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GEOTECHNICAL AND GEOPHYSICAL METHODS FOR CHARACTERISATION OF THE SOIL AND ROCK DESIGN PARAMETERS IN MASS MOVEMENTS' AREAS

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Abstract. Paper is based on author research and ISC-2, the International Site Characterisation Conference, organised by International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), TC-16 *in situ* Testing, University of Porto (FEUP), International Society of Rock Mechanics (ISRM), International of Association Engineering Geology (IAEG), Geo-Institute of the American Society of Civil Engineers (ASCE), Portuguese Association of Engineers (OE) and British Council (BC), in September 19–22, 2004 in Porto. New geotechnical and geophysical investigations of soils, with special attention given to the CPTU tests, as geodynamical, mass movements and seismic risks presented at the Conference, are reviewed in the paper. Some conclusions from ISC-2 are also included.

Key words: soil investigations, CPTU tests, mass movements risks.

Abstrakt. Artykuł oparto na badaniach autora oraz na wnioskach z międzynarodowej konferencji ISC-2, International Site Characterisation Porto 2004, zorganizowanej przez International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), TC-16 *in situ* Testing, Uniwersytet w Porto (FEUP), International Society of Rock Mechanics (ISRM), International of Association Engineering Geology (IAEG), Geo-Institute of the American Society of Civil Engineers (ASCE), Portuguese Association of Engineers (OE) oraz British Council (BC), w dniach 19–22 września, 2004 w Porto. Konferencja dotyczyła nowych geotechnicznych i geofizycznych metod badań gruntów oraz zagrożeń geodynamicznych, osuwiskowych i sejsmicznych.

Słowa kluczowe: badania gruntów, testy CPTU, ruchy masowe.

REPORT FROM ISC-2 CONFERENCE

The conference was organised by the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE), TC-16 *in situ* Testing, University of Porto (FEUP), International Society of Rock Mechanics (ISRM), International Association of Engineering Geology (IAEG), Geo-Institute of the American Society of Civil Engineers (ASCE), Portuguese Association of Engineers (OE) and British Council (BC), in September 19–22, 2004. A total selection of 219 technical papers from over 40 different countries addressed methods of site exploration to help exchange ideas and geotechnical knowledge between geologists and civil engineers.

Investigations presented at the conference were performed on slopes, foundations, mines, dams, transportation, environmental issues and others. They included geotechnical and geo-environmental problems connected with geodynamical, mass movements and seismic risks. Soils and rocks have wide range of stiffness and design parameters. Some methods of investigations could be used for cohesive soils only, other for rocks. Presented projects represent all types of soils from soft soils to stiff rocks, including polluted soils. They covered cohesive and not cohesive soils, sedimentary rocks (shale, limestone, sandstone), igneous (tuff, granite) and metamorphic rocks (schist, phyllites) and nontextbook geomaterial.

The papers were divided into nine areas of interest, presented bellow:

- Mechanical *in situ* testing methods.
- Geophysical methods applied to geotechnical engineering.

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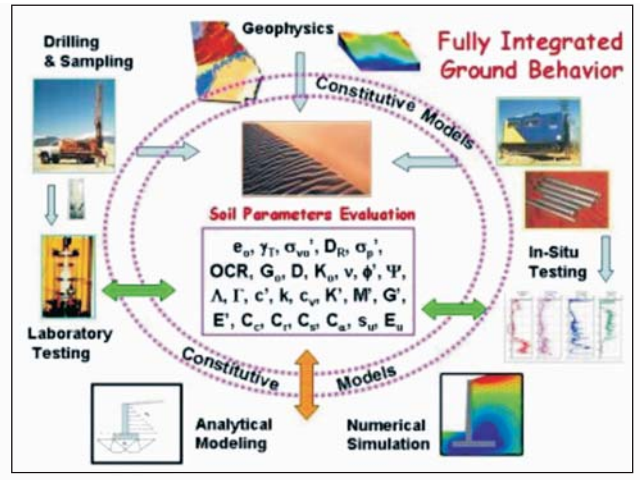

