Use of penetration testing for determination of soil properties in earth dam

Emploi des essais de pénétration pour déterminer les propriétés de sol pour barrages en terre

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ABSTRACT: The Paper describes a case of a small earth dam for which remediation work was planned, due to bad construction and possible damage to the dam that could have occurred during filling of the retention. In order to assure relevant data for the remediation design solution it was necessary to determine the current state of the compacted dam and properties of the clay fill in the dam. Investigation work consisted of drilling boreholes and performing *in situ* test on the dam, and of laboratory testing of soil samples. CPT and DMT *in situ* tests were carried out nearby the boreholes on the crest. Potential of these *in situ* tests in describing physical and mechanical properties of the clay was analysed, since standard methods of interpretation of these tests are based on natural soils, while the dam was constructed by compacting clay. It has been shown that CPT and DMT tests are useful in describing properties of a compacted clay embankment, but also that one should be cautious in using common methods of interpretation of their test results in case of earth fill embankments.

RÉSUMÉ : L'article décrit le cas d'un petit barrage en terre, pour lequel une remise en état est planifiée à cause de mauvaise réalisation et du danger potentiel d'endommagement au cours de remplissage de la retenue. Afin d'avoir des données pertinentes pour les techniques de confortement il a été nécessaire de déterminer l'état actuel du barrage et les propriétés de l'argile utilisée dans la construction du barrage. Les travaux de reconnaissance ont compris les forages et les essais in situ sur le barrage, ainsi que les essais en laboratoire. Les essais de pénétration au cône (CPT) et les essais au dilatomètre (DMT) in situ ont été faits auprès des trous de forage dans la crête du barrage. Le potentiel de ces essais dans la description des propriétés physiques et mécaniques d'argile est analysé, étant donné que les interprétations de ces essais sont basées sur les sols naturels tandis que l'argile a été mise en œuvre dans le barrage par compactage. It est démontré que les essais CPT et DMT sont utiles pour l'analyse d'état du sol compacté, mais qu'il faut être très attentif dans l'emploi des procédés standard d'interprétation des résultats de ces essais quand il s'agit des essais pour les ouvrages en remblai.

KEYWORDS: earth dam, compacted clay, piezocone test, flat dilatometer test, interpretation
MOTS-CLÉS : barrage en terre, argile compactée, essai au piézocône, essai au dilatomètre plat, interprétation

1. INTRODUCTION

A small earth dam was built as a part of a future irrigation system. The dam was about 10-meter high at the deepest point in depression, and was constructed of the clay from its vicinity. During the construction of the dam it was noticed that the construction company didn't fully follow the design requirements and criteria related to zoned construction, replacement of foundation soil and degree of compaction of the lifts of clay. During the filling of the lake, when only few meters of dam slopes were covered with water, problems with bottom discharge were observed and filling of water had to be stopped. It was decided that the dam should be checked for safety against sliding and deformability, for which geotechnical properties of compacted clay in the dam should have been should have been checked in detail. The site testing program consisted of drilling boreholes for getting samples for laboratory testing of clay, of penetration testing – CPT and a flat dilatometer test (Marchetti dilatometer – DMT). This paper presents the results of analysis of the properties of clay in the dam based on *in situ* (CPT and DMT) and laboratory testing. Only boreholes in the crest were used for the analysis, see Fig. 1.

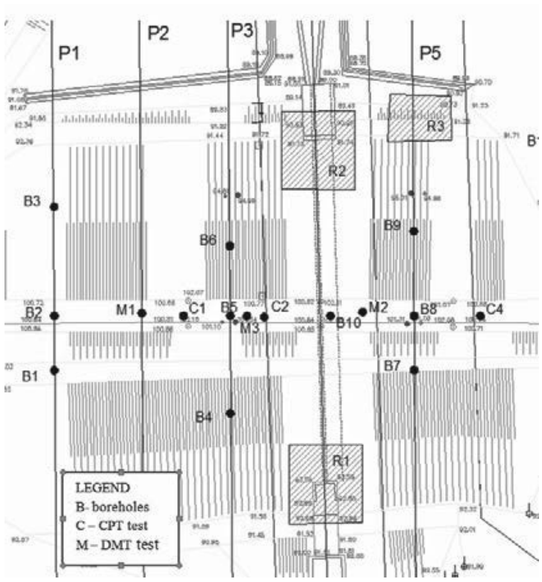

Figure 1. Position of *in situ* tests and boreholes on the dam; most important work was done on the crest (line B2-C4)

From the samples taken during drilling boreholes specimens were formed for the laboratory testing program, which comprised the testing of physical and mechanical properties of clay from the dam. Fig. 2 shows the plasticity of clay from the dam, determined on samples from the B2 and B5 boreholes.

