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Risks of using artificial sand base in difficult geotechnical conditions

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Abstract. Excavation of pits, trenches for foundations of civil buildings and industrial structures in saturated clayey soils often leads to soil structural change and great decrease in the soil strength and deformation characteristics. In some cases, an artificial sand base is used as a method for construction on saturated clayey soils. However, technology violations and unsuitable material used during construction can be the reason for excess settlement of the erected facilities. The study includes a real example of an emergency situation at gantry crane railways with three hundred meters in length in the town of Tobolsk. The artificial base was made using local sand with specific properties such as subsidence and frost heaving, which were not taken into account in the design process. The observed excess non-uniform base deformations were up to 240 mm. The base properties of the silty sand were analyzed in a laboratory study. Two tests were carried out to simulate possible impact on the artificial sand base. They showed that the values of the initial compaction factor K_{com} of sand base were found in the range of 0.87-0.92. So, the base subsidence was about 12% of the actual base deformation and the total base settlement under the total operation loading made about 19%.

1. Introduction

In recent years urban development of Tobolsk includes construction of industrial facilities. Excavation of pits, trenches for foundations of civil buildings and industrial structures in saturated clayed soils often leads to soil structural change and great decrease in the soil strength and deformation characteristics [1]. The situation is becoming even more complicated by adverse soil conditions, such as bogginess of the territory, possibility of flooding and severe climatic conditions.

Design solutions for construction in the areas with adverse soil conditions often include the arrangement of artificial sand bases to save the natural structure of the soil. Sometimes the height of sand cushions can reach significant values (more than 2m). Builders often use local materials because of the high cost of imported materials for creating artificial fills. It is efficient; though, failure to take into account the specific properties of local materials, especially the high dispersion of silty sands, determines the subsidence, frost heaving of such bases. It often leads to difficulties in facility operation or even to emergency situations.

The gantry crane railways with three hundred meters in length is an example of such facilities. All over the crane railways length, settlements from 50 to 240 mm were observed in the first year after construction, practically without their operation. It resulted in unacceptable values of crane railways topographic elevation marks. To make the artificial base of the crane railways, the sand found near the construction site was used. In accordance with laboratory tests, the sand was fine-grade, silty, inhomogeneous. Besides this, the sand had a medium density and organic inclusions.

Artificial base soil properties were studied by domestic scientists: M.Yu. Abelev, G.G Boldyrev, M.N. Ibragimov, M.S. Kim, V.I. Krutov, P.A. Lyashenko, A.L. Nevzorov, E.A. Sorochan [2-4], and foreign



scientists: Liu Jiankun, D. L. Galloway, T. J. Burbey, J.-W Kim, F. Qu, Z. Ouyang and others [5-10]. Works of these authors contain the basic requirements to the artificial bases.

The compaction factor is the most important when making artificial sand bases. It should be equal to 0.95 or more for this type of structures.

The observed excess non-uniform base deformations revealed the necessity to analyze the situation, including laboratory modeling research of the silty sand behaviour. It should be noted that the earthworks were performed in winter. In some areas the level of groundwater was high.

2. Materials and methods

The soil for the study was selected from the pits directly below the crane railways foundation. The compaction factor of the artificial sand base according to the as-built documentation was equal to 0.95. Figure 1 shows cross-sections of the artificial base. The left part of Figure 1 shows a design solution of the artificial sand base, whereas the right part of figure 1 shows the results of the on-site pit survey. It should be noted that the actual solution of the artificial sand base does not correspond to the design solution. In particular, it was observed that the thickness of the sand cushion increased by almost 45 cm due to peat layer excavation at different depths. The natural base was represented by plastic and fluid-plastic clays. The final calculated settlement of the natural base caused by total load, including crane load, still did not exceed 50 mm. At an initial stage of operation calculated settlements were equal to 25-30 mm. Consequently, the settlements above the allowable level were mainly formed in the artificial sand base layer.