Fig. 1. Methods of ground behaviour modelling (published by P. Mayne ISSMGE, TC-16 section)

Fig. 2. ISC-2 Conference in Porto, presentation of CPTU penetrometer

- Innovative technologies and equipment.
- New developments in interpretation of *in situ* data.
- Case studies involving practical projects.
- Characterisation of nontextbook geomaterials.
- Applications to geotechnical structures.
- Enhanced characterisation by combined *in situ* testing.

Topics presented at the conference included application of rotary or percussive drillings, sampling and coring techniques. Particular interest was shown in the variety of *in situ* tests, including standard penetration (SPT), cone penetration (CPT), flat dilatometer (DMT), pressuremeter, vane shear (VST), piezocone (CPTU), seismic cone (SCPTU), dynamic penetrometers (DPT), borehole shear (BST), plate load (PLT), Swedish weight sounding (WS) and specialised tools, as well as to the geophysical techniques: resistivity surveys, surface waves cross-hole, down hole, electromagnetic conductivity and ground penetrating radar (GPR). Special attention was paid to careful and proper site evaluation, required in the analyses and designs of new structures and monitoring. In several papers, a combined approach using multiple methods and complementary set of geotechnical and geophysical tests was discussed. These combined methods were proposed to ascertain the reliable characteristics of the ground. Usage of these different types of *in situ* and laboratory tests, connected with numerical simulations, should allow for predicting fully integrated ground behaviour (Fig. 1).

Numerous projects included interpretation of the CPTU tests. New cones were proposed. One of them was T-bar cone for soil flow modelling (Fig. 2). These types of investigations are now conducted in Australia and Sweden (SGI). New types of cones with video-camera (Baillot *et al.*, 2004) and for geo-environmental or chemical tests were also developed. Drilling with fully automatic acquisition of rotation speed, drilling resistance and other parameters could deliver a lot of useful data on the rocks mechanical parameters (Möller *et al.*, 2004; Rahardjo *et al.*, 2004). Also some new methods of seismic investigation for geotechnical purposes were presented.

NEW METHODS OF THE *IN SITU* SOIL AND ROCK CHARACTERISATION SUITABLE FOR MASS MOVEMENTS AREAS

Many new methods or new devices are now available for ground parameters characterisation. In the mass movements areas, the appropriate types of investigations should be used for each case. Different types of investigations should be applied for clays, rocks or for mixed cohesive and rocky soils, such as flysch deposits. The *in situ* investigations, presented at the conference, were performed in all soils types, from soft cohesive deposits to hard rocks, including the polluted soils and geo-environmental tests. They included new CPTU tests types and new devices for these tests: CPTU during drillings (CPTDW, Figs. 3, 4), new methods of the drilling parameters acquisition and new types of equipment which enables lithology observation within the drilled holes. New geophysical methods and equipments for *in situ* geotechnical site characterisation were also presented. New types of the seismic cones (SCPT) were developed. New drilling parameters monitoring techniques were proposed (DPR). This method and CPTWD method could help to investigate soils where it is difficult to perform *in situ* tests, especially in the mixed cohesive and rocky soils or with rocky sublayers.

Drilling with fully automatic acquisition of the advance rate, downthrust and pull-up pressures, rod torque, rotation rate, mud/water pressure flow, depth and time could deliver useful data on the rocks mechanical parameters. Drilling parameter recorders (DPR) are the computerised systems which monitor a series of sensors installed on standard drilling equip-

