# Evaluation of Geotechnical Parameters of Clay built in Dam Core based on DMT

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*Keywords:* embankment dam, the clay core, soil compaction, DMT, compactive prestress

ABSTRACT: In the paper the application of the Flat Dilatometer Test (DMT) for determination of clay core characteristics of embankment dam during and after construction is presented. The tests have been carried out among others like Cone Penetration Test (CPT) and BAT permeability tests. The results of DMT allowed to verify and validate the geotechnical parameters determined in design phase on soil samples compacted in the laboratory, as well as based on laboratory tests carried out on soil samples taken directly from the core during construction phase. It has been proved that during construction the upper part of the core is prestressed (overconsolidated) by compaction energy. On the basis of DMT result two zones in the clay core can be distinguish: prestressed (overconsolidated) OC and normally consolidated NC.

## 1 INTRODUCTION

The Czorsztyn Dam, at 55 m high, is the biggest zoned embankment dam in Poland. The typical cross-section of the dam consists of a central silty clay core, based on a concrete gallery, surrounded by two transition (filter) layers, and external coarse gravel shells (Fig. 1).

The construction of the core (1990-96) imposed the solution of complex design and executive problems (Barański et al. 1994, 1997, Skutnik, 2000, 2002, 2004). The geotechnical investigations executed during construction had the following purposes: allow determining the appropriate method of quality control of the clayey mass, verify the strength and compressibility parameters. Additionally define the construction details so as to guarantee the maximum efficiency of the construction method and assess homogeneity in the clay core, identify actual stress state within the core to detect zones of stress concentration which may result in any unfavorable phenomena e.g. as hydraulic fracturing etc. (Lo and Kaniaru, 1990, Skutnik, 2000)

The Świnna Poręba Dam (50 m high), is the second largest zoned embankment dam with the central clay core in Poland. The typical cross-section of this dam is presented in Fig. 2.

The construction of the Świnna Poręba Dam has been almost finished in 2009, but reservoir has never been fill because some other works had not been finished up to now. During the construction of the core (2003–2007), among others geotechnical soundings DMT have been performed at the end of each construction season.

The construction of the core of each dam poses the solution of many design and executive problems, related to the appropriate selecting and incorporation of the fine grained soils into the structure. Usually the quality of the earth works during construction, are estimated on samples taken from each completed layer based on standard index properties and Proctor tests. The method of compaction control is important from the economic as well as from a technical standpoint. With the speed of construction achieved in modern earthworks, rapid testing techniques are required (Charles, 1997). Taking into account the height of the Czorsztyn and Świnna Poręba Dams the standard method of the compaction control cannot be only applied. It was decided to introduce the geotechnical soundings also DMT tests for the quality control assurance of earthworks. A qualitative estimation of the clay core homogeneity was possible based on distribution of $p_0$ and $p_1$ pressures in the profile. Undrained shear strength $\tau_{fu}$ and compressibility modulus M, as well as OCR or $K_0$ have been determined from DMT using adequate equations. The grain size distribution curves of dam cores materials are shown in Fig. 3.

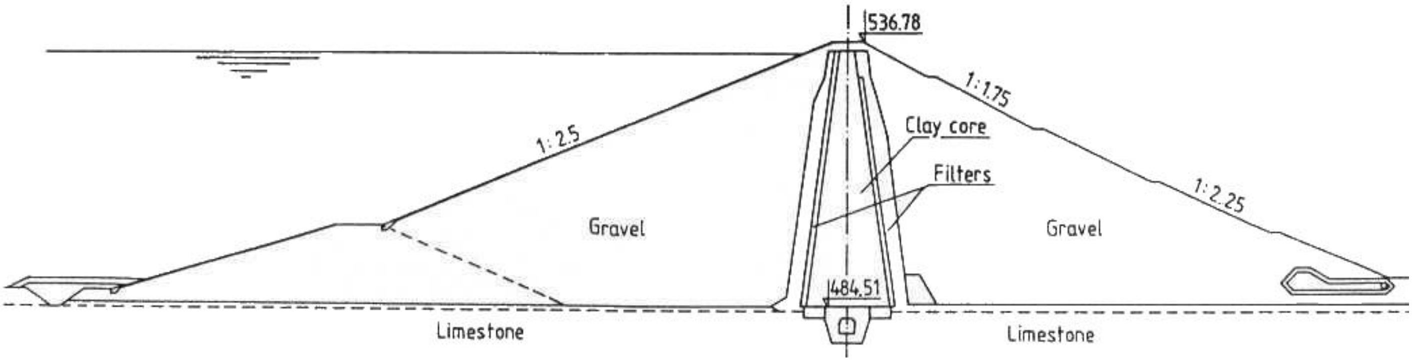


Fig. 1. Typical cross-section of Czorsztyn Dam.

