

TESTING OF SOIL IMPROVEMENT BELOW A HALL FLOOR

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ABSTRACT. Construction of a hall situated in North-West Slovakia was prepared in winter. After finishing an elementary ground adaptation in February there were extreme weather conditions: the precipitation exceeded by over 300 % the normal long term measured amount. This indisposition of climate led to a stopping of the construction work. Checks on the required quality of the base course using static load tests showed a failure in performance of compaction. The sampling and laboratory testing of the original and the improved soils are discussed in the paper.

KEYWORDS: Quality control, base course, laboratory analysis, consolidation test, cement content.

1. INTRODUCTION

The required intensity of deadlines for finishing the construction regardless of limiting conditions (e.g. climatic, occurrence of soils with low bearing capacity) conducted on a good number of occasions to improvement efforts on the base course. These are usually similar technologies to those used in road construction. Among the most common technologies there is included adding a certain percentage of lime or cement to fine-grained soils (so-called soil stabilization). Mixing cement with soil and compaction reduces the compressibility of the treated soil. Subsequent quality control of any improvement is mostly done by static load test.

The underlying layers of the future floors were simply improved within the rainy weather and were not protected. The adverse weather situation caused the suspension of work. Checking the quality of the underlying layers using static load tests after a week of completion of the stabilization showed a failure to satisfy the required improvement. It was necessary to immediately resolve the situation and help meet deadlines. Consequently soil was taken from the unsatisfactory area of the hall and then a check was made on the properties of both treated and untreated layers by laboratory tests.

2. LABORATORY TESTS

On the construction site of the hall there were removed undisturbed soil samples improved by cement, but also the original soil without improvement by cement. On the original soil samples there were firstly detected the basic descriptive soil characteristics. Based on STN 72 1001 [1] there was soil classified as firm clay with low plasticity (F6 - CL). The original moisture of the soil was more than 20 %. The moisture of the improved soil with cement did not differ from the moisture of the original soil.

To determine the optimum moisture of soil for compaction there was used the Proctor test (see

Fig. 1). The optimum moisture of the tested soil was determined $w_{opt} = 15.2\%$. This corresponds to the maximum dry density of soil $\rho_{max} = 1.768 \text{ g/cm}^3$. The collected samples had significantly higher moisture content than its optimal moisture.

2.1. OEDOMETRIC TESTS ON UNDISTURBED SOIL SAMPLES

Compressibility testing on the oedometer was made to the original and also the improved soil. At improvement there was added into the soil 5 % of cement. The results of average deformation characteristics of original and improved soil are collected in Table 1.

On the basis of laboratory results there can be determined for the improved soil the following increases in deformation characteristics:

- at stresses in soil $\sigma \leq 50 \text{ kPa}$

$$\frac{E_{oed \text{ stab}}}{E_{oed \text{ not}}} = \frac{32.25}{5.10} = 6.32 \quad (1)$$

- at stresses in soil $50 \leq \sigma \leq 100 \text{ kPa}$

$$\frac{E_{oed \text{ stab}}}{E_{oed \text{ not}}} = \frac{14.13}{5.70} = 2.47 \quad (2)$$

- at stresses in soil $100 \leq \sigma \leq 200 \text{ kPa}$

$$\frac{E_{oed \text{ stab}}}{E_{oed \text{ not}}} = \frac{15.19}{9.62} = 1.58 \quad (3)$$

Based on the stress range of its own weight and the expected load from buildings, the improvement of soil after adding cement was 1.5 to 2 times. The recommended values in the deformation modulus of improved soil should not exceed the value $E_{oed} = 14 \text{ MPa}$.

