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Complementary Soil Investigation as a Chance to Optimize the Foundation Design

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Abstract. Properly performed soil investigation is important for almost all civil engineering tasks. Nowadays when there is a serious lack of plots with good ground water conditions Investors are often forced to make their projects even when ground water conditions are poor or not suitable. The article presents the case study of a small commercial facility in Chojna, Poland, for which poorly conducted preliminary soil investigation could have caused excessive costs for the investor. The layer of organic soils in the ground was the reason for planning huge exchange of soil. Quick reaction of the construction manager, caused that investor decided to hire a geotechnical specialist. A preliminary calculation showed that simple ground improvement should solve the problem. After that, additional static plate tests were performed. Also from organic soil oedometer test, and direct shear tests has been made. In the next step FEM model of subgrade was developed, and serviceability limit state was checked. That provides the possibility to design subgrade improvement by crushed concrete pressed into the organic layers. This type of soil improvement helps to decrease the settlement from 44 mm to more or less 15 mm under the foundation bench. The additional problem to solve was the construction of the roads and parking, especially in the zone of supplies, where heavy trucks were planned to drive. The individual project of geosynthetics reinforcement of pavement and its subbase was performed to prevent uncontrolled settlements. As a next step surveyor measurements of settlement are planned to be performed for the object in different construction stages. Authors of the paper wants to show that even when ground conditions of the plot are not very good, properly planned and developed soil investigation can provide some unexpected savings for the Investor. Paper ends with some conclusions about geotechnical investigation and its influence for the building process.

1. Introduction

In today's civil engineering, geotechnics and geotechnical investigations occupy their proper, important place. Research carried out at geotechnical institutes around the world leads to the development of methods for identifying the soil substrate. And as a consequence, they lead to better geotechnical documentation. Methods that were the domain of university laboratories enter permanently into engineering practice. The article main aim is to draw attention to the importance of responsible geotechnical investigation. A common problem encountered in geotechnical



documentation is the lack of investor awareness, how important it is to properly identify the ground conditions, and what potential benefits it can bring.

The subject of the study is a commercial and service building together with the development of the adjacent area and the necessary technical infrastructure in Chojna. The designed building is a single-storey building, without a basement, covered with a gable roof. [1] In preparing for the investment, the investor ordered geotechnical tests without consulting the constructor of the facility. As a result, they were made sparingly and in a preliminary way. The complex ground conditions caused that due to the lack of data for the design of reinforcement, it was planned to perform a large and expensive ground exchange under the construction. After consultation with the geotechnician and geologist, the construction manager proposed to perform supplementary soils investigations. These studies were planned with the participation of a geologist, geotechnician, constructor and road construction designer.

2. Ground-water conditions and methodology of performed tests

The research area is located in the West Pomeranian Voivodeship, in Chojna. Currently, discussed terrain is a wasteland on which warehouse buildings used to be. Underground utility is a rainwater drainage. In terms of geomorphology, the area under assessment is a part of the local field depression, in which the deposits (mules) were formed, deposited after the ice sheet subsided, undercoated with moraine clays from the Chojńska subphase, the main part of the North Polish glaciation.

During the upper Holocene, they were covered with organic silts and alluvial sands. Today, the original, low-lying and boggy area has been treated by the construction of embankments with a thickness of 1.0-2.3 m. The area of the examined part of the plot rises to a height of about 19.6 - 20.4 m above sea level, and decreases in the south-west direction [2].

After analysing the existing documentation, the decision was made to characterize the soil and organic soils. Therefore, it was planned to perform additional tests in accordance with PN-EN-1997-1: boreholes with casing although with sampling with undisturbed structure, in order to perform oedometer tests of compressibility modulus. In addition, test samples for the purpose of sampling the ground for direct shear testing. As part of the new ground soil testing documentation, standard laboratory tests such as content, organic parts, natural moisture and degree of consistency were also performed. A characteristic geotechnical cross-section is shown in Figure 1.