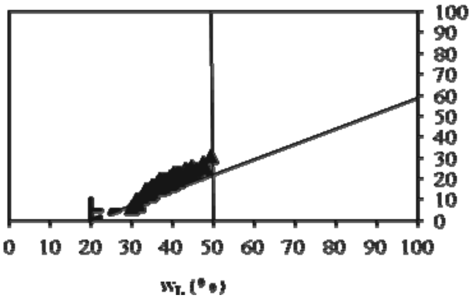

Figure 2. The clay from the dam was of low plasticity; there were zones of silty clay at some depths

It was determined that generally clay compaction degree was under 95 % of Proctor value, that water content was a bit higher than w_{opt} according to Proctor test and that clay of somewhat lower plasticity was used than that which was defined by the design solution.

2. CPT AND DMT TESTS

Four CPT test-boreholes and three flat dilatometer (DMT) test-boreholes were realised, along the crest of the dam. General interpretation of test results of these two test types is established for natural soils, and in this case there is compacted clay – human made soil. Therefore it was necessary to check the applicability of standard interpretation methods to compacted clay, for both tests.

Both tests were conducted according to relevant standards (EN 1997 – Part 2:2006). Glycerine was used as fluid in porous stone in CPT cone. It should be noted that there is not much experience presented in literature covering CPT and DMT testing in compacted clay. All empirical and theoretical expressions for the interpretation of test results of these two tests are based on natural soils (Larsson and Mulabdic, 1991, Lunne et al, 1996, Marchetti, 1980).

2.1. Soil identification

Clay in the embankment was never under water, except for the part deeper than 9 m as measured from the crest. That required careful cone filter saturation with glycerine. CPT soil-type identification was done according to a widely used chart (Robertson, 1990), and in doing so clay of low plasticity was identified in most cases, with some thin layers of silty clay (see plasticity chart in Fig. 2). Pore pressures measured behind the cone (u_2) were almost zero, or slightly negative, in all depths.

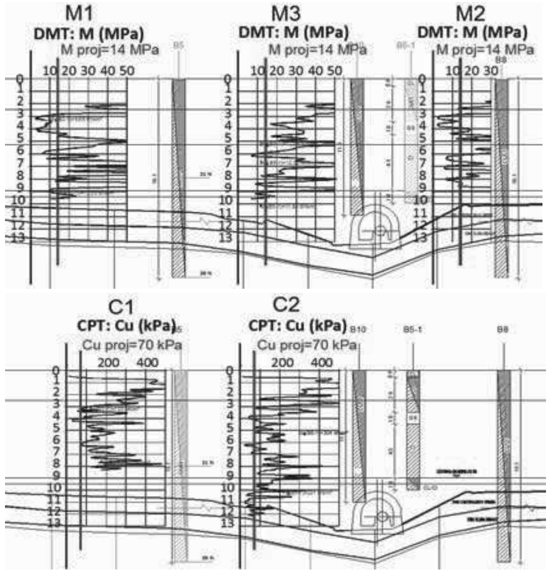

Figure 3. DMT (M1, M2, M3) and CPT tests (C1, C2), over the dam height (cross-section along the crest). Both, CPT and DMT tests revealed inhomogeinity in the clay embankment – it seems that almost every lift of clay can be spotted over the dam height; DMT test illustrate interpreted versus required Mv, and CPT test interpreted versus required c_u

On the other hand, DMT test detected a sandy-silty to silty-sandy soil type, with very rare clayey-silty thin layers. Therefore there were almost no data for undrained strength in DMT interpretation. According to Marchetti (1980), soil type in DMT test interpretation is related to $I_d = (p_1-p_0) / (p_0-u_0)$, and for clay soil-type it should satisfy $0.1 < I_d < 0.6$. Since the value of I_d in compacted clay of the dam was found to be about or higher than 2 (suggesting a sandy or sandy-silty soil type), and there was no *in situ* pore pressure in soil, it could be concluded that p_0 was too small, due to structure of compacted soil and absence of *in situ* pore pressures.

2.2. Undrained shear strength by CPT

Undrained shear strength from CPT test is calculated according to common expression (Lunne et al, 1997)

$$s_u = \frac{q_c - \sigma_{v0}}{N_k} \qquad (1)$$

Value for N_k=15 was used in this case, which is the mean value of proposed values for natural soils (suggested values are N_k=11-19), and it was confirmed to be applicable for compacted clay as well (Fig. 4).