2.2. COMPRESSION TESTS OF SOIL WITHOUT IMPROVEMENT AT COMPACTION AFTER THE PROCTOR STANDARD

Artificially prepared samples of soil compacted after Proctor standard were tested in the oedometer. The

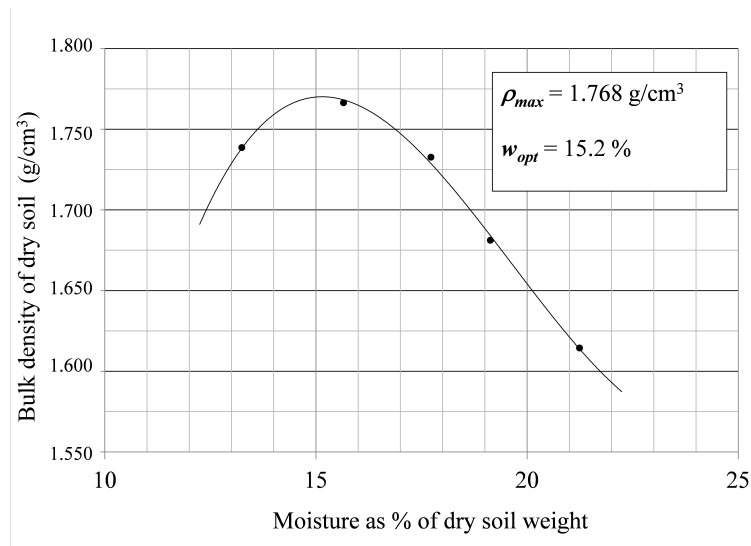


FIGURE 1. Determination of the maximum bulk density versus optimum moisture.

| Normal stresses $\sigma_1 - \sigma_2$ (MPa) | Average modulus | | | |
|---|-----------------|-----------------|-----------------|-----------------|
| | Improved soil | | Primary soil | |
| | E_{oed} (MPa) | E_{def} (MPa) | E_{oed} (MPa) | E_{def} (MPa) |
| 0.010 – 0.025 | 35.73 | 16.79 | 3.84 | 1.81 |
| 0.025 – 0.050 | 32.25 | 15.16 | 5.10 | 2.40 |
| 0.050 – 0.100 | 14.13 | 6.64 | 5.70 | 2.68 |
| 0.100 – 0.200 | 15.19 | 7.14 | 9.62 | 4.52 |

TABLE 1. Deformation modulus of soils determined from compression tests.

resulting average oedometer modulus corresponding to different moistures of tested soils are evaluated in Table 2.

Effects of changes in soil moisture on the oedometric modulus are shown in Fig. 2. The plasticity index of soil was $I_P = 10\%$ (liquid limit $w_L = 30.5\%$ and plasticity limit $w_P = 20.5\%$). Until the soil was in natural conditions and firm consistency, there were found very small values of deformation characteristics of tested soil to all extents of normal stresses. Increasing the soil stiffness (higher values of E_{oed}) was possible by observing a decreasing of soil moisture below 17%. The consistency of soil at such moisture was $I_C = 1.4$. Decreasing the moisture below 17% significantly increases the oedometric modulus of the soil.

Analysis of Fig. 2 taking into account Fig. 1 can be stated as:

- Exceeding the optimum moisture w_{opt} occurred in samples loaded by normal stress of 50 kPa with rapid decreasing of E_{oed} .
- With an increasing of moisture there was observed a significant decreasing of E_{oed} at lower normal stress (< 50 kPa) - more than 5-times. Exceeding the value of normal stress 50 kPa and with increasing the moisture there was found a decreasing of E_{oed} approximately 3.5 times.

In the test range of normal stress E_{oed} was significantly affected by moisture. In Fig. 3 there is shown

the relationship between deformation characteristics and normal stresses of soil at various initial moistures of the soil. Also in this evaluation it was proved the moisture was around 17% than the limit. At lower moisture there were detected significantly different deformation parameters, especially at normal stress to 50 kPa.

2.3. IMPROVING THE SOIL CHARACTERISTICS BY ADDING CEMENT

At natural moisture of soil 20% of collected samples had values of deformation modulus of the original soil which were very low. The addition of cement decreased soil moisture, whilst increasing the deformation parameters was not sufficient.

