997. – M. : Gosstroj RF, 1977. – 37 s.
6. CHernov, V. K. O deformaciyah glinistyh gruntov vokrug zabivnyh svaj / V. K. CHernov, V. V. Znamenskij, YU. P. YUrko // Stroitel'stvo v rajonah Vostochnoj Sibiri i Krajnego Severa. – Krasnoyarsk, 1971. – Vyp. 17. – S. 59–66.
7. Cooke, R. W. Strains and displacements around friction piles / R. W. Cooke, G. Price // Proceedings of the eighth international conference on Soil Mech and Found engineering. – Moscow, 1973. – Vol. 2, p. 1. – P. 53–60.
8. Lapshin, F. K. Raschet svaj po predel'nym sostoyaniyam / F. K. Lapshin. – Saratov : Izd-vo Sarat. un-ta, 1979. – 151 s.
9. Berezancev, V. G. Raschet prochnosti osnovanij sooruzhenij / V. G. Berezancev. – M. : Gosstrojizdat, 1960. – 138 s.
10. Solov'ev, YU. I. Variacionnyj metod opredeleniya nesushchej sposobnosti osnovanij i sooruzhenij / YU. I. Solov'ev // Izvestiya vuzov. Stroitel'stvo i arhitektura. – 1970. – № 7.
11. Grunty. Metody polevyh ispytanij staticheskim i dinamicheskim zondirovaniem. GOST 19912-2012. – Vzamen GOST 19912-2001, vved. 01.11.2013. – M. : Standartinform, 2013. – 23 s.
12. Pojta, P. S. O vzaimosvyazi opredelennyh v laboratornyh usloviyah parametrov gruntov s dannymi ih staticheskogo zondirovaniya / P. S. Pojta, T. P. SHalobyta // Vestnik Brestskogo gosudarstvennogo tekhnicheskogo universiteta. Seriya: Stroitel'stvo i arhitektura. – 2005. – № 2 (32). – S. 83–85.
13. Spravochnik geotekhnika. Osnovaniya, fundamenty i podzemnye sooruzheniya / pod obshch. red. V. A. Il'icheva, R. A. Mangusheva. – M. : Izd-vo ASV, 2014. – 728 s.
14. Mel'nikov, A. V. Eksperimental'no-teoreticheskie issledovaniya metoda statisticheskogo zondirovaniya gruntov : avtoref. dis. … kand. tekhn. nauk : 05.23.02 / Mel'nikov Aleksej Vladimirovich ; Mosk. gos. stroit. un-t. – Moskva, 2015. – 20 s.
15. Poyta, P. S. Nekotorye problemy proektirovaniya i stroitel'stva fundamentov zdanij i sooruzhenij / P. S. Poyta, N. N. Shalobyta, T. P. Shalobyta // Perspektivnye napravleniya innovacionnogo razvitiya i podgotovki kadrov : Mezhdunarodnaya nauchno-prakticheskaya konferenciya, Brest, 31 oktyabrya – 2 noyabrya 2024 g. – Brest, 2024. – S. 280–287.
16. Mel'nikov, A. V. Issledovanie haraktera deformirovaniya peska v processe staticheskogo zondirovaniya / A. V. Mel'nikov, G. G. Boldyrev // Osnovaniya, fundamenty i mekhanika gruntov. – 2014. – № 6. – S. 14–18.
17. Mel'nikov, A. V. Issledovanie deformirovannogo sostoyaniya peschanogo osnovaniya pri vypolnenii staticheskogo zondirovaniya / A. V. Mel'nikov // Voprosy planirovki i zastrojki gorodov : trudy XX Mezhdunarodnoj nauchno-tekhnicheskoj konferencii. – Penza : PGUAS, 2013. – S. 132–135.
18. Sanglera, G. Issledovanie gruntov metodom zondirovaniya (s primeneniem penetrometrov) / G. Sanglera ; per. s fr. N. P. Belyakovoj ; pod obshch. red. N. I. Maslova. – Moskva : Strojizdat, 1971. – 232 s.
19. Busel, I. A. Prognozirovanie stroitel'nyh svojstv gruntov / I. A. Busel. – Minsk : Nauka i tekhnika, 1989. – 246 s.
20. Ziangirov R. S. Staticheskoe zondirovanie v inzhenerno-geologicheskih izyskaniyah / R. S. Ziangirov, V. I. Kashirskij // Inzhenernaya geologiya. – 2006. – № 11. – S. 13–20.

Material received 11/12/2024, approved 16/12/2024, accepted for publication 16/12/2024