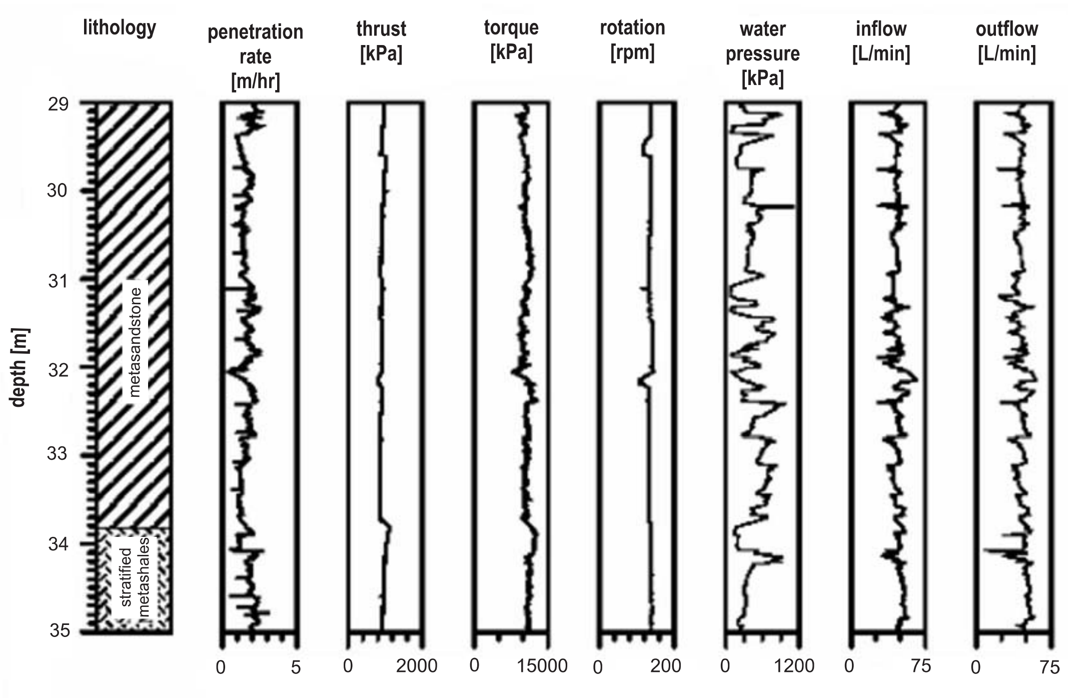

Fig. 3. Results of MDW — monitoring in a drilled hole

ment. These sensors continuously and automatically collect drilling parameters . Using DPR measurements and variations of the drilling parameters, the presence of fractures, changes in lithology and competency of the bedrock could be discovered.

Variation in the advance rate could suggest a change in stratigraphy, fracture or cavity. Higher torque value indicates harder material or badly fractured rock while a lower torque would indicate the presence of fracture. The penetration rate increases within the soft rocks such as for example shales and is lowering in hard sandstones. It will also be varied in soils occurring inside a landslide area or in a bedrock. The water pressure and flow measurements can also be used to estimate the location of fractures and sliding surfaces (Möller *et al*., 2004).