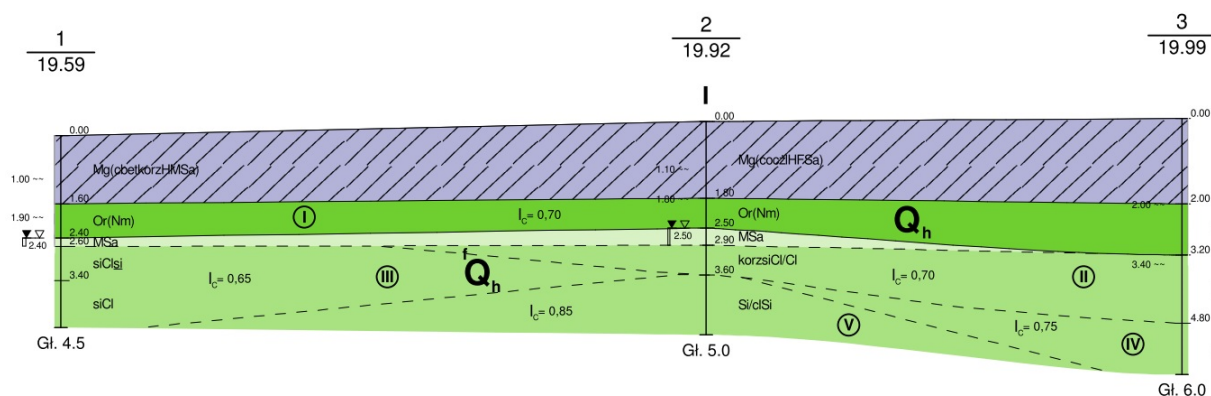


Figure 1. Geotechnical cross section [2]

An additional problem was the fact that the investor expressly requested that the roads and parking have to be designed and constructed in such a way that it will be possible to move heavy trucks delivering goods to stores. Thus, additional tests were performed using the static VSS plate. It was necessary to determine primary and secondary strain modulus of the ground for the needs of the road project.

Field and laboratory test results are showed in table 1, [3].

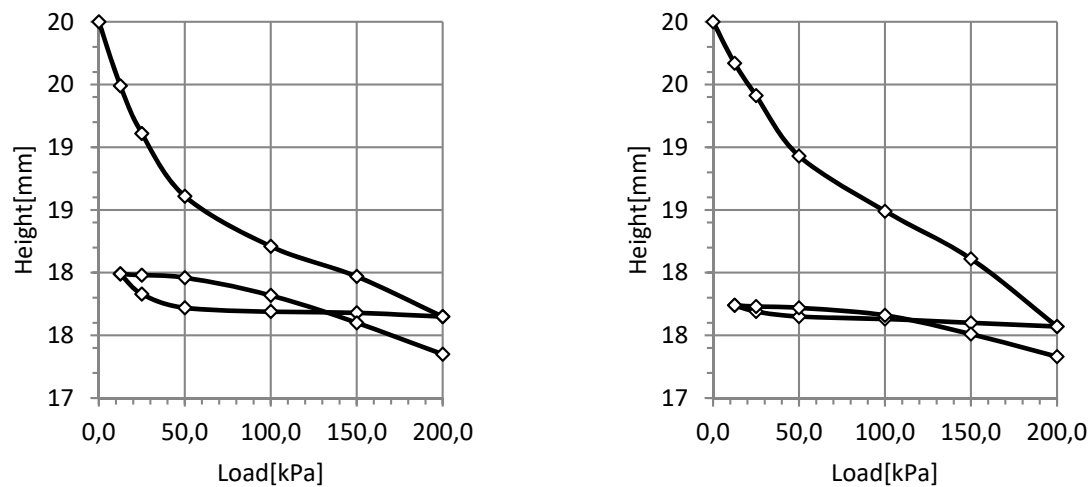


Figure 2. Chosen oedometer test results [3]

Table 1. Soil characteristics from additional ground investigation

	ϕ_u [°]	c_u [kPa]	E MPa	γ [kN/m ³]	Poisson ratio [-]
I (Mg)	28	2	45	17	0.27
II(Or)	15	10	2.5	13.5	0.30
III(clSa)	13	13	17	20	0.25

