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USE OF CPTU AND DMT IN REHABILITATION OF FLOOD EMBANKMENTS

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Abstract: The shear strength in the soft soil under the central part of the embankment was found to be higher than that the subsoil at the downstream and upstream sides of the embankment. Subsoil overconsolidation near the embankment body was determined with the data from cone resistance and dilatometer test and confirmed by dilatory pore pressure response in CPTU dissipation tests. The subsoil under the central part of the embankment can be considered to be normally consolidated according to CPTU and DMT tests and monotonic pore pressure dissipation curve.

1. INTRODUCTION

Some renovation works have been carried out in order to increase the compaction and stability of flood embankments and to reduce filtration. A series of DMT and CPTU complete with dissipation tests were performed for the flood embankments of the Vistula river in the Żuławy Lowland. Cone penetration test with pore pressure measurements (CPTU) together with dilatometer test (DMT) permit a reliable and comprehensive evaluation of soft soil parameters, MAYNE [9], MŁYNAREK [10]. CPTU dissipation test completes the complementary character of both tests. As the CPTU penetration in less permeable soils is held under undrained conditions, the pore pressure is generated around the probe. When the penetration is stopped at a given depth, the dissipation of the induced pore pressure is monitored.

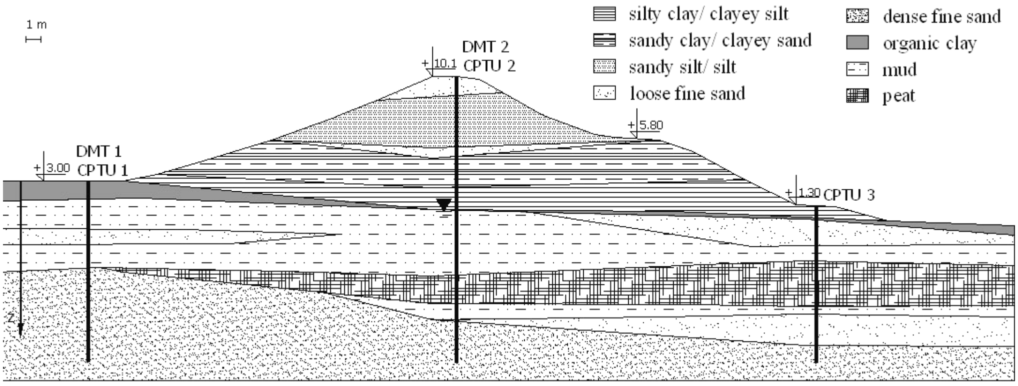

Fig. 1. Flood embankment and its geotechnical cross-section, BAŁACHOWSKI [1]

The embankment, about 7.0 m high (figure 1), is generally made of silty soils. In the subsoil, one can observe a superficial organic clay layer, covering sandy or silty mud, and local peat layer. Some sandy inclusions can be found in the mud. At the bottom fine and medium dense sands were deposited. CPTU and DMT soundings were performed at the crown and at the upstream and downstream toes of the embankment. Typical CPTU probe for the pore pressure u_2 measurement was used. A series of CPTU dissipation tests were carried in mud and peat.

2. SHEAR STRENGTH OF THE SOFT SUBSOIL

Undrained shear strength in the soft subsoil was determined with CPTU and DMT. For CPTU tests the following formula was used (LUNNE et al. [6]):

$$s_u = \frac{q_t - \sigma_{v0}}{N_{kt}}, \tag{1}$$

where:

q_t – corrected cone resistance,
σ_{v0} – initial total overburden stress,
N_{kt} – cone factor assumed to be equal to 20 for mud and peat.

Undrained shear strength with DMT was estimated using the formulae proposed by LECHOWICZ and SZYMAŃSKI [5]:

- for mud

$$s_u = \sigma_v' \cdot 0.35 \cdot (0.5 \cdot K_D)^{1.25}; \tag{2}$$

- for peat

$$s_u = \sigma_v' \cdot 0.5 \cdot (0.45 \cdot K_D)^{1.2}, \tag{3}$$

where:

σ_v' – effective overburden stress,
K_D – lateral stress index.

Quite similar values of shear strength were obtained with CPTU and DMT (figure 2). The undrained shear strength in the subsoil under the central part of the embankment was systematically higher than that at the embankment toe. The analysis done for 15 cross-sections of the embankment confirmed this observation (figure 3). It can be attributed to the long-term consolidation of the soft soil and higher stress level under the central part of the embankment.