Fig. 4. CPTDW equipment

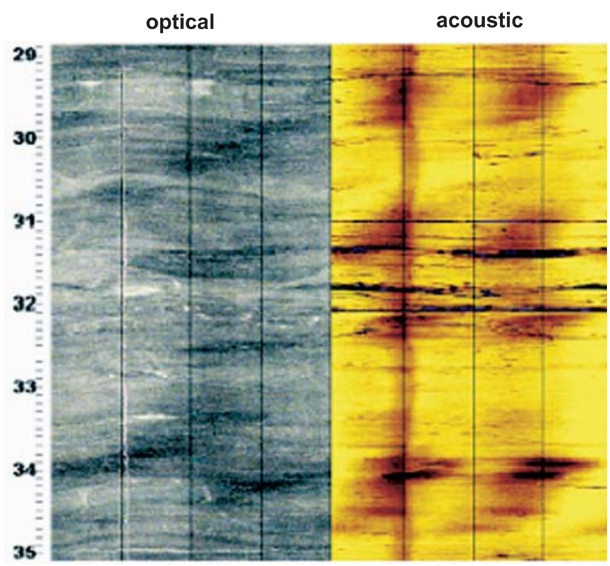

Fig. 5. DPR measured parameters and lithology

CPTWD method is based on the wire-line drilling system, piezocone and MDW-monitoring during the drilling. During the test, a cone is protruding in front of the drill bit in the same way as a corer. The CPTU data are stored in a memory unit. At the same time as the CPTU data are logged, drilling parameters (MWD) are also recorded. The system allows for the change between CPT testing, continuous core drilling, down-hole testing and non-coring drilling with MWD. The combination of CPT parameters and drilling parameters could be basis for interpretation of the data. The advantage of this system compared to the other down hole type CPTU is that much longer strokes than the normal 1.5 m to 3 m can be made. The information from the drilling parameters could be useful, especially in hard soils or rocks where CPTU cannot be performed. It is planned to add new tools to this system, such as field vane test, permeameter, fluid sampler, thin wall samplers and dilatometer DMT.

For the rock parameters investigations, also special video cameras to let down into the drilling hole could be used. Results of such test are presented on Figure 5. They present a comparison between (DPR) parameters results (optical and special acoustic sensor) and lithology described from the drilling hole profile.

Geophysics traditionally has been used as an indirect means of targeting and dimensioning sub-surface features. This application has its origin in oil and mineral exploration. Until recently, it has been only marginally successful in the engineering site investigation. That was mainly due to the lack of resolution and poor choice of geophysical technique. At the conference, new interpretation methods of the geophysical seismic investigations used for geotechnical purposes were presented. Special attention was paid to geophysical prospecting using the surface and shear waves. It was concluded that interpretation of the seismic waves propagation could be useful for the prediction of the soil design parameters. Presented research included interpretation of signal/noise relation and its influence on the results.

Attention was also paid to the tests deeper than 60 m and to the geophones distance/seismic wave velocity relationships (Park, 2004). Geotechnical characterisation based on the methods of the impact energy generation for the surface waves was used for seismic sites. It included the borehole blasting, SPT as a source, use of special surface wave generator, or the use of a hammer. It has been found that the field information is more suitable for exploring the properties of the deep laying material and that it provides more precisely spatially localised data usually affected by lateral heterogeneity existing between the source and the receivers.

The computed shear wave velocity profiles have went down to about 60 m depth with the use of short (2 m) receivers spacing (*op. cit.*). The performed interpretation of the surface waves have reached the depths of between 100 and 300 m within an urban area when the impact energy generated by SPT was used. This method is a combination of SPT and geophysi-