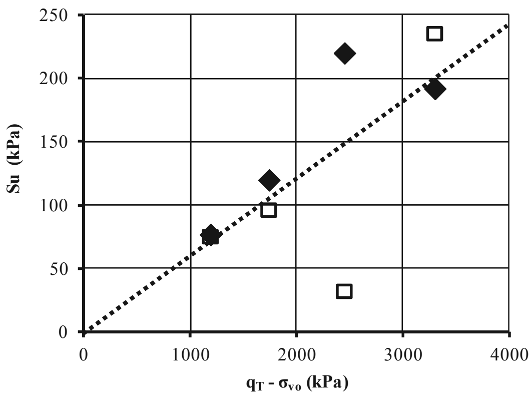

Figure 4. Nk=15 Nk = 15 for compacted clays was found to be applicable, based on comparable UU and CPT test results

2.3. Modulus of vertical deformation

Comparison of modulus of vertical deformation was made for relevant results for oedometer and CPT test. Lunne et al (1997) critically analyse expression for modulus of vertical deformation from CPT test when determined as

$$M = 8{,}25(q_T - \sigma_{v0}) \tag{2}$$

In this case it seems that this value should be devided by factor of two (Fig. 5). This might be due to the fact that this general expression has limitations, and becouse oedometer tests were performed on submerged specimens while CPT and DMT tests were performed on clay fill in the embankment that was not submerged. Values of Mv from DMT test were the highest of these three (Fig. 6) (Fig. 6).

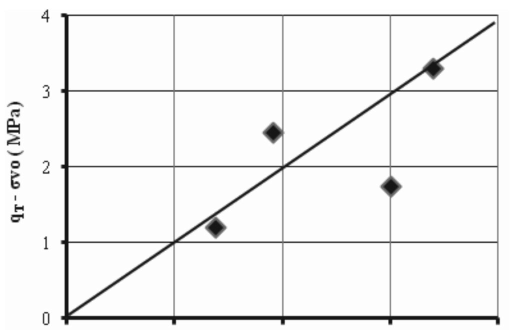

Figure 5. Relationship between laboratory determined modulus of vertical deformation and corrected tip resistance for CPT test, around B5 borehole

Based on a limited number of available test results, the expression Mv=4, 3 (q_t-σ_{vo}) seems to better fit test results than the equation (2). Modulus seems to be half of the value suggested by that commonly used equation. If relationship between DMT-M_v and LAB M_v from Fig 6 would be respected, then bigger portion of the embankment would show lower values then required compared to situation illustrated in Fig 3 (M proj) .

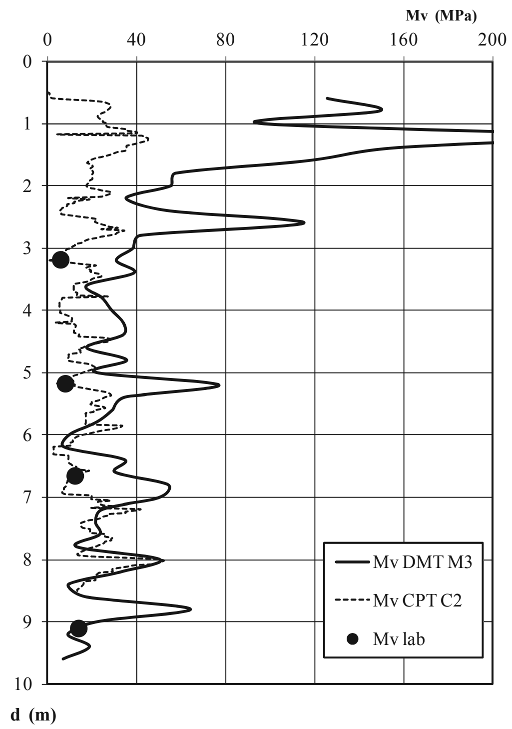

Figure 6. Modulus of vertical deformation from oedometer (on submerged specimens) was much smaller than from CPT interpretation (equation (2)) or even lower if compared to DMT standard interpretation values (performed on clay layers that were not submerged)

Fig. 7 presents the sets of CPT and DMT tests with a view to illustrate soil resistance in relation to depth. It seems that the results of tests from different locations are very similar throughout the depth of testing.