3. Geotechnical project

3.1. Foundation benchmark soil improvement

The data collected during the supplementary soil investigation allowed to create a geotechnical FEM model. For further analysis, the Coulomb Mohr model was assumed as the criterion of the strength of the soil on the wall. The Mohr-Coulomb surface can be defined by means of three limit functions that outline an irregular pyramid in the space of main stresses, based on an equilateral but different hexagonal angle. The surface of plasticity on the deviator and meridian plane is shown in Figure 3. In Figure 3 it is clearly visible (part a) that the function of plasticity MC has vertices. It can cause some complications in the application of this model in the finite element method; on the other hand, the advantage of such a solution is that traditional soil mechanics is based on this model.

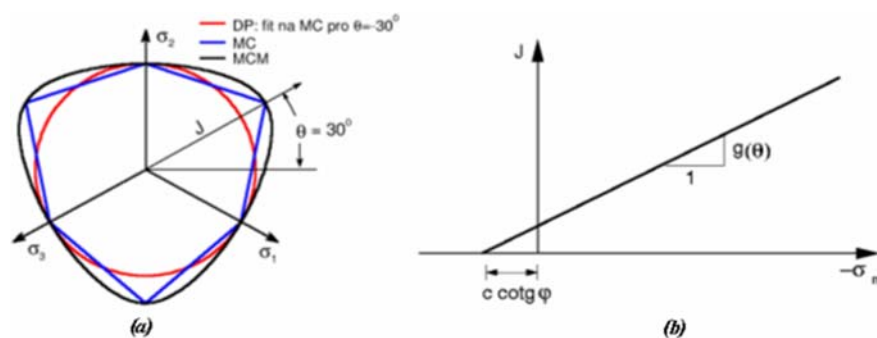


Figure 3. Projection of the plasticity surface on: (a) the deviator, (b) the meridian [7]

While it was relatively easy to fulfill the ultimate load condition for the weak layers, due to their certain depth and not so bad strength parameters, the problem appeared while calculations of the settlement for the object. Calculations were applied for individual foundations with the assumption that they have a variable width, so that they do not transmit stresses greater than 75 kPa to the subsoil, which, according to calculations, was a safe value due to the displacement of weak soil.

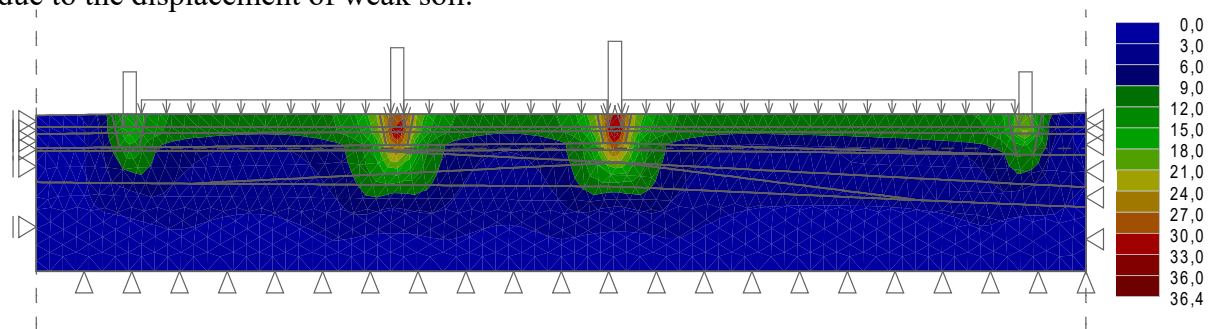


Figure 4. Settlements of the foundations without ground improvement [mm]

All deformations realized in the model in the layer with the smallest compressibility module of organic sandy silts. Calculated settlement ranged from 18 to 36.4 mm. Therefore, geotechnical engineers decided that the modulus of deformation of the low-bearing soil should be increased by pressing the recycling of the concrete fraction 0 / 31.5mm. So made soil reinforcement should provide a modulus of deformation of the low-bearing layer under the foundations at the level of 45-55 MPa. Again, made calculations this time, gave a relative subsidence of 15 mm.