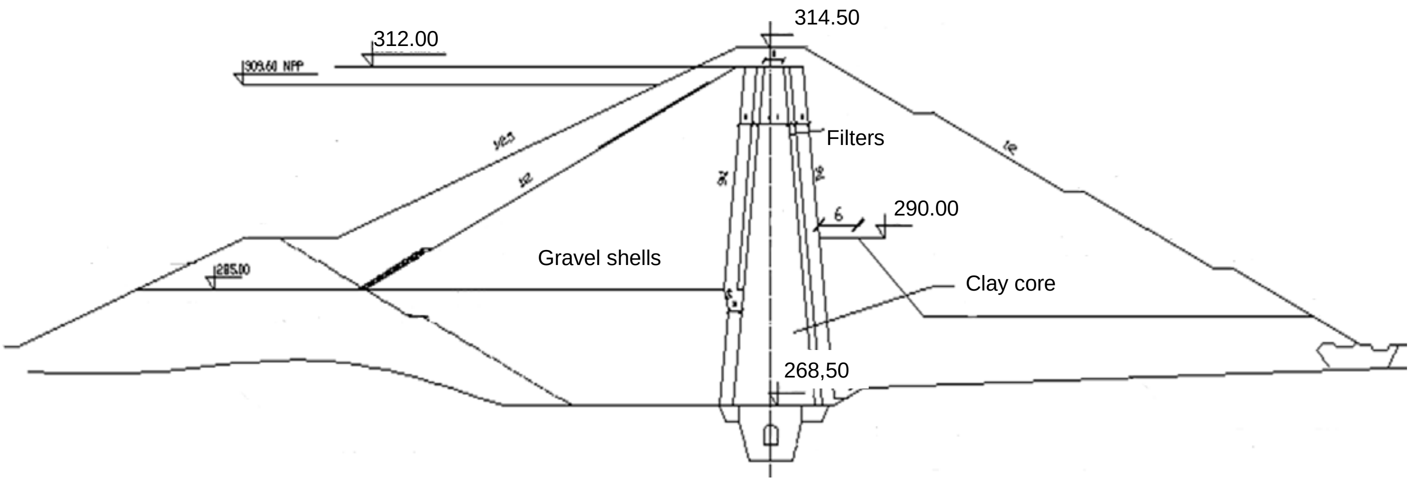


Fig. 2. Typical cross-section of Świnna Poręba Dam.

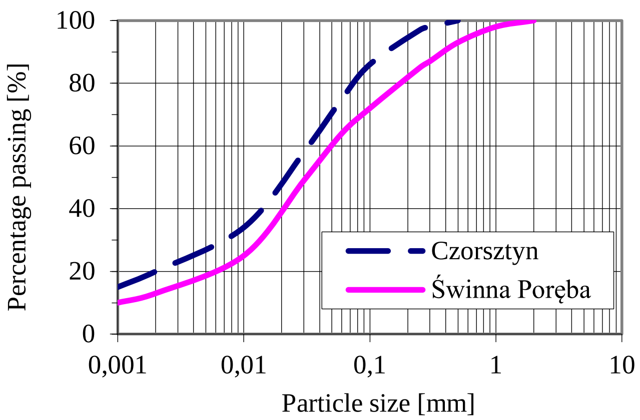


Fig. 3. Grain size distribution curves of the cores materials of Czorsztyn and Świnna Poręba Dams.

## 2 INVESTIGATION OBJECTIVES AND METHODS

Both in the core of the Czorsztyn Dam and in the core of Świnna Poręba Dam, among others in situ tests, like CPT and BAT permeability tests, DMT tests were performed. In this paper only application of DMT for determination of clay core characteristics of each embankment dam during construction is presented.

Generally at the design stage of the dam during search of sources of the soil construction material the mechanical and others geotechnical parameters are determined by laboratory tests carried out on the soil samples compacted in the laboratory. These parameters required verification by performing the laboratory tests carried out on the soil samples taken off from the just constructed structure.

## 3 DMT TESTS

In regular engineering practice DMT tests are mostly carried out in order to assess of the subsoil conditions. In case of the Czorsztyn Dam and Świnna Poręba Dam, DMT tests have been applied for the determination of clay core homogeneity and of for estimation of OC zone range as well as for the evaluation of chosen dam clay core geotechnical parameters like compressibility modulus M, undrained shear strength $c_u$, overconsolidation ratio OCR, coefficient of earth pressure $K_0$.

For performed tests the standard device developed by Marchetti (1980), was used. Based on the measured pressures $p_0$ and $p_1$ the dilatometer indexes i.e. material index $I_D$, horizontal stress index $K_D$ and dilatometer modulus $E_D$ were calculated. Next the geotechnical parameters: M, $\tau_{fu}$, OCR, $K_0$ have been evaluated according to the formulas 1, 2, 3 and 4 (Marchetti, 1980; Marchetti el al., 2001):

$$M = R_M \cdot E_D \quad (1)$$

where: $R_M$ – is a function of $I_D$ and $K_D$.

$$c_u = 0.22\sigma'_{v0}(0.5K_D)^{1.25} \quad (2)$$

$$OCR_{DMT} = (0.5K_D)^{1.56} \quad (3)$$

$$K_0 = \left(\frac{K_D}{1.5}\right)^{0.47} - 0.6 \quad (4)$$

The example of DMT test results performed after construction completion of 75 % of total height of the Swinna Poreba Dam clay core (elevation of the top of the core 302 m above sea level) is presented in Fig. 4. Two years after completion of the dam core next series of DMT and other in situ tests have been carried out. The results of one of DMT tests is presented in Fig. 5. Performed that time the in situ tests have included also borings with soil sampling by means of Shelby sampler. The undisturbed soil samples were taken of in the vicinity of the profiles of soundings. The laboratory tests among others (index properties, triaxial tests, permeability tests) includes also oedometer tests. The determined from oedometer tests values of compressibility moduli (M) were used for the verification of the moduli values which have been determined by DMT tests (Fig. 5).