Very interesting results were obtained from evaluation of the effect of the 5% addition of cement (see Fig. 4). At lower humidity than 20.5% (on a stiff consistency) there was observed a significant effect of the cement. At the same time, the effect of improvement increases with lower levels of normal stress. Adding 5% of cement at optimal soil moisture brought a 2-3 times increase of E_{oed} compared to unimproved soil. Exceeding soil moisture $w = 20.5\%$ the soil fell into firm consistency and the impact effect of the cement was shown to be very low to negligible. Cement added to the soil with natural moisture, got between 19 to 21%, extracting a portion of water by hydration. This will inevitably reduce soil moisture itself. It can be assumed that the excess of the initial

| Normal stresses $\sigma_1 - \sigma_2$ (MPa) | Oedometric modulus E_{oed} (MPa) | | | | |
|---|------------------------------------|---------------|---------------|---------------|---------------|
| | $w = 13.25\%$ | $w = 15.65\%$ | $w = 17.73\%$ | $w = 19.13\%$ | $w = 21.24\%$ |
| | E_{oed} | E_{oed} | E_{oed} | E_{oed} | E_{oed} |
| 0.010 – 0.025 | 23.05 | 18.31 | 6.66 | 5.35 | 3.18 |
| 0.025 – 0.050 | 21.72 | 16.61 | 4.72 | 2.42 | 2.22 |
| 0.050 – 0.100 | 13.36 | 9.40 | 5.49 | 3.20 | 3.04 |
| 0.100 – 0.200 | 13.36 | 9.66 | 7.44 | 5.12 | 4.98 |

TABLE 2. Average oedometric modulus of tested soils at various moistures.

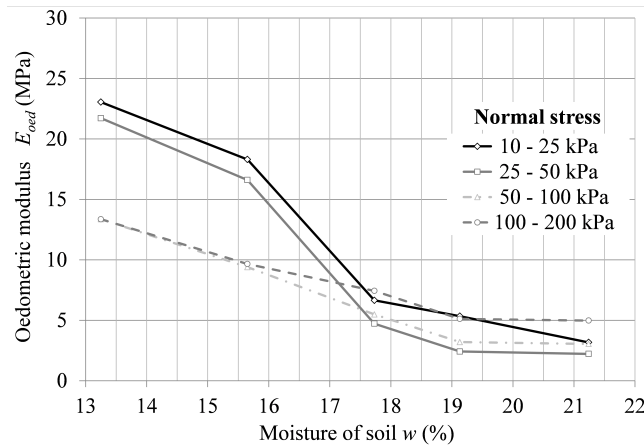


FIGURE 2. Relationship between moisture of tested soil and oedometric modulus.

moisture content in excess of the $w_{opt} + 5\%$ there is to be expected a significant decrease in the effect of stabilization.

3. THE QUALITY ASSESSMENT AND THE CEMENT CONTENT IN THE SOIL

Cement and its contents were independently tested in the stabilized soil. Laboratory tests of the physical-mechanical properties of cement were carried out and supplemented by X-ray and DTA analysis. Stabilized soil was investigated by DTA and also X-ray analysis.

Tested cement was used to stabilize the soil at the construction site. The studied properties and the results derived are as follows:

- After 28 days, the compressive strength reached 48.3 MPa. This value is in accordance with the requirements of the class of cement 42.5 MPa according to EN 197-1.
- Bulk density with a timed deposit of test samples slightly increased. After 28 days, the bulk density reached a value around 2190 kg/m^3 , which corresponded with standard values.
- By testing the cement slurry, it was found that the cement needs to reach a slurry of normal density of 32 % water.
- The initial set of cement slurry observed after 195 minutes, in which it fulfilled the limit set by the standard. Final set occurred after 250 minutes.

