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Discussion Session1.1: Field investigations

Séance de Discussion 1.1: Investigations en place

K. Rainer Massarsch[1]
Geo Risk & Vibration AB, Solna, Sweden

ABSTRACT

The role of field testing is reviewed, considering in particular the geological and geotechnical setting of the European continent. The papers submitted to this session were reviewed. Eurocode 7, 1997 - 2 outlines methods and data evaluation for field testing. Topics of papers of particular relevance to this session are discussed.

RÉSUMÉ

Le rôle des essais en place est revu, compte tenu en particulier le contexte géologique et géotechnique du continent européen. Les documents soumis à cette séance ont été revus. Eurocode 7, 1997 - 2 décrit les méthodes et l'évaluation des données pour des essais en place. Sujets des contributions d'un intérêt particulier pour cette session sont discutées.

Europe, field investigation, testing, ground improvement, in situ, static, seismic, penetration testing, pressuremeter.

1 INTRODUCTION

Geotechnical field testing plays an important role in geotechnical engineering which can comprise construction work below, in or on the ground, when using ground as construction material or for assessing groundwater conditions. Field investigations are needed as basis for geotechnical design (*functional* design), execution of construction work (*process design)* and control of construction execution (*performance monitoring)*. In addition, and not least, geotechnical field investigations provide essential information for geotechnical research and development work.

Geotechnical field investigations are difficult to perform in most soils, but especially complicated in stiff soils and soft or fractured rock – the topic of the present conference. These aspects are reflected by the papers submitted to this session. In order to appreciate the specific requirements of field investigations in Europe, some important aspects will be briefly discussed and can provide useful background information.

1.1 European Setting

Europe is a small continent with an area of less than 10 million km^2 comprising 47 countries with a population of 727 million people. The European Union (EU) comprises 27 countries with a population of 500 million people, covering over 4 million km^2 of land. This region has a well-developed infrastructure. Around 40 % of

[1] Corresponding Author.

the population lives in this core area, which covers only 20 % of the territory, but accounts for 50 % of GDP per year within the EU.

An interesting feature of the European continent is its extremely long coastline, which is much longer than that of any other continent, cf. Figure 1. Many major cities and industrial regions developed in or near coastal areas. This aspect has had a decisive influence on the construction techniques required for bridges, harbor structures and the development of the transportation infrastructure.

Figure 1. Topographical map of Europe from www.google.com.

1.2 Geological Conditions

Europe has a complex geology, which is illustrated by a map of the continents pre-quaternary geology, Figure 2. The oldest geological regions are found in the north-eastern part of Europe, dominated by the Fennoscandian (or Baltic) shield which includes Norway, Sweden, Finland and the north-western part of Russia. Most of Scandinavia is covered by moraine. Glacial erosion has reshaped the surface layers of Scandinavia and the northern areas of central Europe and the British islands, with glacial and post-glacial deposits in valleys and depressions. Deep fjords towards the west and an extensive archipelago, with numerous small islands towards the east, characterize the coastal regions of Northern Europe.

The flat areas of the Scandinavian and Baltic region, the Kola peninsular and Karelia were exposed to glacial erosion and are characterized by numerous lakes. The flat areas of southern Sweden and most of Denmark belong geologically to the Central and Western European morphological zone, characterized by moraine deposits and glacial riverbeds, filled with post-glacial deposits. The central and northern areas of Europe are drained by large rivers, flowing in shallow valleys, such as the Wisla, Elbe and Rhine.

Figure 2. Geological map of Europe. Published with the permission of BGR. Copyright BGR, [1].

Towards the south dominate moderately high mountains, plateaus and rolling hills. In the west, several large basins (London-, Aquitaine- and Paris basin) are drained by large rivers, such as the Thames, Garonne, Loire and Seine. Ridges of sedimentary rock (Cuesta landscape) form undulating landscapes, which are typical for the London and Paris basin as well as in southern Germany. The Central Massive is located to the east of the Aquitaine basin, with extinct volcanoes and carstic lime stone regions.

The eastern flat lands from the Baltic to the Ural mountain range are the largest flat areas of Europe, usually with elevation below 200 m high. The northern plateaus are characterized by moraine and ice-age deposits, while the southern regions are dominated by eolian (loss) soils. Large rivers drain these areas towards the north and the south. The Caucasus mountain range and the Caspian Sea create the southern boundaries, while the Ural mountain range defines the eastern boundary.

