Determination of the characteristics of compacted sandy soils by field and laboratory methods

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Abstract. Nowadays, it is a common practice to erect buildings and structures on base soils, which were previously compacted in various ways. During this process, the physical and mechanical properties of the following base soils are changed in order to increase their bearing capacity. In this article, on the example of some construction sites, test studies of the physical and mechanical properties of soils are described. Some results of these studies, both before and after soil compaction are given. Physical, deformation and strength characteristics were determined in both laboratory and field conditions. During the work, the following objectives were set: to conduct full-scale (field) and laboratory studies aimed at reliable determination of the strength and deformability characteristics of compacted sandy soils; to analyze the characteristics of compacted soils that determine the development of deformations over time; to conduct experimental field and laboratory studies on the use of compacted sandy soils of various granulometric composition and density as the structure base; to establish a set of controlled parameters of the compacted soils properties on the basis of conducted analytical studies. Thus, the object of the study during this work was sandy soils with different granulometric composition. The conclusions were drawn on the results of the work.

1. Introduction

Large strata of alluvial and filled soils are located in the areas of seas and deltas of large rivers in the United Arab Emirates, China, Indonesia, Australia and other countries. The peculiarity of these soil cushions lies in the fact that they are compacted during the construction of structures on them, and therefore, the possibility of changing soil properties during the compaction process must be taken into account in calculations and projects.

In recent years, in Moscow, territories that were previously unsuitable for construction have been increasingly used for these purposes. So, a perfect example of this practice is the construction of several residential areas in the microdistrict of Nekrasovka. In 2011, a decision was made to reclaim the areas of the Lyubertsy aeration fields, which had been performing their functions since 1964. The territory of more than 500 hectares was heavily silted up and, for the construction of residential areas, the excavation was carried out, followed by filling it with sandy soils, which were compacted afterwards.

In this work, studies were also carried out on some other construction sites in Moscow and the Moscow region (Vидное), where, similar to the case of the Lyubertsy aeration fields, the excavation of weak soil was carried out, followed by the filling process and compaction of sand cushions.
When building in difficult soil conditions, two methods of foundation construction are mainly used. Either the cutting of the entire thickness of weak and highly compressible soils is designed with piles, the lower ends of which rest on the underlying strong soils, or artificial basements are arranged if strong soil layers lie at a depth of 8-20 m.

Unfortunately, the arrangement of compacted soils to a certain depth to form the base of the structure is not regulated. There is the concept of “compacted” soil for subsiding loess soils. This is the volumetric weight of the soil skeleton, at which the subsiding soils cease to be of such a nature when soaked under the load. However, for most types of artificially compacted bases from various soils, these characteristics are not established in regulatory documents.

1.1. The study purposes were as follows

• Investigating soil properties, both in the process of compaction and after it, since these characteristics are necessary to control the calculations of foundations according to the limit conditions;
• Establishing the characteristics of the soil properties after compaction, which are specified by the designers in the assignment when performing measures to transform the properties of the soil, in particular, compaction and in the calculations.

1.2. The study objectives were as follows

• Conducting full-scale (field) and laboratory studies to reliably determine the strength and deformability characteristics of compacted sandy soils;
• Carrying out experimental studies in the field and laboratory conditions on the use of compacted sandy soils of various granulometric composition and density as the structure soil base;
• Establishing a set of controlled parameters of compacted soil properties based on the basis of analytical studies.

Thus, the object of the study when performing this work was as follows: sandy soils with different granulometric composition.

2. Sandy foundations of the structure (controlled parameters)

2.1. Description of experimental sites with a compacted sand base of the structure

Tests of sandy soils were carried out on several construction sites. The main experimental landfills were arranged at the following construction sites:

1. Moscow, the microdistrict of Nekrasovka, the irrigation fields of the Lyubertsy aeration station, where 500 hectares of land are being developed by 4 million square meters of housing. The soil is represented by coarse, medium and fine sands of different layer thicknesses (from 2-6 m.).

2. Moscow region, the city of Vinoe, at the construction site of the residential complex consisting of 17-storey buildings, erected in the framework of the 111M building system. The soil is represented by medium sands with varying degrees of heterogeneity. Originally, this site was presented by a number of various clay deposits, of different consistency. When making a decision, the option of extracting weak soil and filling the pit with further layer-by-layer compaction of the sand cushion was chosen. The sand was, mainly, of a medium size. Different batches had varying degrees of heterogeneity.