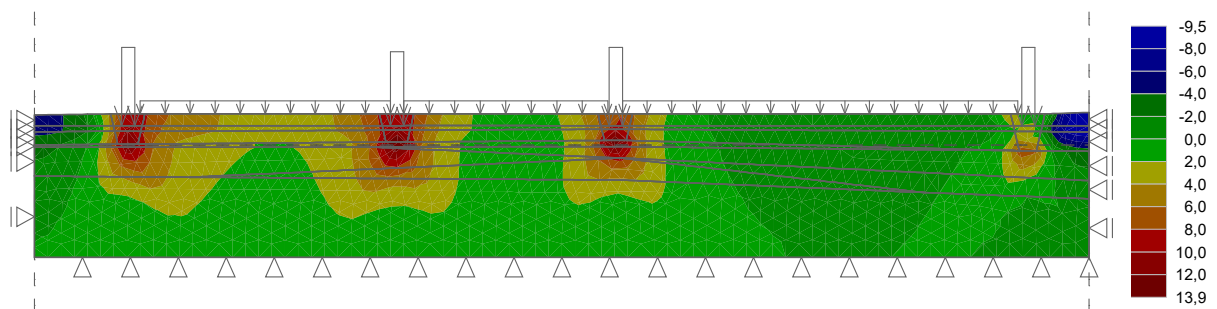


Figure 5. Settlements of foundations with a ground improvement [mm]

3.2. Road subbase improvement

In the case of road placement on weak subsoil, it is just as important to characterize them in the best possible way. In this case, static plate tests were also carried out under the planned roads and parking. The tests were made on the planned elevation of the road subsoil.



Figure 6. Static plate test performed for road improvement design

Due to the presence of organic soils in the subsoil of planned roads and parking, ground reinforcement with the use of geosynthetics was designed. It was assumed that at the phase of contraction, the assumptions made in the project of strengthening the weak ground will be checked. The required load-bearing capacity for the square foundation was set at 120 MPa.

Improvement to a load capacity of 120 MPa was calculated based on nomograms developed by the Department of Road Construction Structures in the Institute of Road Construction at the University of Hannover in Germany [4]. For the calculations, it was assumed that the model of the substrate reinforced with a mechanically stabilized aggregate layer is a two-layer system: aggregate - a subsoil. Table 2 presents the values of the coefficient of reduction of the reinforced geogrid aggregate layer thickness in relation to the unreinforced layer as a function of the load bearing capacity of the weak ground substrate - the secondary deformation modulus [4].

Table 2. Values of coefficients of reduction of unreinforced aggregate layer

Secondary strain modulus E_2 [MPa]	Coefficient of reduction [-]
10	1.54
15	1.50
20	1.46
25	1.43
30	1.40
35	1.39
40	1.37

On this basis, nomograms were developed in two variants: for non-reinforced aggregate layer and reinforced aggregate layer with rigid geogrid. Assuming the value of the secondary strain modulus of the ground $E_2 = 15$ MPa (determined by field tests) based on the nomogram (Fig. 7), the required thickness was determined to obtain a bearing capacity of 45 MPa and in the second stage of loading capacity of 120 MPa. The result was obtained in the first stage 10-15 cm of aggregate in the second stage 20-25 cm of aggregate.