The central European region is dominated by the Alps and the Alpine Foreland. The Bohemian mountain range to the east changes gradually into the Carpathian Mountains. The river Rhine and its tributaries drain the Alpine Foreland towards the north, along occasionally deep valleys. The Alpine region was glaciated and is characterized by U-valleys, lakes and major moraine deposit. At the eastern boundary of the Alps is located the Vienna basin, which was formed during the tertiary period. It is composed of deep sedimentary deposits of dense gravel, sands and stiff clays and marl (Wiener Tegel). The basin continues towards the east into the Hungarian and Romanian low lands. The Danube River and its tributaries drain the central European region towards the east.

Southern Europe consists of three major peninsulas and a large number of larger and smaller islands. The Iberian Peninsula is to a large extent a high plateau, which is limited to the north by a mountain range (Pyrenees). Lowlands are found along the major rivers. The Apennine peninsular is dominated by a north-south oriented mountain range. The river Po flows from west to east across northern Italy and passes through many major Italian cities. The estuary creates a wide delta region with many channels. In the southern part if Italy several active volcanoes (Etna, Stromboli) are located. Also the Balkan region is mountainous with extensive carstic regions. The southern and eastern European region is a highly active seismic zone. The Mediterranean coastline is very variable, with several large mountainous islands (Crete, Malta, Sicily, Corsica and Sardinia). Iceland and the Faroe Islands are of recent volcanic origin where basalt has formed large plateaus. Central Iceland is an active volcanic region with a large glacier in the southeast. Large sand deposits exist along the southern coast.

1.3 Geotechnical Conditions

The climatic changes during the Quaternary period have influenced the geological and geotechnical conditions of today. In particular, the most recent glacial period, which ended about 10 000 years ago, has had a fundamental impact on the geological and geotechnical conditions in Europe. The northern hemisphere and the Alpine region were then covered by 2 – 3 km of ice. As a result of the action of the advancing glaciers the surface was reshaped and soil transported over large distances, creating different types of moraines. Moraine deposits can be found in all areas, which have been covered by glaciers. Their granular composition can vary considerably but moraine deposits are usually dense and overconsolidated. Early Holocene conditions seem to have been slightly warmer than at present, peaking around 8,000-5,000 years across central and northern Europe. During the glacial and post-glacial period, glacial rivers transported large quantities of sediments towards the cost, where they were deposited as very loose sands, silts and clays. Eskers are an important geological feature, which can cause significant geotechnical problems. Eskers are only found in areas that were once glaciated. Because they were created by glacial meltwater they tend to meander across the surface and may resemble the drainage patterns of rivers and streams of today.

1.4 Stiff Soils from Ground Improvement

This conference focuses on geotechnical problems in hard soils and weak rocks and most papers submitted to this session address problems in such ground conditions. However, it is not appreciated that soft soils improved by different ground improvement methods, such as deep mixing, have similar geotechnical properties. Figure 3 shows a machine using dry mixing of cement and lime to improve very soft and compressible soils, which are frequently encountered in the Nordic region. Such soft clays have typically an undrained shear strength below 10 to 15 kPa, and a natural water content in excess of 50%. By mixing about 10 to 20 kg of dry agent mechanically with the soft soil in-situ, the undrained shear strength is usually increased to over 150 kPa and more. The application of deep mixing in Europe has been described in a Regional Report ion deep mixing [2].

Figure 4 shows the ground surface of an area of soft, sensitive clay, which was improved by dry lime-cement mixing using equipment shown in Fig. 3.

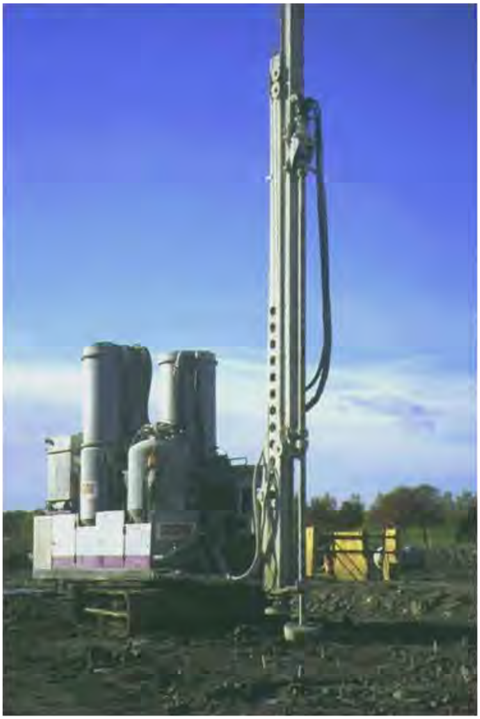

Figure 3. Deep dry mixing equipment, mixing tool and base machine with containers for supply of binder (cement and lime).