3. Moscow region, Krasnogorsk, the communal zone “Krasnogorsk-Mitino” in the area of construction of a residential multi-storey complex (up to 33 floors). The soil is represented by coarse and fine sands. Backfilling of the pit was also carried out at this facility after the excavation of weak clay and peat soils. Remarkably, pile foundations were originally designed, which were later abandoned in favour of an artificial sand foundation. At the same time, the economic effect was significant, and as a result, during the design work the sand cushion was reduced by a third. The high-quality compaction made it possible to save time on rolling of reduced layers, as well as on the material (the supplying of the sandy soil itself).
Soil compaction in all cases was carried out by surface methods: rolling and vibratory ramming with rollers weighing from 14-24 tons.

Some photos of the general view of these experimental sites are given below (in figures 1 to 3).

**Figure 1.** Moscow, microdistrict of Nekrasovka (irrigation fields of the Lyubertsy aeration station): (a) View of silt sites before reclamation and installation of experimental sites, (b) Backfilling with coarse, medium and fine sands.

**Figure 2.** City of Vidnoe at the construction site of the erected residential complex (Process of preparation and carrying out of experimental sand compaction).

**Figure 3.** Moscow region, Krasnogorsk, the communal zone "Krasnogorsk-Mitino" (Stamp tests at the experimental site, the excavator as a support).
2.2. Methods and equipment of conducted experimental studies

Field tests were carried out at all sites. When studying the properties of compacted soils of the base, an integrated approach was used. In addition to field tests, which included the stamp tests with different diameters both from the surface of compacted sandy soils and in wells (stamp of 600 cm²), static probing with the homemade equipment, by the company “FUGRO” and express determination of compaction coefficient with the help of static manual probing by a density meter were used. Moreover, samples of both disturbed and undisturbed structure were taken for examination in the laboratory conditions (compression tests, destruction tests with a stabilometer, experimental compaction, determination of physical characteristics) (see table 1).

Table 1. Research methods and equipment.

| Field studies                                                                 | Laboratory studies                                                                 |
|------------------------------------------------------------------------------|------------------------------------------------------------------------------------|
| - From the surface with stamp (3000, 5000, 10000 cm²)                       | - Laboratory determination of physical characteristics                             |
| - In wells stamps of 600 cm²                                                  | - Compression tests                                                               |
| - Static probing by devices PIKA-17                                          | - Triaxial compression test                                                       |
| - Static probing by "FUGRO" devices                                         | - Defining the Angle of Natural Slope                                             |
| - Express method for determination of compaction coefficient by Penetrometer type V-1 | - Standard Proctor method compaction                                             |

Due to the large number of tests carried out, it is not possible to present all the results. Some of them are shown below in figures 4 and 5.

Figure 4. Determination of particle size distribution (Vidnoe).
2.3. Compaction factor. Parameters of compacted sandy soils
In the process of compacting sandy soils of different granulometric composition, soil samples were collected over time for standard compaction in laboratory conditions and an express determination of the compaction coefficient was carried out at all experimental sites [2]. At the same time, the work was carried out to determine the physical and mechanical properties of the compacted soil, due to what it became possible to compare the obtained results of field and laboratory studies (primarily, the deformation modulus) and the obtained compaction coefficient. The results of these comparisons will be given just below.

During compaction by field and laboratory methods, the following parameters were determined and monitored:
- Natural moisture of soil
- Optimum soil moisture
- Porosity factor
- Soil skeleton density
- Maximum soil skeleton density
- Deformation module
- Internal friction angle
- Particle size distribution

3. Complex of controlled parameters of compacted basements of buildings and structures
Often, when developing a technical specification, a designer indicates the necessary controlled parameters, among which there is a compaction coefficient (K). It is believed that when the specified characteristics are achieved, the base to be compacted must acquire the necessary mechanical properties [3].

The current regulatory documents in Russia do not indicate the maximum possible values of the compaction coefficient depending on the soil type (this means a coefficient with values not exceeding 1, i.e. it is not over-compacted soil).

Experimental studies of sandy soils have shown that it is not advisable to compact all soils to the maximum compaction coefficient within the range of values up to 1, since these compaction works are economically unjustified, labour-intensive and time-consuming. In this regard, there is a risk of not achieving the given parameter under specific engineering and geological conditions.

Along with this, a comprehensive study of base soils of buildings and structures has shown that a sufficient compaction result, expressed by the compaction coefficient, does not always reach maximum values, taking into account the fact that when compacting the tested soils, the design deformation modulus is achieved.