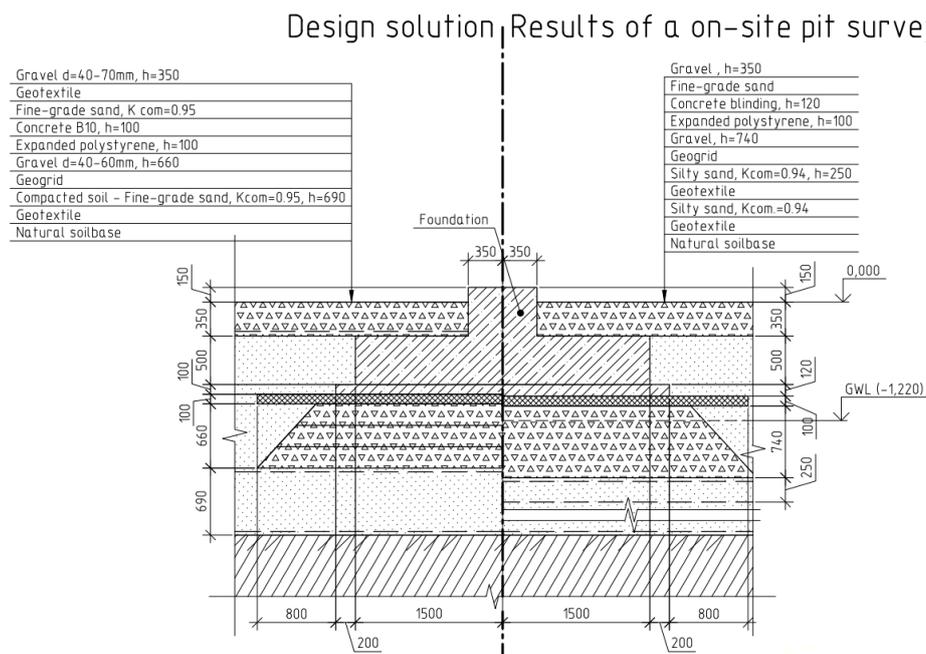


Figure 1. Cross-section of artificial sand base.

The relative subsidence ε_{s1} was determined according to GOST 23161-2012 “Soils. Method of Laboratory Determination of Subsiding Characteristics”. Twin specimens were tested in compression devices during soil saturation. The relative subsidence was determined on the specimens which showed the following:

- 1) the initial moisture content of soil was equal to zero ($\approx 0-2\%$);
- 2) the initial soil moisture content was equal to the natural moisture content of the soil ($\approx 10-12\%$).

The data were taken from as-built documentation.

Figure 2 shows two test diagrams that were considered to simulate possible impact on the artificial sand base:

Scheme A: Firstly, the specimens were loaded stepwise to a pressure of 50 kPa, which was equal to average confining pressure σ_{zg} . Secondly, the full water saturation of the specimens was realized. After

that the specimens were loaded stepwise to a pressure of 150 kPa, which was equal to total pressure from average confining pressure and crane loading $\sigma_{zg} + \sigma_{zp}$.

Scheme B: Firstly, the specimens were loaded stepwise to a pressure of 150 kPa, which was equal to total pressure from average confining pressure and crane loading $\sigma_{zg} + \sigma_{zp}$. After that, the full water saturation of the specimens was realized.