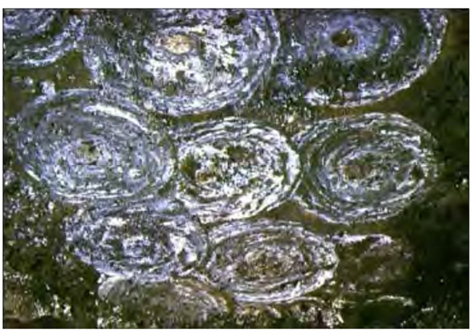

Figure 4. Block type pattern in dry mixing with overlapping columns. Undrained shear strength prior to treatment below 15 kPa and after treatment typically in excess of 150 kPa.

Testing of blocks of stabilized soil is an important aspect of geotechnical design. Special testing tools have been developed, similar to vane and push-in and pull-out penetrometers [2]. Also, seismic methods have been employed to determine the stiffness of individual columns and of blocks of improved ground [3].

It is apparent that the strength and deformation properties of improved ground is similar to that of stiff and hard soil occurring naturally. It is unfortunate that not a single paper submitted to this session addressed this aspect of geotechnical field testing.

2 EUROPEAN STANDARD - EN 1997-2

Geotechnical design and investigation procedureds in the EU are governed by the European standard, Eurocode, EN 1997. Eurocode 7 - Geotechnical design - Part 2: "Ground investigation and testing" was approved by CEN on 12 June 2006, [3]. CEN members are bound to comply with the standard comprising the national standards bodies of: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

EN 1997-2 gives guidance for the planning and interpretation of geotechnical laboratory and field tests that are used for the support of geotechnical design of buildings and civil engineering works. EN 1997-2 is intended for clients, designers, geotechnical laboratories, field testing laboratories and public authorities. This document gives no specific provisions for environmental ground investigations. Only commonly used geotechnical laboratory and field tests are covered in this standard. These were selected on the basis of their importance in geotechnical practice, availability in commercial geotechnical laboratories and existence of an accepted testing procedure in Europe. Section 1.8 defines the symbols and units to be applied. Of particular relevance is the list of abbreviations of field investigation methods. The standard discusses in detail the planning of ground investigations, their objectives, sequence of ground investigations during different project phases. Table 2.1 gives a Simplified overview of the applicability of field investigation methods and discusses the application of different methods at sites with rock, coars and fine soil. Section 4 of the standard is of particular relevance as it discusses field investigations in soil and rock, the following investigation methods are of direct relevance for this session: borehole jack test (BJT); cone penetration and piezocone penetration tests (CPT, CPTU), dynamic probing tests (DP); field vane test (FVT); flexible dilatometer test (FDT); flat dilatometer test (DMT); ground water measurement (GW), measuring while drilling (MWD); plate loading test (PLT); pressuremeter tests (PMT); rock dilatometer test (RDT); seismic measurement (SE); soil/rock sounding (SR); standard penetration test (SPT); weight sounding test (WST).

It should be noted that EN 1997, Part 2 does not address geophysical methods.

3 SCOPE OF SUBMITTED PAPERS

Considering the relatively large areas of Europe which are covered by stiff and hard soil and soft rock it is surprising that not more papers have been received. Issues arising during field testing of improved ground have not been addressed in any of the submitted papers.

Seventeen papers from 16 countries, one from outside Europe (Brazil), were submitted to Session 1.1. The papers deal with the following issues:

- Site characterization based on cone penetration testing (CPT).
- Improvement of SPT testing method (energy control) and correlation of N-value with soil properties.
- Computer-aided recording of dynamic penetrometer (DP).
- Extended application of measuring range of Pressuremeter (Hyperpac 25 MPa) (PMT).
- Seismic measurement (SE) for geophysical site characterization and interpretation/application of test results.
- Study of groundwater and hydraulic conditions by in situ measurements.
- Recording of drilling parameters and correlation with SPT.
- Biolocation method – detecting fractured zones in rock.

It is noted that many of the papers submitted to the session did address field testing issues either in passing or not at all. Although the presentation of case histories and the role of field testing is an interesting and important aspect of geotechnical design, many papers were barely relevant for the session. The applications of field testing to case histories can be grouped as follows:

- Dam site investigations: permeability and geological formations.
- Stabilization of natural slopes and excavations.
- Infrastructure projects: tunnels and roads.
- Hard concretions and litified beds.
- Stabilization of gravel deposits by microoranisms.
- Tank foundation on soft ground
- Soil anchors.
- Landslide stabilization.

4 DISCUSSION OF IMPORTANT PAPERS

The objective of this discussion paper is not to deal with every paper submitted to this session. Rather, an effort is made to address some of the important issues and developments in the area of field testing.