![Graph](image-url)
In the course of experimental studies of base soils, when determining the compaction coefficient, the optimum moisture values, as well some variations in possible results, expected in case of moisture deviation from the optimum values, were established.

Table 2 shows the values of the compaction coefficient at the optimum moisture content with the maximum economic effect, and the compaction coefficient ($K_u$) with the deviation of moisture values by 30% from the optimum effect.

The probability of compacting base soils with a larger compaction coefficient than those given in these tables is rather high, but, as practice has shown, this is not always feasible from an economic point of view, moreover, it is not always necessary to maintain the given compaction coefficient, due to the fact that even at a lower value, the necessary and sufficient deformation characteristics can be achieved, in particular, the deformation modulus [4].

Table 2. The value of the compaction coefficient $K(u)$ at optimum moisture $W(\text{opt})$.

| Types of sand | The value of the compaction coefficient $K(u)$ at optimum moisture $W(\text{opt})$ | The value of the compaction factor $K(u)$ with deviation of optimum moisture $W(\text{opt})$ 30-40% |
|---------------|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Coarse sand   | 0.99 $\geq$ 0.99                                                                | 0.99 $\geq$ 0.99                                                                |
| Medium sand   | 0.98-0.99 $\geq$ 0.98-0.99                                                      | 0.98-0.99 $\geq$ 0.98-0.99                                                      |
| Fine sand     | 0.97 $\geq$ 0.97                                                                | 0.96 $\geq$ 0.95                                                                |
| Fine sand with a significant amount of dust and clay particles (up to 20%) | 0.96-0.97 $\geq$ 0.95-0.97 | 0.95 $\geq$ 0.95 |

Moisture is an important control parameter during soil compaction.

Figure 6 shows the values of the compaction coefficient of various soils [5], depending on the deviation of moisture from its optimum values up to 70%.

Figure 6. Compaction coefficient depending on the type of soil and the degree of excessive moistening.
3.1. Dependence of the modulus of deformation on the coefficient of compaction

In this work, during the study of base sandy soils, various experimental studies were carried out (stamp tests, static probing, an express density determination method with density meters, laboratory studies with compression and triaxial compression devices, standard compaction). A significant number of tests conducted made it possible to compare the values of the deformation modulus and the obtained values of the compaction coefficient for various types of sandy soils [6].

The graphs presented in figure 7 show the dependence of the deformation modulus on the sandy soils compaction coefficient.

Graphs of the dependence of the deformation modulus on the compaction coefficient for sandy soils

![Graphs of the deformation modulus dependence on sandy soils compaction factor](image)

Figure 7. Graphs of the deformation modulus dependence on sandy soils compaction factor.

After analyzing the results obtained, it can be determined that with the same value of the compaction coefficient, the deformation modulus for sands of varied granulometric composition will be different. In addition, as the values of the compaction coefficient approach 1, a large increase in the values of the deformation modulus is not observed, and therefore there is no point in re-compacting the soil. On the contrary, over-compacted base soils can often show more heaving properties under certain conditions (fine sands with a large amount of clay and silt particles, temperature differences, waterlogging), which are additional difficulties and risks, especially if the construction of relatively light buildings or structures is planned.

4. Conclusions

1. Important controlled parameters that determine the deformation characteristics of sandy soils when compacting are the following ones: dry soil density, maximum dry soil density, porosity coefficient, granulometric composition, degree of nonhomogeneity, optimum moisture content.

2. When compacting sandy soils with a significant amount of clay and silt particles (up to 20-25%), the role of soil moisture increases and is mandatory to take into account for an effective compaction process.

3. Granulometric composition of sandy soils is also an indicative characteristic, on which the efficiency of work on compaction of sandy bases depends. So when developing a compaction project, preference should be given to coarse and medium sands.
4. For medium and fine sands, which include more than 10% of fine clay and dusty particles, to predict the possibility of the transition of sands to the state of "quicksand" and liquefaction of sand in the thickness of the soil massif under dynamic influences, an additional study should be carried out in the device for determining the angle natural slope under water.

5. The use of fine sands and especially those with a high content of silt and clay particles is less effective from an economic point of view due to labor costs associated with the following things:
   – a larger number of penetrations during rolling (the number of penetrations increases by 40-60%, and in special cases it is not possible to compact the soil to the specified values);
   – maintaining optimum moisture content at the construction site, which has a significant impact on the efficiency of compaction of these soils;
   – the risks of “quicksand” phenomena under excessive moistening make it difficult to use widespread effective vibration rolls, so, in this regard, additional investigation of this effect is required.

References

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