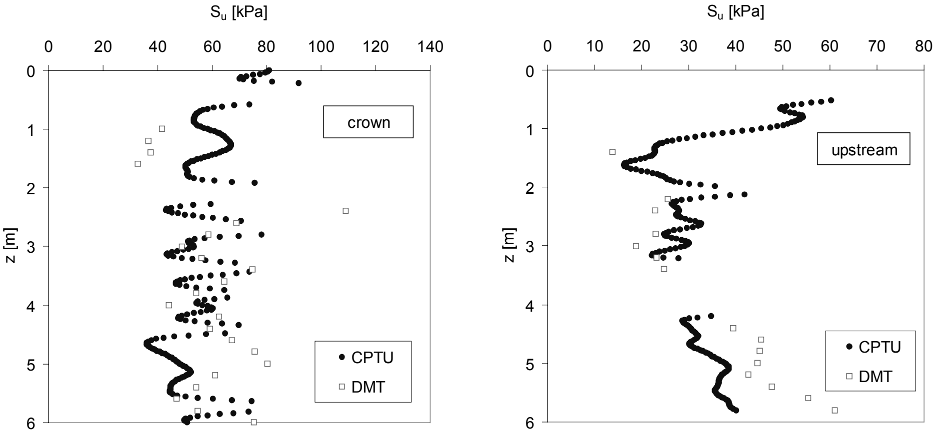

Fig. 2. Undrained shear strength in the subsoil under the crown and at the upstream side

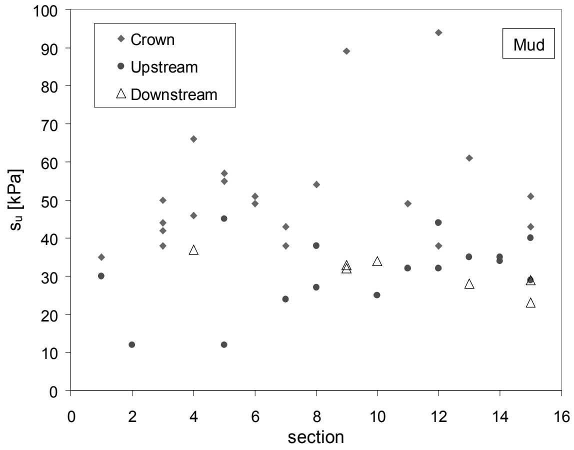

Fig. 3. Undrained shear strength in mud layers from CPTU in the cross-sections tested

3. STRESS HISTORY IN THE SUBSOIL

Soil overconsolidation was determined from CPTU data, LUNNE et al. [6]:

$$OCR = \frac{a(q_t - \sigma_{v0})}{\sigma'_{v0}}, \tag{4}$$

where a is the coefficient ranging from 0.2 to 0.5 related to plasticity index. LUNNE et al. [6] suggest that the average value of the coefficient a is 0.3, which has been assumed in the present study.

For soft soils under the embankment the *OCR* values (figure 4) slightly exceeding unity were found based on CPTU. At the embankment toe the *OCR* values from 3 to 4 were obtained. At small depth even higher *OCR* values are obtained.

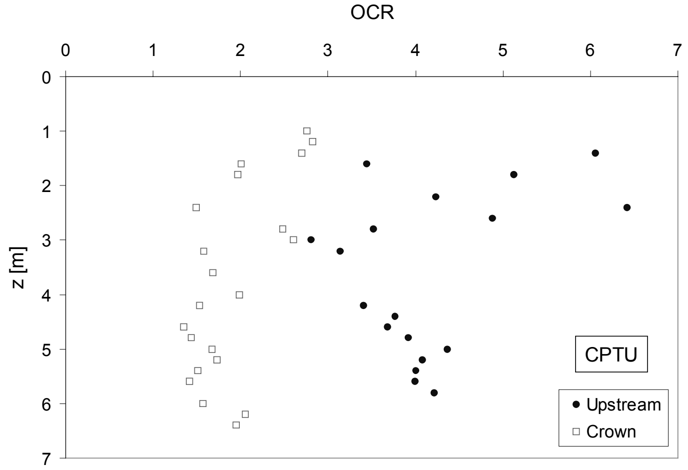

Fig. 4. *OCR* profiles from the CPTU under the central part of embankment and at its toe, BAŁACHOWSKI [1]

The formula of MARCHETTI [7], valid for the soils with material index I_D smaller than 1.2, can be applied:

$$OCR = (0.5K_D)^{1.56}. \tag{5}$$

A local correlation (LECHOWICZ and RABARIJOELY [4]) was used for organic soil:

$$OCR = (0.45K_D)^{1.40}. \tag{6}$$

The values of *OCR* in the soft soil under the central part of embankment and at its upstream toe are compared (figure 5). While an overconsolidation ratio close to unity is found in the soil under the central part of the embankment, *OCR* value ranging from 1.5 to 3 is obtained at its upstream side.

The analysis of CPTU and DMT data confirms that the soft soil under the central part of the embankment is normally consolidated, while the soil under the embankment toe is in overconsolidation state. This overconsolidation is a complex phenomenon including mechanical overloading, lateral stress increase due to embankment construction and structural overconsolidation, WOLSKI [13]. The weight of the embankment was sufficiently large to exceed overconsolidation pressure in the soft subsoil under the central part of the embankment.