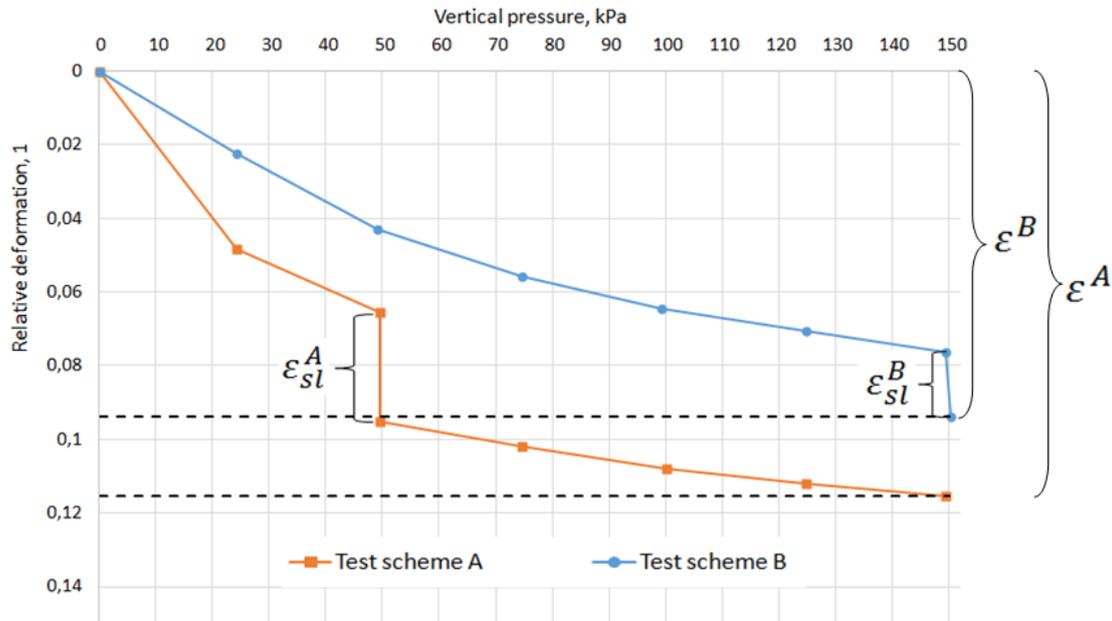


Figure 2. Test diagrams of artificial sand base behaviour modelling.

3. Results and Discussion

The soil density ρ , soil moisture content W , the dry unit weight ρ_d and the compaction factor K_{com} were determined at the end of the compression tests. The test results are presented in table 1.

Relative subsidence was carried out by water saturation at constant vertical pressure (table 2). The compaction factor was taken as a controlled variable, because it was the main quality parameter at the construction of the artificial sand base.

Table 1. Values of soil characteristic determined by the compression tests.

No	Soil characteristic	Test №1		Test №2		Test №3		Test №4	
		Initial values	Final values Scheme A Scheme B						
1	2	3	4	5	6	7	8	9	10
1	Soil density ρ , g/cm ³	1.16	$\frac{1.86}{1.66}$	1.32	$\frac{1.82}{1.79}$	1.49	$\frac{2.10}{2.12}$	1.28	$\frac{1.07}{1.09}$
2	Water content W , %	0.00	$\frac{30.83}{26.05}$	0.00	$\frac{24.17}{24.60}$	0.00	$\frac{2.42}{26.08}$	10.58	$\frac{26.76}{27.20}$
3	Dry soil density ρ_d , g/cm ³	1.16	$\frac{1.42}{1.31}$	1.32	$\frac{1.46}{1.43}$	1.49	$\frac{1.69}{1.68}$	1.16	$\frac{1.40}{1.42}$
4	Compaction coefficient K_{com} , 1	0.70	$\frac{0.86}{0.79}$	0.80	$\frac{0.88}{0.86}$	0.90	$\frac{1.02}{1.01}$	0.70	$\frac{0.84}{0.86}$

The end of Table 1. Values of soil characteristic determined by the compression tests.

No	Soil characteristic	Test №5		Test №6		Test №7	
		Initial values	Final values Scheme A Scheme B	Initial values	Final values Scheme A Scheme B	Initial values	Final values Scheme A Scheme B
1	2	11	12	13	14	15	16
1	Soil density ρ , g/cm ³	1.48	<u>1.75</u> 1.84	1.65	<u>1.94</u> 1.97	1.79	<u>2.27</u> 2.18
2	Water content W, %	11.97	<u>25.55</u> 26.27	10.81	<u>25.96</u> 24.63	10.6	<u>26.76</u> 25.70
3	Dry soil density ρ_d , g/cm ³	1.32	<u>1.40</u> 1.46	1.49	<u>1.54</u> 1.58	1.62	<u>1.79</u> 1.73
4	Compaction coefficient K_{com} , 1	0.80	<u>0.84</u> 0.88	0.90	<u>0.93</u> 0.95	0.98	<u>1.08</u> 1.04

Table 2. Results of soil subsidence characteristic determination.