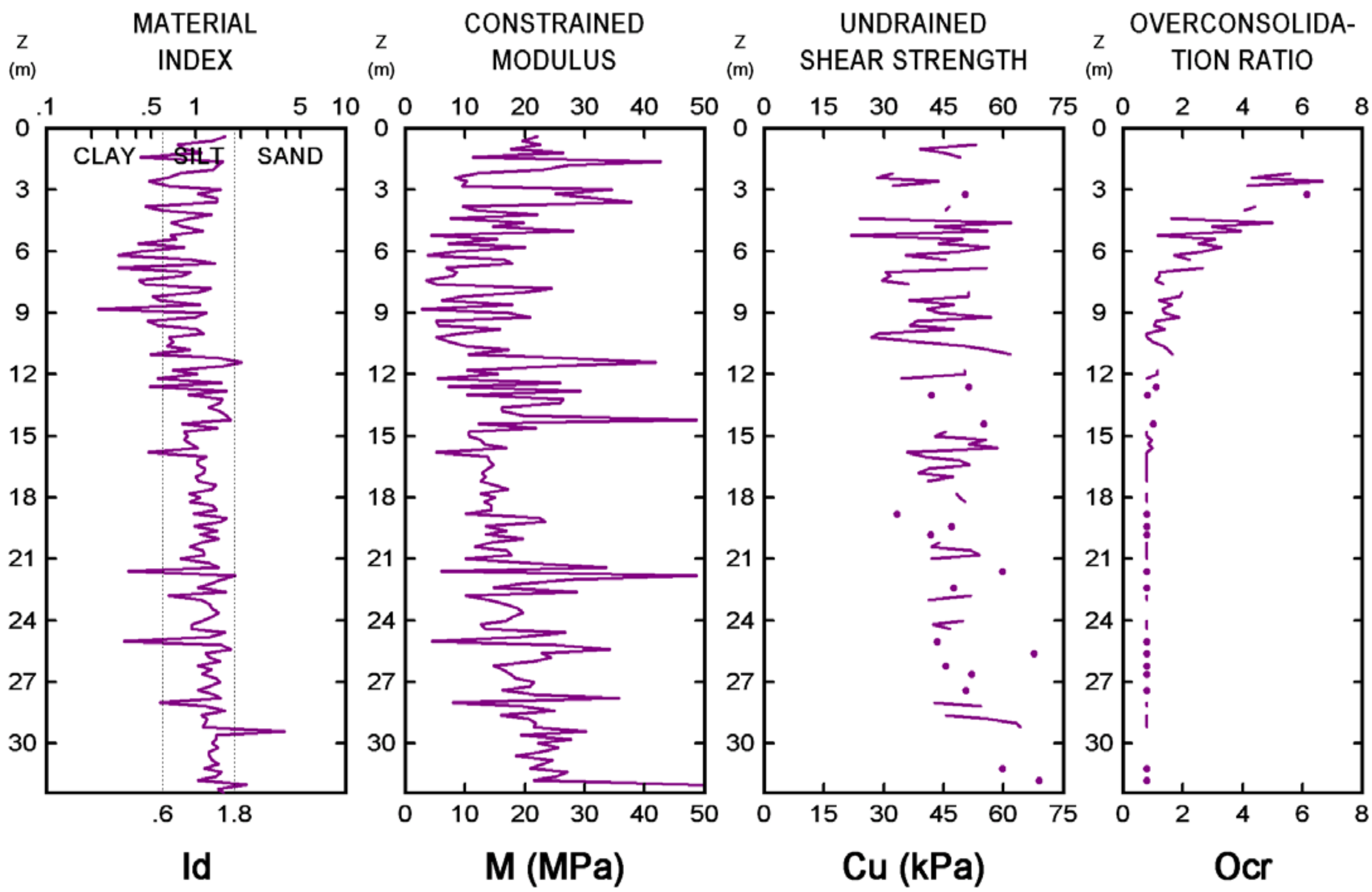


Fig. 4. Example of DMT result (performed from the 75 % of total core height of Świnna Poręba Dam)