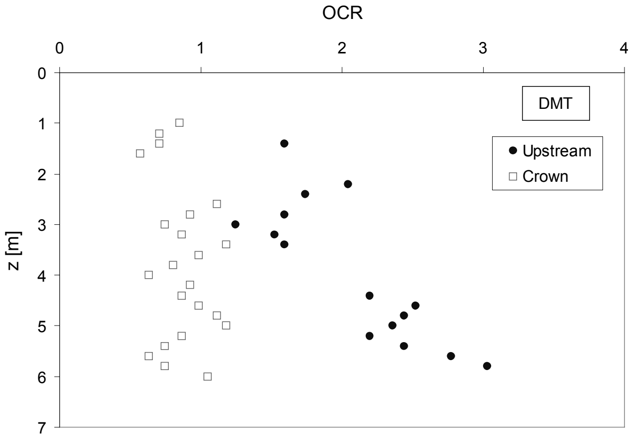

Fig. 5. *OCR* profiles in the subsoil of the embankment from DMT, BAŁACHOWSKI [1]

4. DISSIPATION CURVES IN NORMALLY CONSOLIDATED AND OVERCONSOLIDATED SOILS

The interpretation of monotonic dissipation curve is already made valid, HOULSBY, TEH [3], PAREZ, FAURIEL [11], LUNNE et al. [6]. The analysis of the dissipation test with dilatory response is, however, more complex, BURNS and MAYNE [2], SULLY et al. [12], MAYNE [9]. A monotonic decrease in excess water pressure (figure 6) observed

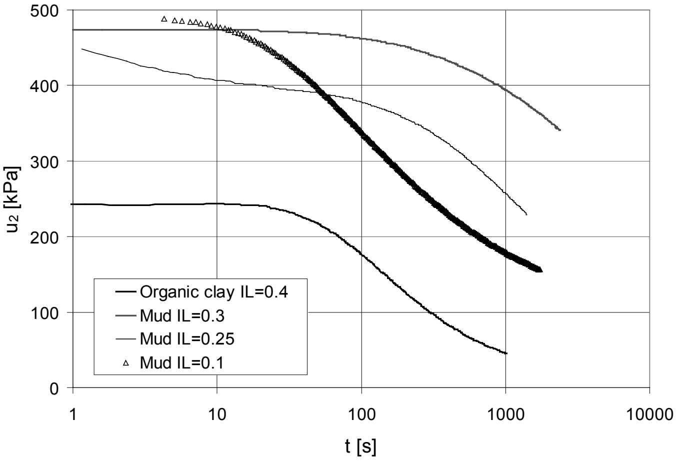

Fig. 6. Dissipation curves under the central part of the embankment, BAŁACHOWSKI [1]

under the central part of the embankment confirms normal consolidation of this subsoil found in CPTU and DMT tests. A set of dissipation curves registered in plastic mud at the toe of the embankment is shown in figure 7. The dilatory response, classified as a Type III dissipation curve according to SULLY et al. [12], confirms the overconsolidation of the soft subsoil at the toe of the embankment found with CPTU and DMT tests.

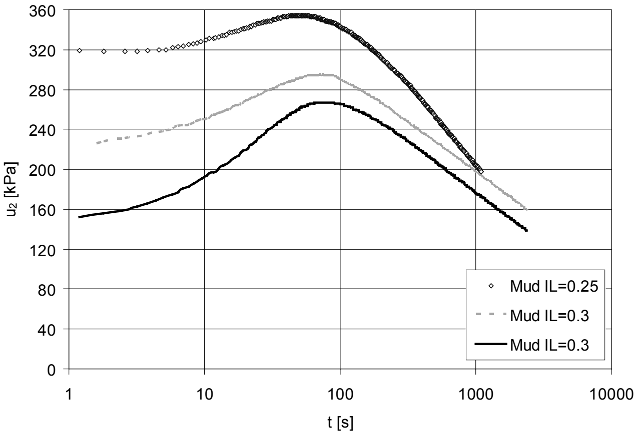

Fig. 7. Set of dissipation curves at the toe of the embankment

5. CONCLUSIONS

An undrained shear strength obtained in CPTU and DMT tests in the soft subsoil under the central part of the embankment is higher than that at its toe, which is a result of a stress level increase and long-term consolidation. The compaction of the embankment itself (generally low) and safety analysis are outside the scope of this paper.

While a monotonic pore pressure response was found in the dissipation tests performed under the central part of the embankment, a dilatory pore pressure response was observed in the overconsolidated subsoil at the embankment toe. The shape of dissipation curves is conformed with the stress history determined with CPTU and DMT. Similar *OCR* profiles were obtained using CPTU and DMT tests. An estimated subsoil overconsolidation is a complex phenomenon involving both mechanical overloading and structural effect.

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