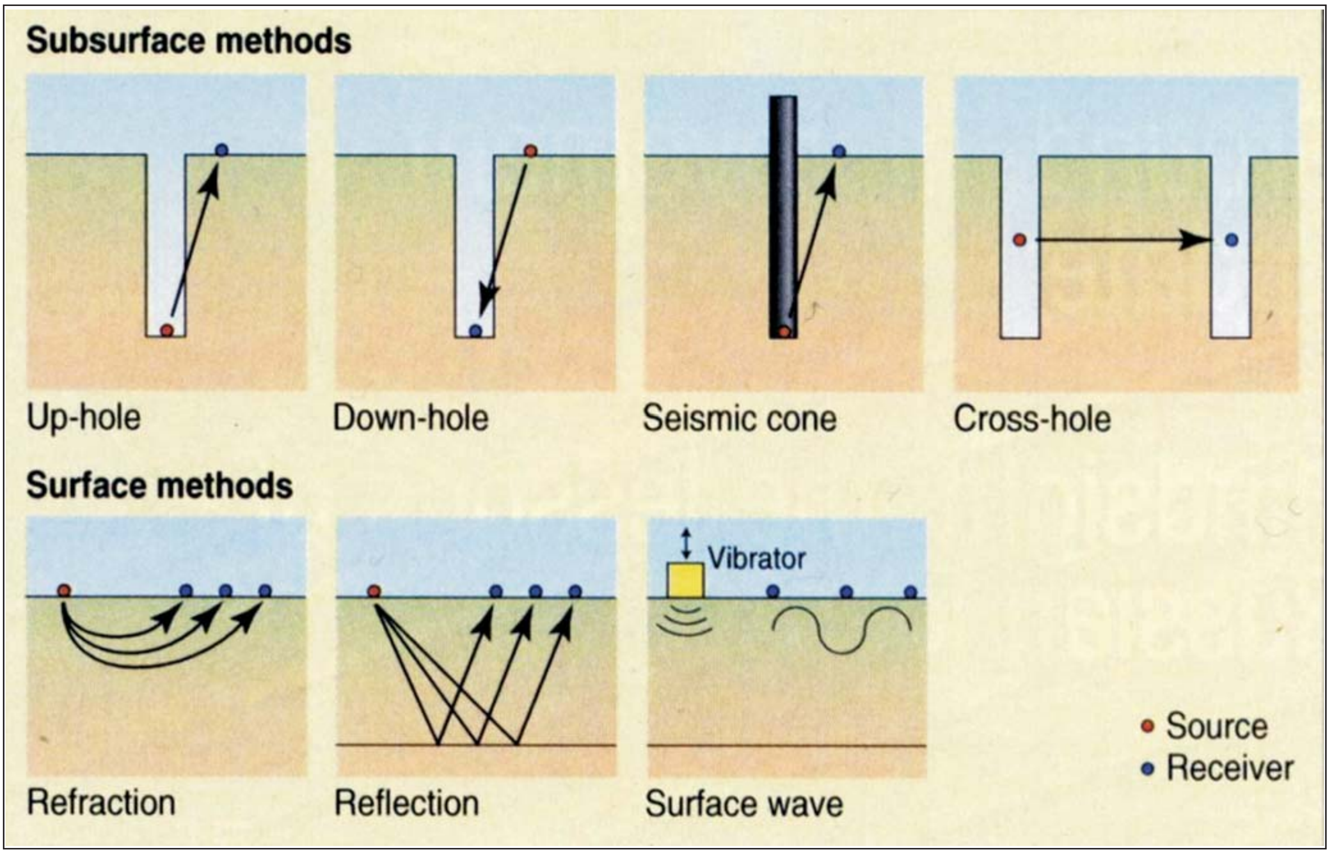

Fig. 6. Different types of subsurface and surface methods for hardness determining

Fig. 7. Seismic velocity measurement

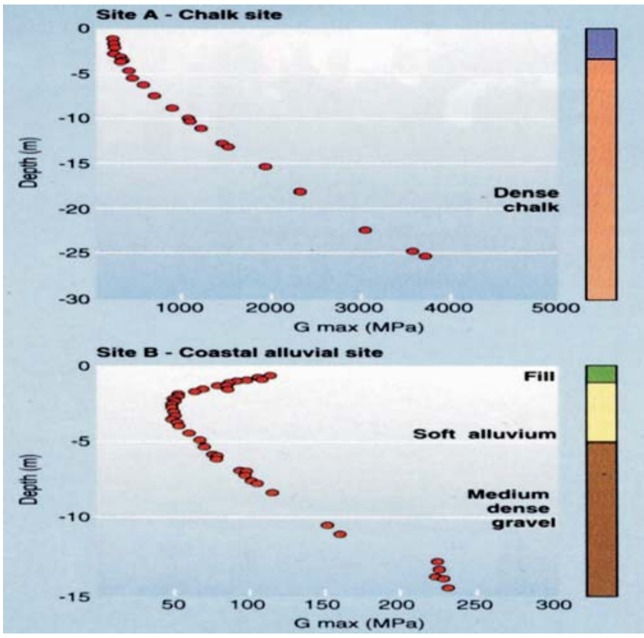

Fig 8. Hardness profile from seismic velocity measurements

cal prospecting and could obtain both the blow counts and the shear wave velocity profiles with the use of the same test. During these combined tests, it was possible to obtain lithological profile as well as geotechnical parameters from SPT and from geophysical prospecting.