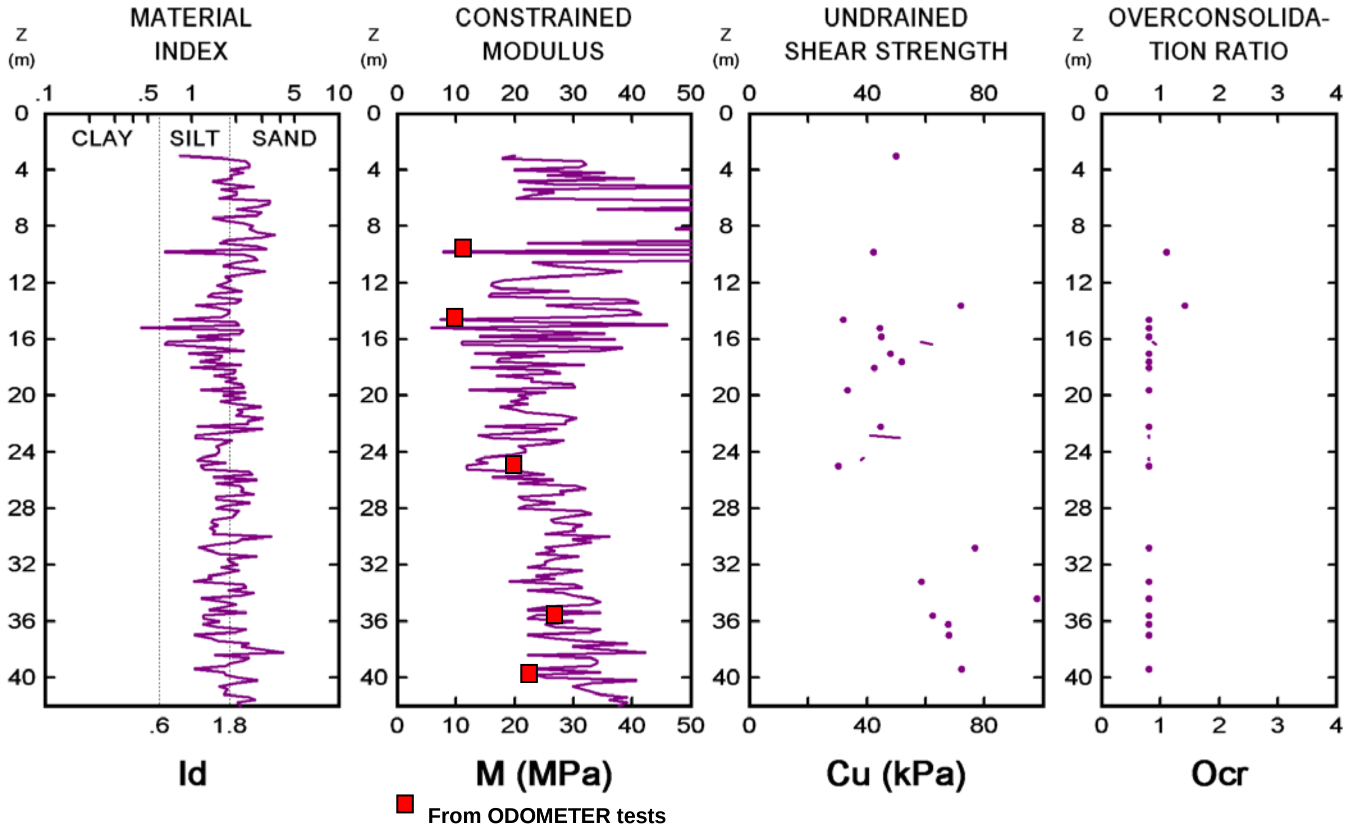


Fig. 5. Example of DMT result (performed two years after completion of the dam core construction of Świnna Poręba Dam).

During the construction of the core of Czorsztyn Dam, which was started in 1990, since 1992 after the completion of every season geotechnical soundings were performed in order to control the quality of the earthworks. Geotechnical soundings CPT, DMT, BAT and drilling sampling were performed in selected sections. The depth of soundings in consecutive seasons were greater than the thickness of the core layer done. This made it possible to evaluate how changing the geotechnical properties of the soil as a result of the consolidation of the core, and to assess the current stress state in the core of the dam due to compaction and consolidation (Fig. 6).

The example of DMT results performed in the following seasons construction Czorsztyn Dam core are presented in Fig. 7 and in Fig. 8. The prestressed due to the compaction OC zone reaches the depth of more less 10 m. The OCR values varies between 2 and 8, and in the upper part of the core (to the depth of 3 m) reaches even 15, while $K_0$ value varies between 0.5 and 1.6.

This is caused by the compaction energy (Fig. 6) transmitted to the soil skeleton and pore fluids during compaction process. In OC zone the horizontal stress is close to the vertical.

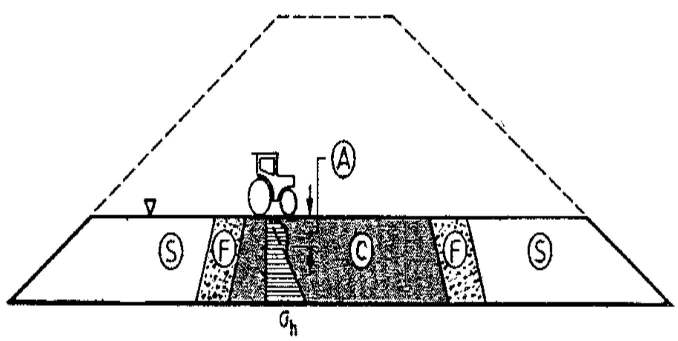


Fig. 6 State of the stress in the core of dam during the compaction process: A – increased horizontal stresses as a result of compaction, C – core, F – filters, S – shells.

After 10 years of Czorsztyn Dam exploitation, two soundings CPT and two DMT to depth of over 50 m (the entire thickness of the core) were performed. The special procedure of rods lubrication has been applied to achieve the desired depth. The example of one of DMT results is presented in Fig. 8. The values of M, OCR, $c_u$ have not changed significantly compared with former tests.

