Experience of using express-methods for determining the fill soils characteristics

S A Sazonova¹,² and A B Ponomaryov¹

¹Department of Construction Operations and Geotechnics, Perm National Research Polytechnic University, Komsomolsky ave. 29, Perm, 614990, Russia
²feliks150@yandex.ru

Abstract. When designing the foundation slab for a building facility, engineers decided to partially replace the base soils with a sand cushion having a deformation modulus of 18-25 MPa. This paper presents the results of quality control of fill soils compaction during the cushion construction. The compaction factor and the compression modulus of deformation were determined for each layer of the sand pad. There were also three stamp tests carried out on its surface. At the same time, several of additional studies were performed to control the quality of sand cushion compaction using express methods: the determination of the dynamic modulus of soil elasticity using the dynamic density meters DPG 1.2 and Terratest 5000 BLU; the determination of the sand cushion homogeneity by the CMPW geophysical method (the correlation method of refracted waves). The test results were presented, and a conclusion was made.

1. Introduction

The study was carried out under the contract, in which the Construction Engineering and Geotechnics Department of Perm National Research Polytechnic University acted as an expert laboratory at one of the facilities under construction in Perm Krai in the spring of 2018. The object of the study was the soil of the PM1 slab base (figure 1). The base of the PM1 slab was partially a 1.4 m deep cushion made of fine sand.

Soils caused the need for a sand cushion arrangement with different characteristics at the PM1 slab base. According to cross-section 121, the slab base was presented by medium-strength limestone and fill-up and gravel-gravely soil according to cross-section 123. To avoid an unacceptable settlement difference, the designers decided to excavate limestone up to -5.000 (30.5) level to make a sand cushion with a deformation modulus of 18-25 MPa up to the design level of the slab position with layer-by-layer compaction. The compaction factor is 0.95.
Quality control is an essential stage in the production of works (Krutov [1]; Krutov and Kogaj [2]; Paulmichl and others [3], Mansour and others [4]). According to the technical specification, the following works were done:

1. Carrying out laboratory studies of soils to the extent necessary for determining:
   1.1. Sand cushion compaction factor for five marks in each fill layer;
   1.2. Deformation modulus by compression tests, testing each fill layer three times.

2. Doing three stamp tests of the PM1 slab base soil following the developed and approved program.

3. Preparing record documents.

The use of express-methods of quality control is increasingly being introduced into practice both in Russia and abroad (Rumyantsev and Sazonova [5]). The development of express quality control methods is necessary to reduce the construction time and thicken the control grid. However, more research is needed due to the lack of normative literature on these issues. Therefore, it was also decided to conduct several of additional studies to control the quality of the sand cushion compaction:

1. Determination of soil elasticity's dynamic modulus using the dynamic density meters DPG 1.2 and Terratest 5000 BLU.
2. Determination of the sand cushion homogeneity by the CMPW geophysical method (the correlation method of refracted waves).

The sand cushion was compacted in layers with a thickness of 0.15-0.3 m. In total, seven layers were made.

2. Results & Discussion

Based on the layer-by-layer quality control of soil characteristics, a summary table of the physical and mechanical properties of sand cushion soils was compiled (table 1). Fine uniform sand was used as fill
soil.

When analyzing the characteristics of sand cushion soils, we came to the conclusion that the requirements set by the designers were met. The average compaction factor is 0.96. The compression deformation modulus was equal to 27 MPa in the pressure range of 0.3-0.4 MPa.

Parallel with the characteristics determined by the methods described in the normative documents, the dynamic modulus of soil elasticity was found with the help of dynamic density meters DPG 1.2 and Terratest 5000 BLUE (Sazonova and Ponomaryov [6], Sulewska [7]). The dependences of deformation moduli, determined by different methods, on the compaction factor are presented graphically below (figure 2).

Table 1. Sand cushion characteristics.

| №  | Soil characteristics                  | Units | Number of definitions | Interval of values | Average value |
|----|--------------------------------------|-------|-----------------------|--------------------|---------------|
| 1  | Water content                        | -     | 56                    | 0.05 – 0.10        | 0.068         |
| 2  | Soil density                         | g/cm³ | 56                    | 1.70 – 1.95        | 1.82          |
| 3  | Solid particles density              | g/cm³ | 21                    | 2.50 – 2.70        | 2.62          |
| 4  | Dry soil density                     | g/cm³ | 56                    | 1.65 – 1.77        | 1.70          |
| 5  | Void ratio                           | -     | 21                    | 0.46 – 0.60        | 0.54          |
| 6  | Compression deformation modulus      | MPa   | 21                    | 20.0 – 40.0        | 27.0          |
| 7  | Compaction factor                    | -     | 35                    | 0.95 – 1.00        | 0.96          |

Figure 2. The graph of deformation modulus – compaction factor dependence.