The recent developments in the laboratory small strain hardness measurements and the use of non-linear finite element analyses have closed the gap which had been thought to exist between static and dynamic measurements of the hardness. This has enabled the determination of the hardness parameters from the seismic velocity measurements (Figs. 6–8). Using the theory of elasticity, the shear wale velocity, shear modulus G and the surface settlement can be determined to the depths of between 10 m (in clays) and 30 m (in some granular soils and weak rocks) from the velocity measurements without the need of a borehole. Also some new techniques of performing *in situ* tests, including pressuremeter tests, were presented at the conference. They included new types of sensors and soil flow modelling around pressuremeter (Bello *et al.*, 2004; Mayne, 2004), including the use of additional membranes in DMT pressuremeters.

METHODS OF THE *IN SITU* AND LABORATORY TESTS COMPARISON IN COHESIVE SOILS

Comparison of the *in situ* and laboratory tests results is very important for the soil design parameters prediction, especially in soft cohesive soils which are often involved in geodynamic processes. For prediction of a mass movements in clays, CPTU tests with the reference laboratory tests could be used.

At the conference, a paper by author and R. Sandven from NTNU (Norway: *Comparison of CPTU and laboratory tests interpretation for Polish and Norwegian clays*), was presented. The reported project has covered the investigations of the Polish and Norwegian clays conducted during the research stay at the Norwegian University of Science and Technology, NTNU, sponsored by the Norwegian Research Council and NATO Advanced Fellowship Programme (Bednarczyk, 2002, 2004a, b). The use of the static sounding for the mass movements investigations in soils is not very popular in Poland, but it is widely used in Scandinavia, USA and Canada. It could be used in cohesive and not cohesive soils, including embankments. The occurrence of very hard rocks or rocky interlayers, such as conglomerates, sandstones, shales or very hard cohesive soils makes, however, limitation for this method.

On the Figures 9–13, there are presented the results of the correlation of the data obtained from the CPTU tests performed

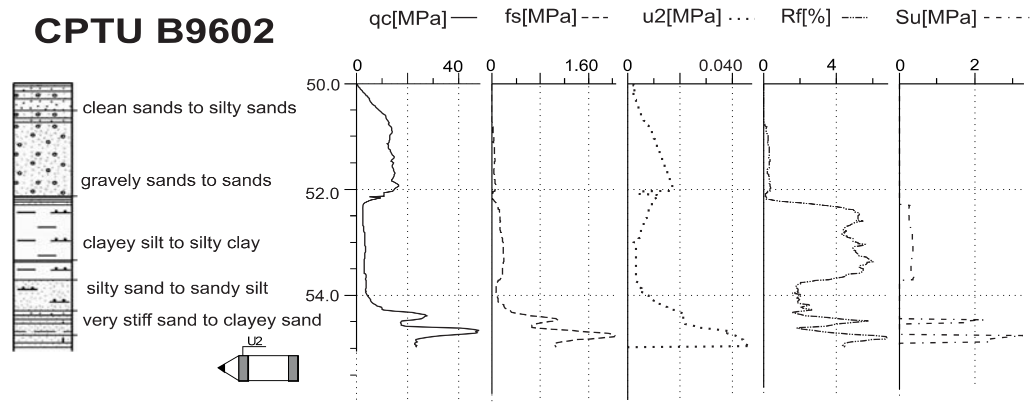

Fig. 9. CPTU test performed by author in near to a landslide on the southern slope of the Bełchatów open-pit mine 50 m below the natural terrain level