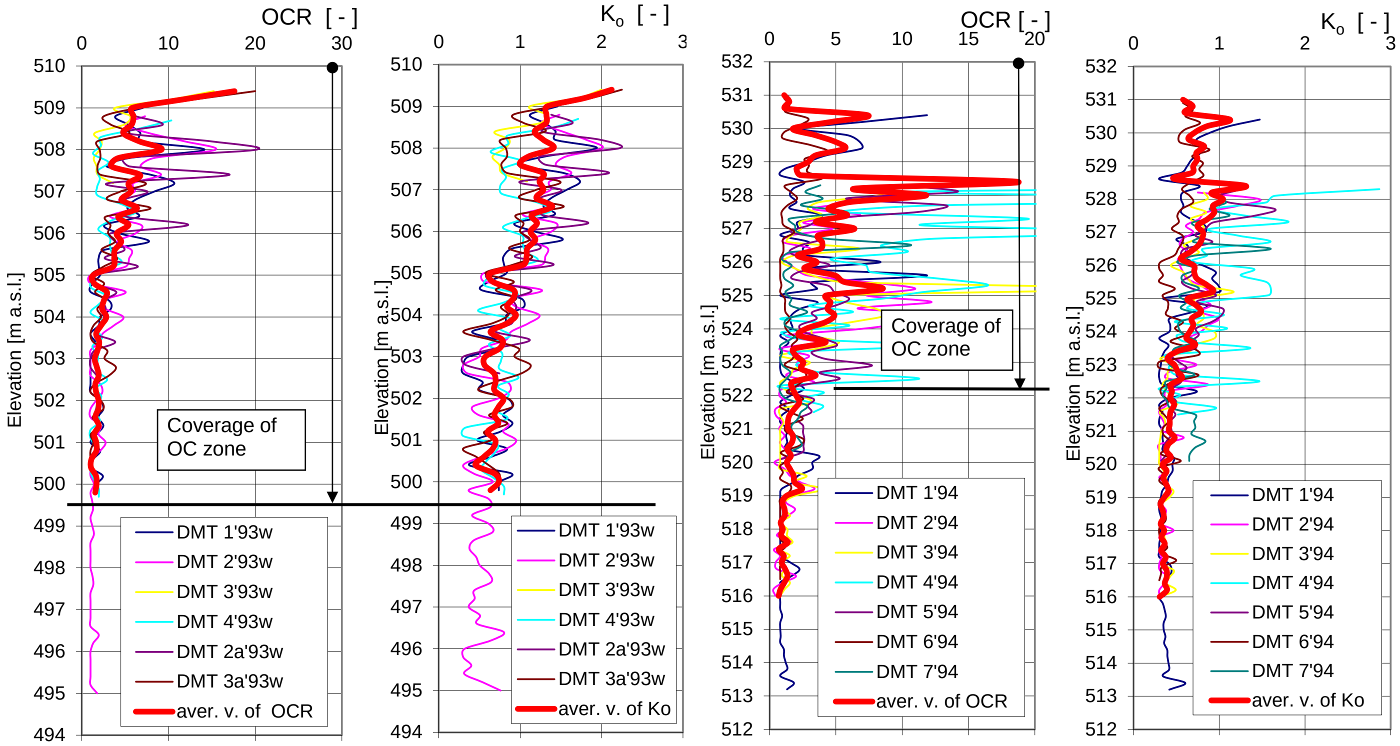


Fig. 7. Example of DMT results (performed during construction of Czorsztyn Dam in the years of 1993 and 1994).