No	Scheme A		Subsidence / total deformation (thickness = 1140 mm), mm	Scheme B		Subsidence / total deformation (thickness = 1140 mm), mm
	Relative subsidence of soil ε_{st} , 1	Relative deformation of soil ε , 1		Relative subsidence of soil ε_{st} , 1	Relative deformation of soil ε , 1	
1	0.098	0.187	<u>111.7</u> 213.2	0.026	0.120	<u>29.6</u> 136.8
2	0.015	0.102	<u>17.1</u> 116.3	0.008	0.079	<u>9.1</u> 90.1
3	0.030	0.115	<u>34.2</u> 131.1	0.024	0.090	<u>27.4</u> 102.6
4	0.067	0.177	<u>76.4</u> 201.8	0.038	0.188	<u>43.3</u> 214.3
5	0.022	0.056	<u>25.1</u> 63.8	0.018	0.094	<u>20.5</u> 107.2
6	0.019	0.037	<u>21.7</u> 42.2	0.024	0.063	<u>27.4</u> 71.8
7	0.036	0.103	<u>41.0</u> 117.4	0.006	0.037	<u>6.8</u> 42.2

According to the results of the on-site survey of pits, it was found that the compaction factor after total loading was equal to 0.93-0.96. It corresponded to the initial compaction factor equal to 0.87-0.92 (figure 3). It should be noted that the value corresponded to laboratory test No. 6, scheme B: the initial moisture content was 10-12%, water saturation was obtained after the total loading of the specimen.

It was found out during the laboratory modeling of the silty sand behavior under water saturation and loading in accordance with various, potentially possible schemes that compaction factor could not be equal to 0.98 at as-built work acceptance. If the initial compaction factor was equal to 0.98 (design compaction factor), the predicted compaction factor at the construction survey time (after saturation and total loading) should be equal to 0.97-1.0 (figure 4).

Table 2 shows the subsidence of the artificial silty sand base under saturation. The design thickness is 690 mm, the obtained thickness is about 17 mm. The total deformation of the artificial silty sand with a design thickness 690 mm from the average confining pressure, saturation process and crane loading should be almost 45 mm.

Moreover, the subsidence of the artificial silty sand base during saturation with an actual thickness of 1140 mm is about 27 mm. The total deformation of the artificial silty sand with an actual thickness 1140 mm from the average confining pressure, saturation process and crane loading should be almost 72 mm.

It was obtained that there was no necessity to compact the soil using the maximum possible compaction factor K_{com} at the earthwork time. The authors recommend to achieve the high compaction factor (about $K_{com} = 0.95...0.98$) by soil compaction with $K_{com} = 0.8$ and artificial or natural water saturation. Then, the facility construction can be continued.