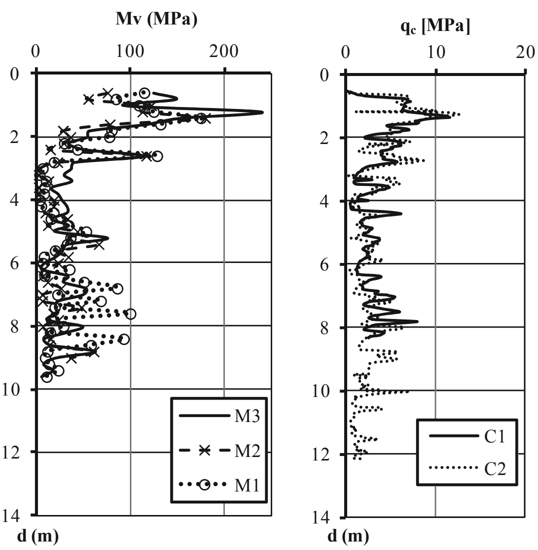

Figure 7. CPT and DMT tests in cumulative presentation

The influence of presence of water on DMT test results interpretation in terms of modulus M_v was discussed in Mulabdic and Bruncic (2000) for natural soils. They concluded that error in water depth assumption had limited influence on interpreted M_v values. Here we are dealing with compacted clay, never being submerged, and obviously soil would be softer if it were submerged. That is, it is difficult to predict soil modulus M_v for the state of a submerged embankment fill from an *in situ* test performed on a non-submerged embankment fill. Only comparison as shown in Fig. 6 can be used as a guide for correcting *in situ* evaluated parameters to laboratory values, but even then correction would not be constant with depth.

Tests marked as M1, M2 and M3 (DMT-tests) were performed in one run as standard tests and seismic tests (SDMT), using a special seismic probe installed above blade (Cavallaro et al, 2006). Fig. 8 shows wave velocities measured in 0,5-meter depth intervals. Since velocity is a „measure“ of soil structure and its rigidity, variability of those two parameters should be regarded as a basic indication of the variability of soil mechanical properties. These variabilities are more pronounced in wave velocity diagrams than in CPT and DMT standard diagrams. Although velocities generally increase with depth, there are weaker and stronger intervals at certain depths in M2 and M1 boreholes. The M3 location shows constant increase in shear wave velocity by depth.

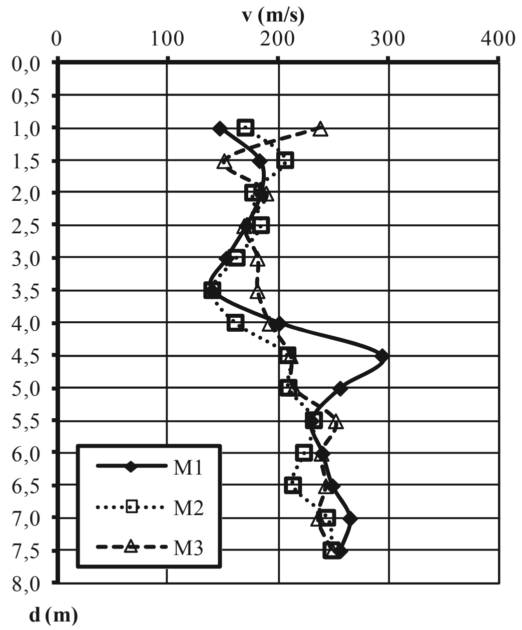

Figure 8. Measured shear wave velocity at different SDMT locations, depth intervals 0,5 m

3. CONCLUSIONS

The paper presented the case of an earth dam of a poor construction quality. In order to characterize clay fill in the embankment in terms of its physical and mechanical properties, CPT and DMT tests were performed in addition to borings and laboratory testing. The purpose of these two *in situ* tests was to determine compacted clay condition and its physical and mechanical properties in a continuous profile by depth and at different positions on dam crest. The tests and the interpretation of their results were performed according to accepted standards. Based on analyses of all test results – from *in situ* and laboratory tests – the following conclusions can be drawn from this case: (1) CPT and DMT detected inhomogeneous clay conditions very clearly along the depth, both in static testing and in seismic testing (SDMT), (2) common interpretation of CPT and DMT test results should be used with caution, allowing for appropriate corrections when tests are performed in compacted clays, since they are developed for natural clays, and here we deal with the compacted – man made soil; (3) it is of importance for the analysis and perception of clay properties whether the embankment is dry or submerged at the time of performing *in situ* tests; (4) CPT and DMT tests showed remarkable repeatability and proved to be valuable aid in characterizing embankment quality, both in terms of inhomogeinity and physical and mechanical properties; SDMT results also proved to be particularly useful; (5) local correlations between laboratory and *in situ* test results should always be used, in order to properly account for effects of the presence of water (submerged or non-submerged), specific structure of compacted soil, specific stress distribution and limited experience in using *in situ* tests for the characterization of compacted soils.

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