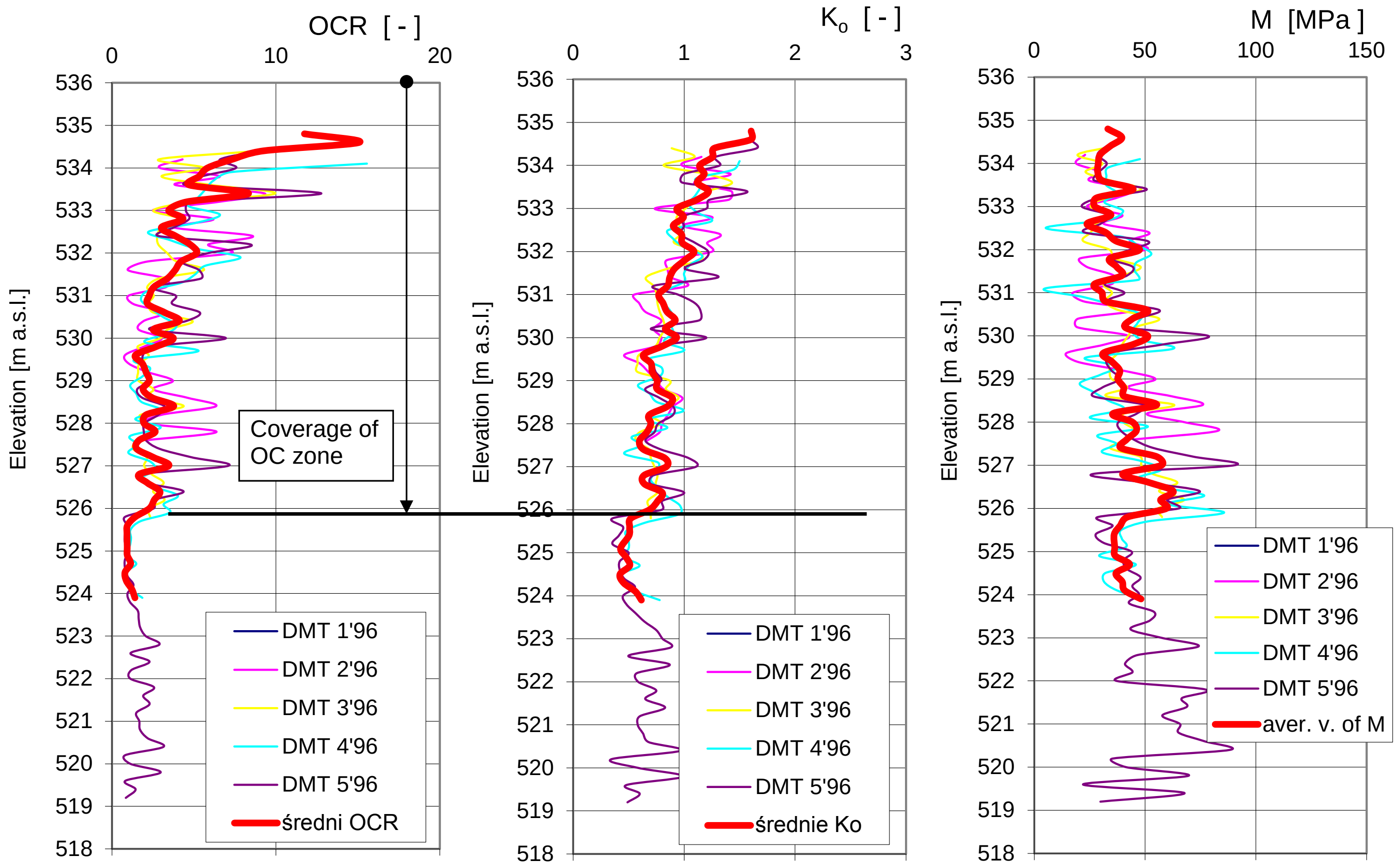


Fig. 8. Example of DMT results (performed at the end of construction of Czorsztyn Dam in the year of 1996).

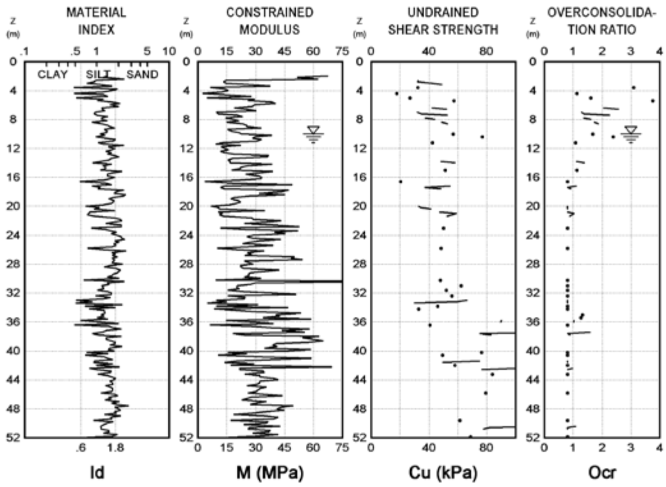


Fig. 9. Example of DMT results (performed after 10 years of exploitation of Czorsztyn Dam in the year of 2006).

## 4 STANDARD COMPACTION CONTROL AND LABORATORY TEST RESULTS

Specifications for control of compaction have been based on percentage of standard laboratory maximum dry density, that was 95 % of the maximum dry density. In the first year of the core construction (elevation 485 – 487), the soil material used was up to 5 % wet of optimum. It caused difficulties to achieve required percentage of dry density. The distribution of water content and dry density within the core estimated during compaction control tests are presented in Figs. 10 and 11.

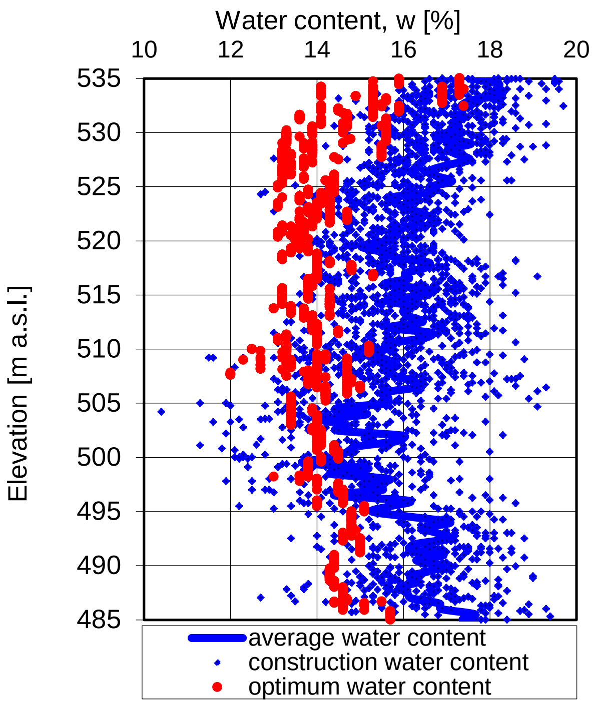


Fig. 10. Water content values of the Czorsztyn Dam core material from control compaction tests.