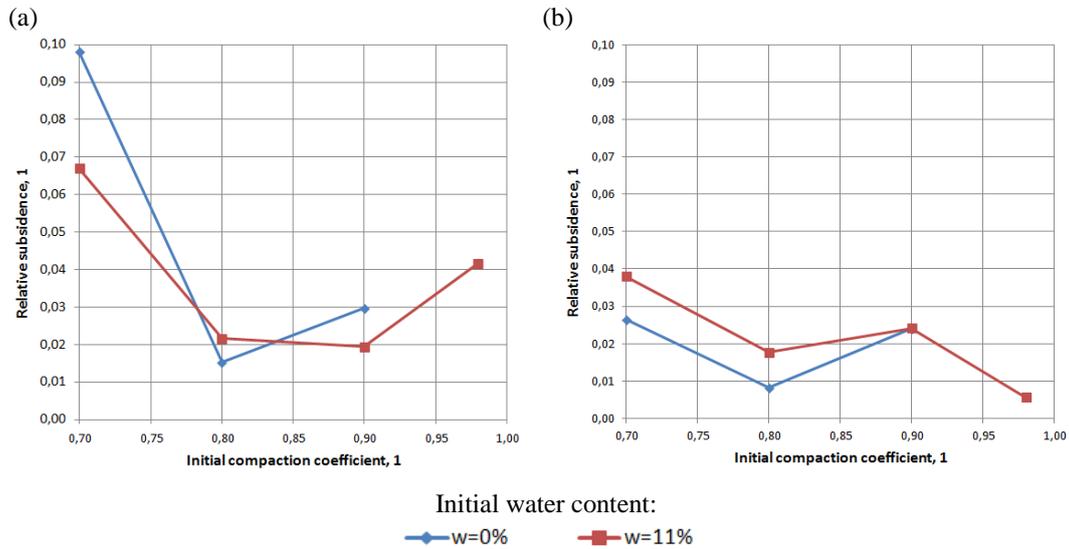


Figure 3. Results of determining soil subsidence characteristics: (a) is test scheme A; (b) is test scheme B.

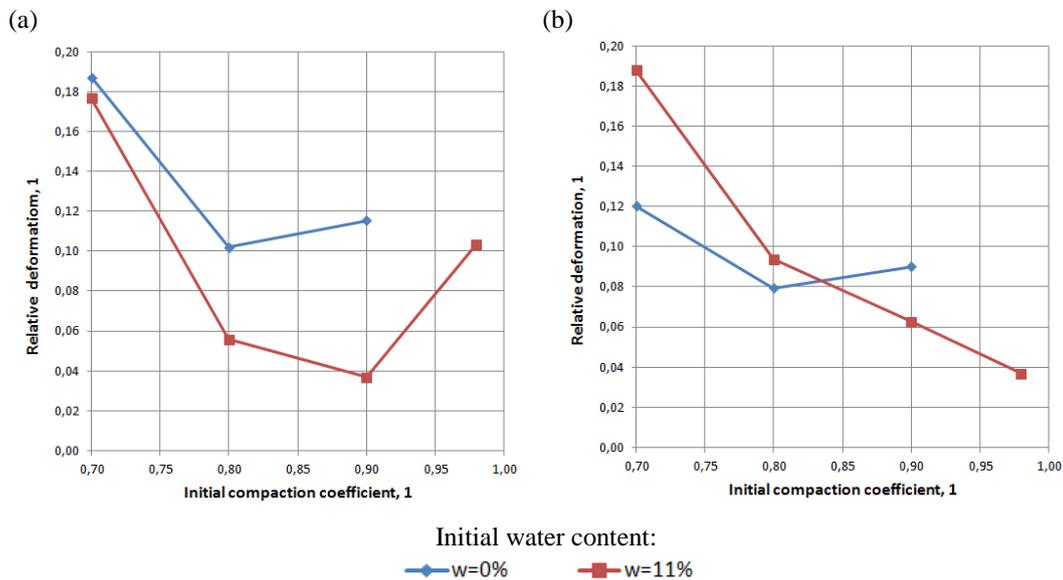


Figure 4. Results of determining final relative soil deformation(a) is test scheme A; (b) is test scheme B.

On the basis of the tests described above it became possible to obtain a diagram of dependence of the final compaction factor with respect to initial compaction factor (figure 5).