When comparing the data obtained by express methods, the following findings were obtained:

1. Overrated values of dynamic modules, being 2-5 times higher, were revealed when freezing the base. They were not taken into consideration in the further analysis.

2. When testing the first layer of compaction (30 cm) with the help of the Terratest device, we also obtained overrated values of dynamic modules being approximately 50 % as high, though our study was not aimed at determining influence zones for that device. That phenomenon can be explained by the close disposition of natural base with relatively high characteristics. Those data were rejected
3. At low compaction factors up to 0.95, the compression deformation modulus remained constant.

4. The values of the dynamic modulus of elasticity registered by the Terratest device exceeded the compression deformation modulus's values from 10 to 15%.

5. The values of the dynamic modulus of elasticity registered by the Terratest device exceeded the values determined using the DPG device by 2-3 times (Sazonova and Ponomaryov [8]).

After the study of the sand cushion had been completed, its homogeneity was determined by the CMPW method (Antipov and Ofrikhter [9, 10]). The layout of the sensors is given in figure 3.

![Figure 3. The layout of the sensors for determination of sand cushion homogeneity.](image)

When analyzing the velocity profiles of longitudinal waves along all three lines, it was found that the refracting boundary was marked at a depth of 1.5-2 m, which corresponded to a sand fill height of 1.4 m. The fill was uniform in-depth and did not contain anomalous inclusions or under-compaction zones that would have been characterized by a significant change in the velocity of a longitudinal wave.

Stamp tests according to GOST 20276-2012 were carried out at the last stage of the sand cushion study. A hydraulic jack with a manual hydraulic station was used as a loading device. Stamp settlement was recorded with the help of flexometers installed using a benchmark system. A general view of the assembled system is presented in Figure 4.

Stamp loading was carried out in stages \( \Delta P = 0.05 \text{ MPa} \). Each pressure stage was kept up to conventional stabilization of the soil deformation (stamp settlement). The stamp settlement rate, not exceeding 0.1 mm per hour, was taken as the criterion of conventional stabilization. \( P = 0.4 \text{ MPa} \) was taken as the final value of \( P_n \). The stamp was of type I (2,500 cm²) with a diameter of 564 mm. In the tests, the pressure under the stamp bottom equal to 0.4 MPa was achieved. The graph of the settlement-load dependence is shown in figure 5.
According to the three stamp test results, the following moduli of deformation were obtained: 19.78 MPa, 24.4 MPa, 20.17 MPa. The average deformation modulus of the sand cushion PM1 slab base at a ground level of 301.9 was $E = 21.45$ MPa. Thus, the discrepancy with the compression deformation modulus was less than 20%.

3. Conclusions

Based on the investigations, the following main conclusions can be drawn:

1. The compaction factor's value and that of the compression deformation modulus corresponded to the required ones. The average compaction factor was 0.96. The compression deformation in the pressure range of 0.3-0.4 MPa was equal to 27 MPa.

2. Based on the homogeneity of the sand cushion determined by the CMPW geophysical method, it was revealed that the fill sand was homogeneous in-depth. It did not contain anomalous inclusions or
under-compacted zones, which would have been characterized by a significant change in the longitudinal wave velocity.

3. When freezing the base, overrated values of dynamic moduli were revealed. The excess made up 2-5 times.

4. On the analysis of the deformation moduli – compaction factor dependence graphs, it was revealed that with the compaction factor's rise, the deformation moduli increased, regardless of the test method. At low compaction factors up to 0.95, the compression deformation modulus remained constant. The values of the dynamic modulus of elasticity by the Terratest device exceeded the constrained modulus's values from 10 to 15%. The values of the dynamic modulus of elasticity by the Terratest device exceeded the values that were determined by means of the DPG device by 2-3 times.

5. The following deformation moduli were obtained on the three stamp test results: 19.78 MPa, 24.4 MPa, 20.17 MPa. The average modulus of deformation of the sand cushion of the PM1 slab at ground level 301.9 was equal to E = 21.45 MPa. The discrepancy with the compression deformation modulus was less than 20%.

According to the authors, the results of this study may be interesting for designers and builders. The introduction of express-methods into construction practice will eliminate work errors and significantly improve its quality and speed.

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