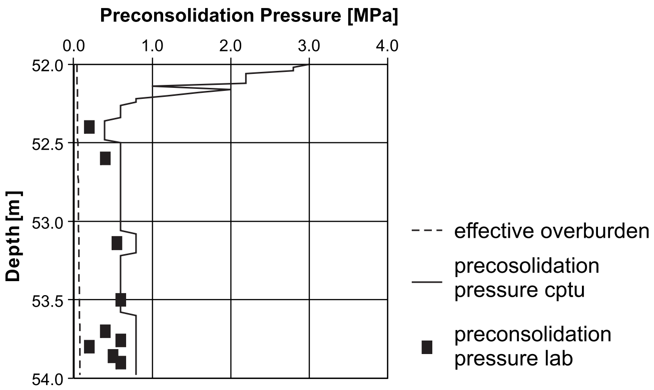

Fig. 10. Clay from Bełchatów Mine, test CPTU B9602, interpretation of the preconsolidation pressure

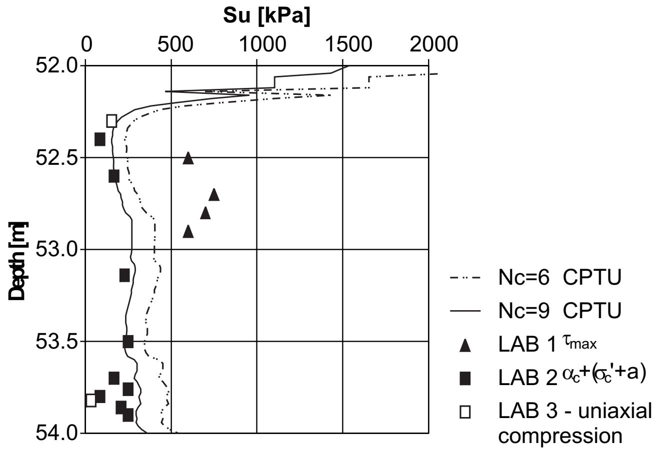

Fig. 12. Clay from the Bełchatów Mine, test CPTU B9602, undrained shear strength interpretation Su (correlation factor Nc = 6–9)

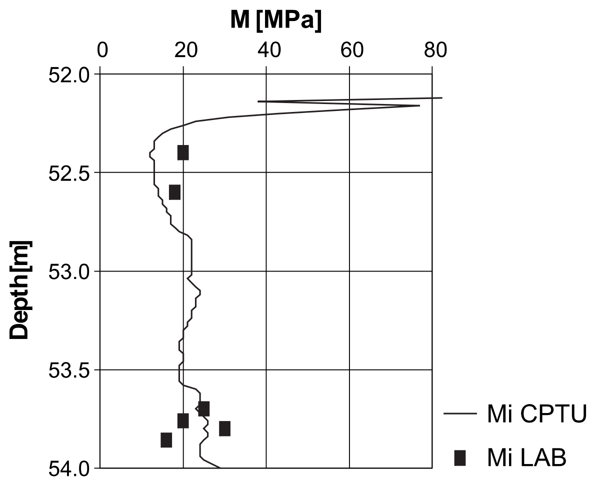

Fig. 11. Clay from the Bełchatów Mine, test CPTU B9602 B9602, interpretation of preconsolidation pressure

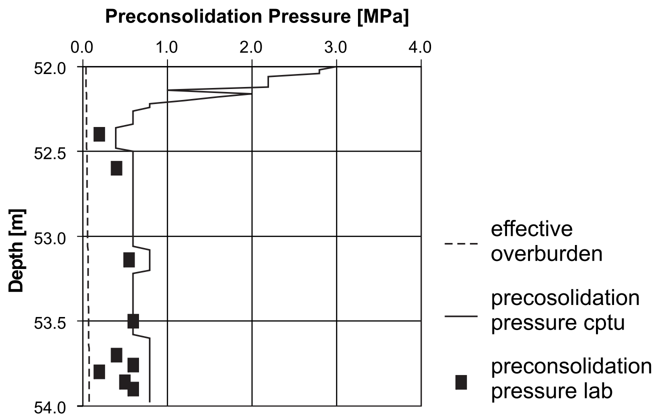

Fig. 13. Clay from the Bełchatów Mine, test CPTU interpretation of friction angle