- Soundness of the testing cement went to 6.0 mm, which met the standard set limit of 10 mm.
- Bulk density of fresh cement mortar was 2160 kg/m^3 . All testing samples had low scatter from the average.
- X-ray analysis showed the incidence of cement clinker minerals as Alite - C_3S (Tricalcium silicate), Belite - C_2S (Dicalcium silicate), Brownmillerite - C_4AF (Tetracalciumaluminoferrite), C_3A (Tricalcium aluminate) and gypsum setting regulator ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$). Furthermore, there occurred Silica (SiO_2), Calcite (CaCO_3) and Portlandite $\text{Ca}(\text{OH})_2$. According to this composition it can be assumed that this was Portland-composite cement CEM II.

Tests of the stabilized soil by method X-ray and DTA showed that samples taken from the hall after the defective area of the static load tests contained less than 2 % of cement. By applying the same method to artificially prepared samples there was found good correspondence with the percentage of added cement.

4. CONCLUSION

Based on the compressibility tests on the stabilized soil it is clear that the high moisture of the soil after the rainy season had not reached sufficiently an increasing of the soil parameters. They showed two reasons for failure to satisfy the criteria required for static load testing. The first reason was lower cement content as determined by the project. Instead of 5 % of the cement which was in samples taken from the

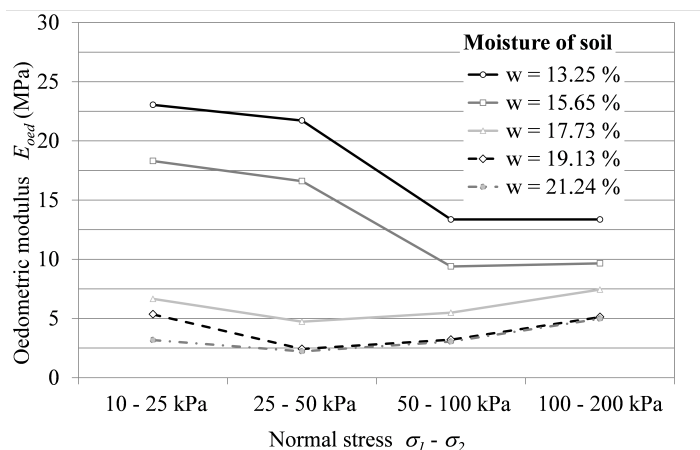


FIGURE 3. Dependence of normal stress and moisture on deformation characteristics of soil.

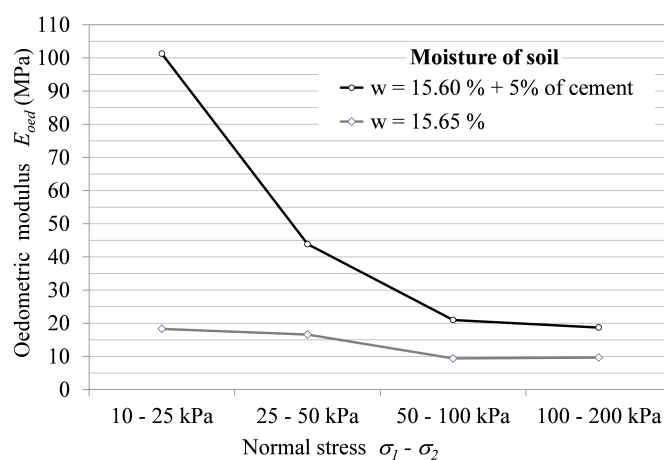


FIGURE 4. Influence of addition 5 % cement into the soil on E_{oed} at optimum moisture.

subgrade in the construction site there was found only a cement content in the range of 1 to 2 %. Significant precipitation caused the natural soil moisture to exceed 20 %. Laboratory experiments have shown that at such a level of moisture in the not improved original soil the deformation properties of soil are very low. Mixed cement decreased soil moisture, but it reflected only a small increase of E_{oed} . Deformation parameters of soil by adding cement may bring an increase 2-3 times. This effect is linked to the initial soil moisture before stabilization; value w_{opt} should not be exceeded by 5 %. In exceeding this moisture there is not expected a major stabilization effect.

5. ACKNOWLEDGEMENT

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