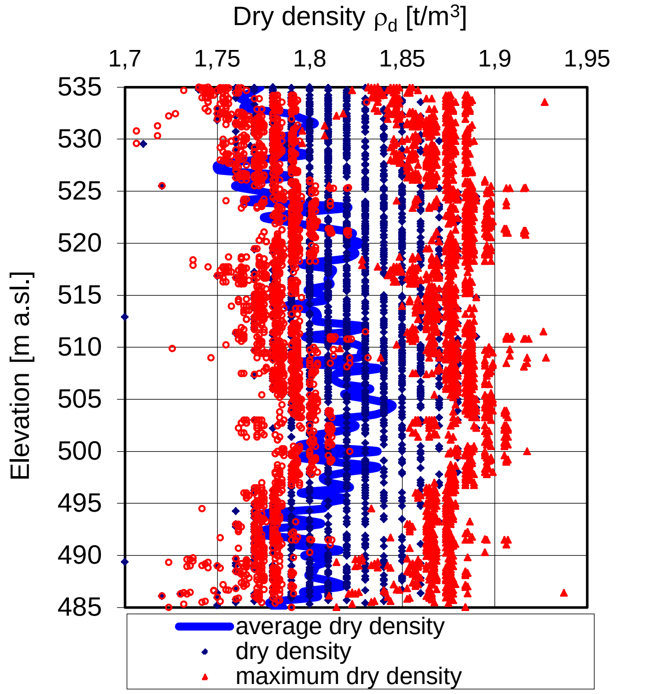


Fig. 11. Dry density values of the Czorsztyn Dam core material from control compaction tests.

In order to formulate the relationship for a wide range of compaction water content, a series of compressibility tests on laboratory soil samples as well as on field compacted soil samples (taken off from the core) have been carried out. The main purpose of oedometer tests was to determine stress - strain characteristics for compacted clay and establish relationships of initial void ratio - compactive prestress ($\sigma_{ps}$). The test results and determined relationship are shown in Fig. 12. In Fig. 13 a range of the overconsolidated OC zone of the core during construction, calculated from the equation $\sigma_{ps}' = 0.536 e_o^{-7.83}$ and determined on the basis of CPT and DMT is presented.

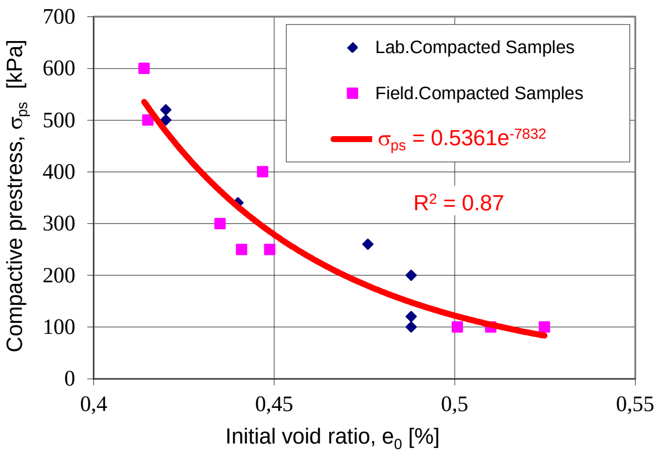


Fig. 12. Relationship between compactive presstress $\sigma_{ps}'$ and initial void ratio from oedometr tests of laboratory and field compacted soil samples (Skutnik, 2002)