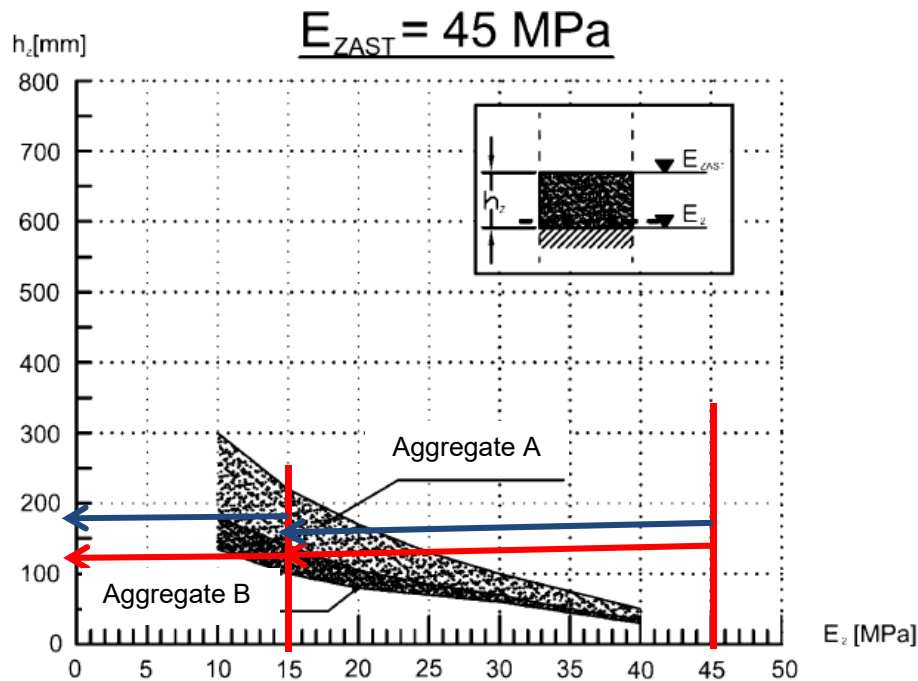


Figure. 7. Design chart to determine the thickness of the aggregate layer reinforced by a rigid geogrids $E_{zast} = 45$ MPa, Aggregate A: mechanically stabilized aggregates or well-grained sandstones, Aggregate B: mechanically stabilized aggregates

The final layers of reinforced subbase are showed below:

- Mechanically stabilized aggregate 0/31.5 mm C50/3 - 20 cm
- Triaxial geogrid (hexagonal) Tensar Triax Tx 150.
- Mechanically stabilized aggregate 0/63 mm C50/3 - 20 cm
- Triaxial geogrid (hexagonal) Tensar Triax Tx 150.
- subsoil

The deformation for the pavement construction selected in this way was calculated in the BISAR program, which is a program based on the theory of a multi-layer elastic half-space used for mechanical surface design created by Shell Corporation. The program allows you to calculate stresses, strains and displacements of a loaded pavement structure. [6]

Assuming the value of the modulus $E_2 = 15$ MPa for the ground (based on field tests) by performing the calculations in the BISAR program, the deflection on the top of the mattress equal to 3.35 mm was calculated. The calculated substitute modulus was 55.3 MPa, which was greater than the predefined value of the substitute modulus $E_{zast} = 45$ MPa. So the reinforcement was designed correctly

4. Conclusions

Problem of proper planned geotechnical investigation is widely discussed from a long time by engineers, geotechnics and geologists. For example, Fourie and Vada [6] also indicates this problem at the wider perspective of urban planning. Both in macro and micro scale

The work reported in this paper has shown the benefits of carrying out supplementary geotechnical investigation, especially when preliminary investigation is made without the consultancy with a construction designer

- Additional laboratory and field test provides data to create FEM model of the subsoil under construction, and that makes the calculation of settlement and displacement possible to check.
- Additional field tests such as static plate test provides data to more economical road subbase designing
- FEM model allowed to evaluate the effect of soil improvement by crushed concrete pushed statically into the organic soil. This type of solution allowed to raise the modulus of the weak soil, and in consequence decrease settlement.
- Both additional soil testing, and the soil improvement, are much cheaper than the initially designed massive ground exchange. In this way Investor achieved unexpected benefit, which is directly connected with the quality of soil investigation.

Without doubt, risk of structure failure is strongly bounded with quality of geotechnical investigation. Here is a great role of geotechnical professionals to educate and convince all the parties of construction project that soil investigation it is not a good place to save money. Geotechnical reporting should be one of the first obligations when the investment plan goes to start.

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