near the landslide area in Bełchatów open-pit mine and the data obtained from the laboratory test. The CPTU tests have been carried out during the cone penetration with the constant test rate of 2 cm/s, and the measured parameters contained the cone resistance qc (MPa), sleeve friction fs (MPa) and the generated pore water pressure u2 (MPa).

The presented by author at the ISC-2 Conference comparison between the laboratory and field CPTU tests were performed on Polish and Norwegian clays for the slope stability calculations. The research had been performed within the potential landslide area in the Bełchatów open-cast mine and on the clays from Stjørdal, at the Geotechnical Department of the Norwegian University of Science and Technology NTNU, in Trondheim (Norway). The laboratory tests made in Norway concerned the soil samples from the Bełchatów mine and included: index tests, triaxial CIU and CID tests, odometer IL and CRS tests, uniaxial compression and CRS test.

The undrained shear strength S_u from the CPTU tests was calculated using the equation:

$$S_u = \frac{q_c - \sigma_{vo}}{N_c} \qquad [1]$$

where:

N_c — correlation factor

q_c — cone resistance [kPa]

σ_{vo} — total overburden pressure [kPa]

The undrained shear strength Su from the laboratory tests was calculated by three methods:

[1] using equation:

$$S_u = \alpha_c(\sigma_c' + c) \qquad [2]$$

where:

α_c — correlation factor dependent on tanφ

σ_c' — preconsolidation pressure [kPa]

c — cohesion [kPa];

(2) from the maximal shear strength max obtained from triaxial isotropic consolidated tests;

(3) from the uniaxial compression tests.

Comparison of the preconsolidation pressure from the CPTU and laboratory tests is presented on Figure 10 and the compression module Mi on Figure 11. They have very good correlation with laboratory results. Only the results of friction angle from the CPTU tests were lower compared with the laboratory tests (Fig. 13).

Table 1

Comparison of the soil parameters from the CPTU and laboratory tests for Polish and Norwegian clays

Parameter	Polish clay	Norwegian clay
Soil type	hard over consolidated clay	over consolidated clay
Undrained shear strength Su[kPa]	250–500 (good correlation)	80–100 (good correlation)
Preconsolidation pressure σc'[kPa]	500–600 (good correlation in test B9602; lower values in test B9603)	200–300 (slightly lower values — CPTU)
Over consolidation ratio OCR [–]	6–8 (good correlation)	5–4 (lower values — CPTU)
Compression module in over consolidated range Mi[kPa]	20,000–30,000 (lower values — CPTU)	7,000–8,000 (slightly higher values — CPTU)
Friction angle tanφ [–]	0.6–0.7 (lower values — CPTU)	0.2–0.4 (good correlation)

SUMMARY AND CONCLUSIONS

1. In the paper, a report from the International Site Characterisation Conference ISC-2, Porto 2004, organised by ISSMGM was presented.
2. At the ISC-2 Conference in Porto, new investigation methods and new types of equipment were described. During that conference, a paper by Bednarczyk and Sandven (2004) from NTNU (Norway) Comparison of CPTU and laboratory tests interpretation for Polish and Norwegian clays was presented.
3. New geotechnical and geophysical methods of soil and rock design parameters characterisation could be useful for the mass movements areas investigations.
4. The projects have been dealing with all types of soils, from soft cohesive to hard rocks and were including the polluted deposits, too.
5. Special respect in the interpretation of the mass movements geotechnical investigations should be paid to *in situ* geotechnical site characterisation and to comparison of its results with the laboratory tests.

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