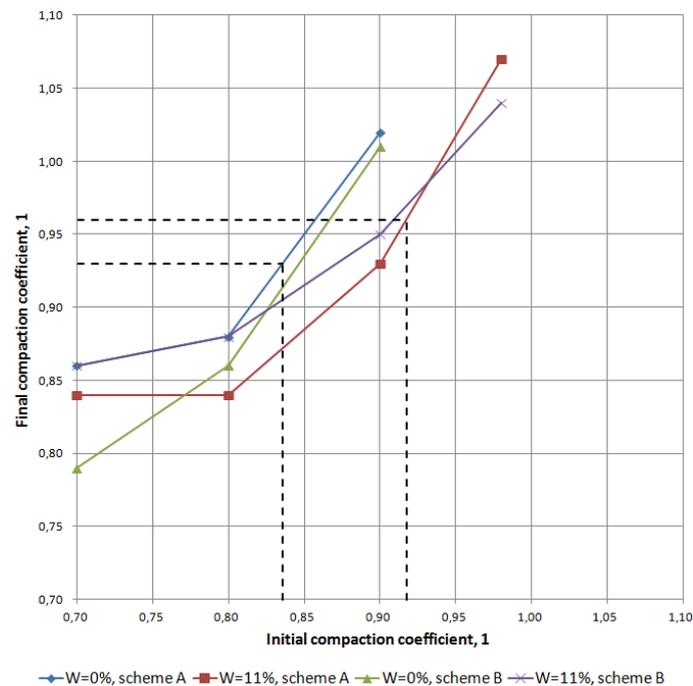


Figure 5. Final compaction factor - initial compaction factor dependence at different water content and test scheme

4. Conclusion

The following conclusions can be drawn according to the experimental result analysis given above:

1. At the construction survey time (after saturation and total loading) the compaction factor was equal to 0.93-0.96. During the laboratory modeling of the silty sand behavior under water saturation and loading in accordance with various, potentially possible, schemes it was found that the compaction factor could not be equal to 0.98 at as-built work acceptance. If the initial compaction factor is equal to 0.98 (design compaction factor), the predicted compaction factor at the construction survey time (after saturation and total loading) should be equal to 0.97-1.0.

2. The initial compaction factor in accordance with research results is about 0.87-0.92. The value corresponds to laboratory test No. 6, scheme B. In this case, the base subsidence is about 12% of the actual deformation. The total base settlement under the total service loading is about 19%.

3. The authors suppose that base settlements of 240 mm were additionally formed due to winter earthworks, technology violations, undetermined boundary conditions of artificial sand bases, possible suffusion and dynamic action of crane equipment.

Thus, the application of local building materials must be constructively- and technologically-based. Consideration of climatic and hydrogeological conditions, such as construction technology, is extremely important. Violations of these requirements and conditions may lead to foundation reinforcement expenditure comparable to the construction cost.

References

- [1] Pronozin Y A and Bragar E P 2019 Changes in soil properties at base unloading of deep foundation pit *Geotechnics Fundamentals and Applications in Construction* 290–5
- [2] Krutov V I, Kovalev A S and Kovalev V A 2013 *Design and installation of bases and foundations on collapsible soils* (Moscow: ASV)
- [3] Abelev M Yu 1983 *Construction of industrial and civil structures on weak water-saturated soils* (Moscow: Strojizdat)
- [4] Mangushev R A, Usmanov R A, Konyushkov V V and Lan'ko S V 2012 *Methods of preparation and installation of artificial foundations. Teaching guide* (Moscow: ASV)
- [5] Ma P, Wang W, Zhang B, Wang J, Shi G, Huang G, Chen F, Jiang L and Lin H 2019 Remotely sensing large- and small-scale ground subsidence: A case study of the Guangdong–Hong Kong–Macao Greater Bay Area of China *Remote Sensing of Environment* **232**

- [6] Ouyang Z, Cai M, Li C and Xie M 2006 Seepage effects of groundwater and its make-up water on triggering ground subsidence *Journal of University of Science and Technology Beijing, Mineral, Metallurgy, Material* **13(1)** 11–5
- [7] Qu F, Zhang Q, Lu Z, Zhao C, Yang C and Zhang J 2014 Land subsidence and ground fissures in Xi'an, China 2005-2012 revealed by multi-band InSAR time-series analysis *Remote Sensing of Environment* **155** 366–76
- [8] Kim J W, Lu Z, Jia Y and Shum C K 2015 Ground subsidence in Tucson, Arizona, monitored by time-series analysis using multi-sensor InSAR datasets from 1993 to 2011 *Journal of Photogrammetry and Remote Sensing* **107** 126–41
- [9] Galloway D L and Burbey T J 2011 Regional land subsidence accompanying groundwater extraction *Hydrogeology Journal* **19(8)** 1459–86
- [10] Liu J, Chang D and Yu Q 2016 Influence of freeze-thaw cycles on mechanical properties of a silty sand *Engineering Geology* **210** 23–32