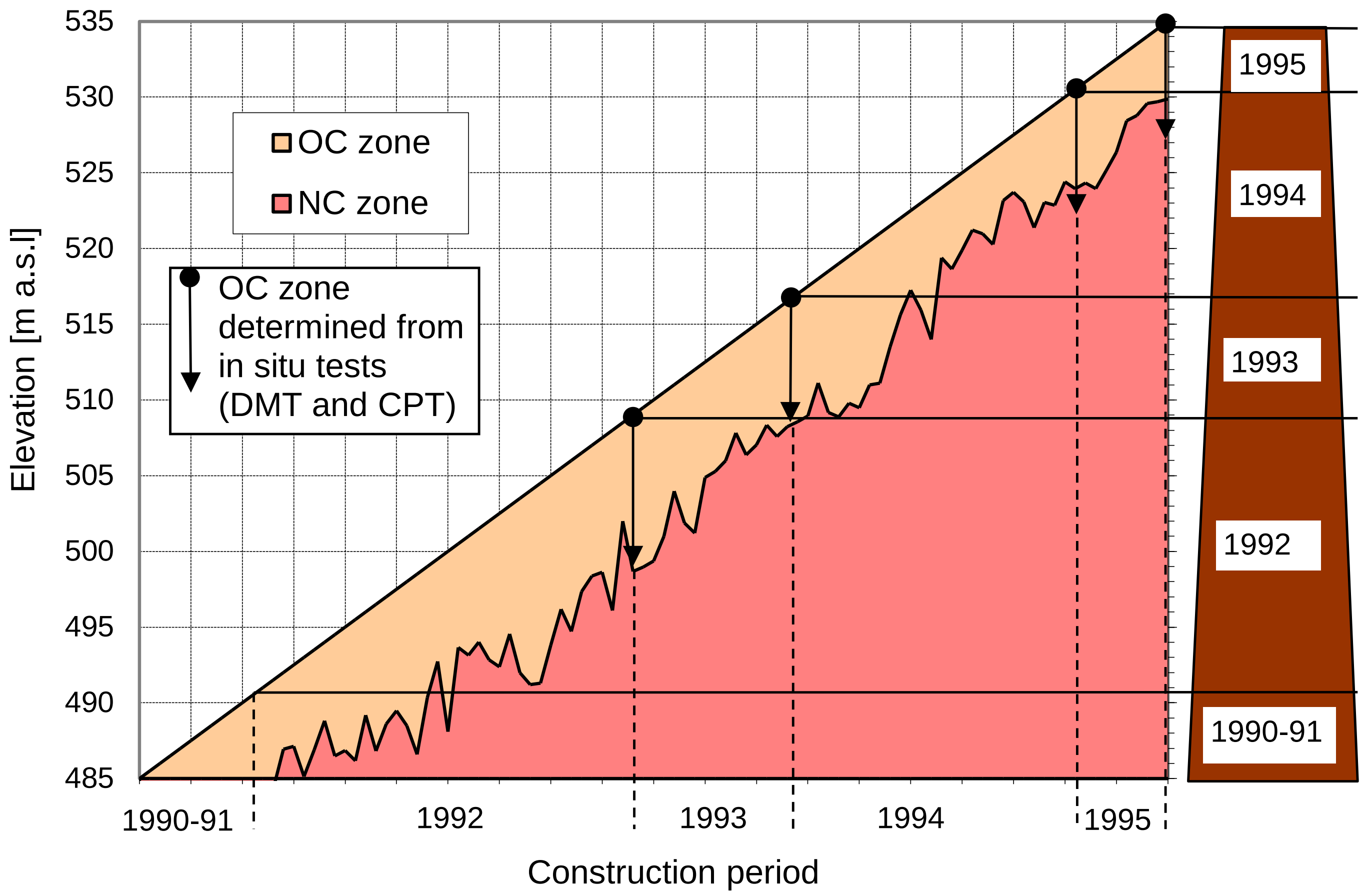


Fig. 13 Range of the overconsolidated OC zone of the core, $\sigma_{ps}$' calculated from the equation $\sigma_{ps}' = 0.536 e_o^{-7.83}$ and determined on the basis of CPT and DMT (Skutnik, 2002).

## 5 CONCLUSIONS

The safety and performance of a dam depend on both quality of the design and execution of the construction work. Comprehensive field control during construction is of vital importance in order to achieve a safe structure. However, reliable field instrumentation including geotechnical soundings performed during construction constitutes the best method to document satisfactory dam performance during operation.

Therefore all investigations carried out during construction stage, all records and observations gathered on site provides information for the proper prediction of the future dam behaviour.

Evaluation of the operational safety of each dam requires quantitative and qualitative information about the dam during construction, first filling of the reservoir and during subsequent operation of the reservoir. Measurements provide the inputs for both engineering design and theories, which tell us whether our design and theories work in practice (DiBiagio, 2000). Measurements during construction may also be required to verify whether the project is being carried out according to the contract specification. The use of instrumentation to monitor and control construction activities is the most common application of all type field measurements.

In the paper a part of methodology of determination of the clay core characteristics of the Czorsztyn Dam and Świnna Poręba Dam is presented. It consists of chosen result of DMT tests carried out during construction phase and laboratory tests performed on soil samples and standard compaction control test results.

On the basis of the nomogram shown in Fig. 13 it can be determined how deep the clay core is prestressed due to compaction, which depends on the initial parameters (water content, as compacted void ratio) of the compacted soil and compaction conditions (compaction energy). Two zones in the clay core can be distinguish: prestressed (overconsolidated) OC and normally consolidated NC. The prestressing effect may be observed in the upper part of the core were overburden stress is lower than the compactive prestress $\sigma_{ps}$. The OC zone is going up with the progress of earthworks as shown in Fig. 14.

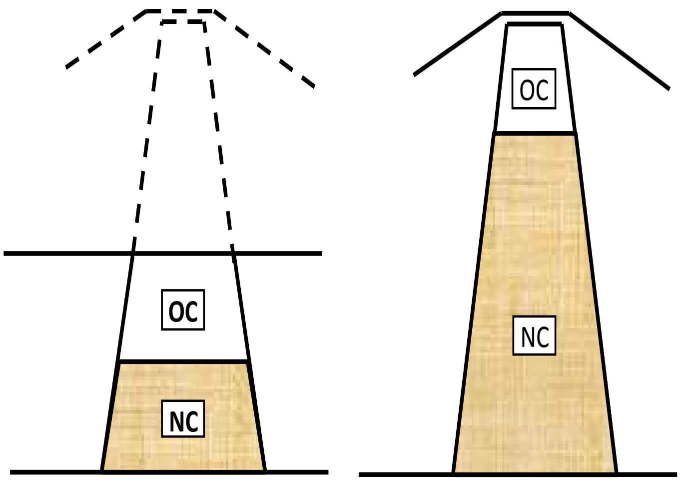


Fig. 14 The movement of prestressed (overconsolidated) OC and normally consolidated NC zones of the core during construction

Geotechnical in situ investigations especially soundings DMT (described in the paper) and others like CPT or BAT tests can be used for estimation and verification of the dam core geotechnical parameters (Skutnik, 2000). The main idea of this way is to cover the whole dam core body and exchange the point measurements into tested profiles. Additionally it allows distinguishing in the core zones of uniform parameters that considerably improve the accuracy of numerical calculations. The determination of shear strength parameters as well as the deformation and hydraulic parameters for in situ stress-state conditions allows to estimate the performance quality of the dam properly and to predict future behaviour. Soundings' profiles allow us to assess homogeneity (monolithicity) of the core that inform us whether there are no gaps or delamination in the core there and enables us to identify any "weaker" zone.

By taking it into account in laboratory tests and in numerical calculations it has been allowed to explain the number of problems on the interpretation of readings of monitoring system installed within the dam for measurement of pore water pressure changes, earth pressure, vertical and horizontal displacements.

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