4.1 Penetration Testing

Several papers describe the application of penetrometers. The paper by Herrmann et al. [5] describes the development of a computer-controlled recording and data acquisition system for the DP to eliminate the influence of operators logging the data manually. In contrast to the standardized method of recording the penetration resistance, in this study an approach is used which defines the penetration resistance N_{10}^{*} =

10 / e, where e = cm of probe penetration per blow). This approach of measuring the penetration resistance is used in some countries (North America etc.) in connection with the light penetrometer and correlations have been developed with soil type and soil stiffness. Although the paper describes a practical application of the system, it would have been valuable to discuss the advantages of this method of data interpretation compared to the method outlined in the European Standard.

Lukiantchuki et al. [6] describe the development of an instrumented subassembly for energy measurements in SPT tests. Although this approach is not novel and similar concepts have been described in the literature, the paper presents useful information on the practical application. The authors confirm that energy correction must be used to determine the energy ratio, mainly in the case of soil showing low *NSPT* index.

The paper by Plytas et al. [7] describes a simplified empirical relationship that correlates the undrained shear strength (c_u) of cohesive formations and the 'as-measured' SPT blowcount (N). It is concluded that a unique correlation does not exist between N-values and the undrained shear strength. The c_u/N ratio decreases with increasing Plasticity Index (PI) and increasing natural water content.

Tumay et al. [8] discuss the effectiveness of different CPT-based classification methods for identification of subsoil stratigraphy for the assessment of subsoil stratigraphy and lithology. In the case when even genetically homogeneous layers are found in a subsoil, but are inter-bedded with soils of varying grain size distributions, then each of the systems responds differently to the identification of these interbeddings. This different reaction of the system results in the evaluation of geotechnical parameters of soils in the subsoil.

4.2 Pressuremeter Testing

The borehole expansion test can be extended to very stiff soils and soft rock by a novel development. Arsonnet et al. [9] describe the HyperPac 25 MPa, an instrument which can fill the gap of application between the Ménard pressuremeter and the flexible dilatometer. The method can be applied to any ground material, from the softer to the harder ones, so as to obtain their stress-strain behavior in situ. Results from some tests are presented which suggest that the system can be used even in slightly fractured rocks.

Baud et al. [10] present concept for soil and rock classification based on high pressure borehole. The data obtained during a borehole expansion test, from which a Ménard E-modulus and a limit pressure can be derive, offers the an overall classification ranging from loose soils to hard rock without any discontinuity.

4.3 Measuring while Drilling

In many cases, there is a need to determine geotechnical properties and soil/rock parameters in deposits which cannot be investigated by penetration testing. A promising development, which has been going on for some time in different European countries is measuring of different drilling parameters. The paper by Reiffsteck [11] describes the recording of different operating parameters of instrumented drilling machine, which can provide useful information regarding the position of transition layers of soil or rocks of different kinds. By combining these parameters it is possible to approximate the variation of mechanical and hydraulic parameters of these ground layers. Results from detailed field tests are presented and compared with Standard Penetration Test and static penetrometer profiles.

It might be useful to also record vibration propagation on the ground adjacent to the drilling rig, recording the arrival of compression waves generated by the drilling tool.

4.4 Geophysical Testing

Two papers address the potential of geophysical and seismic testing. Rocha et al. [12] describes an application, the case of volcanic massifs, where volcanic rock layers are enclosed in volcanic sedimentary deposits. In such a case the results of seismic surface methods (seismic refraction and MASW) can be evaluated by different analytical concepts. The paper describes the combined use of various surface and borehole seismic techniques, for determining the P- and S-wave seismic wave speed (velocity) profile. The advantages and limitations of the different methods are discussed.

The paper by Gasparre et al. [13] is interesting as it describes the practical application of different field investigation methods, including seismic testing. The design and construction of a tall tower with a deep basement in a densely populated urban area is described. Soil parameters were extrapolated from cross-hole tests, which were carried out with two boreholes and from the measurements of the mechanical energy, pressures and torque during drilling. The groundwater water level was found at approximately 20 metres depth. A dominant feature for the design was the presence of the conglomerate material, which was both stiff and with a relatively high strength. This affected the choice and the design of the substructure system. Finite element analyses were carried out to support the structural design of the wall and the foundation raft. Ground movements and their effects on surrounding ground and structures were also estimated. The information provided by the ground investigation allowed the design of the retaining wall and the foundation system and the selection of a construction technique that accounted for the urban context.

5 CONCLUDING REMARKS

The topic of field testing in stiff soil and rock is an important area of geotechnical engineering. There exists a gap between well-established methods for soft/loose and medium dense/stiff soils and very hard ground and rock. Some papers submitted to this session point into interesting directions of equipment development and data evaluation. New, interesting developments can be expected in the area of seismic and geophysical testing. Also, the recording of machine parameters while drilling into stiff ground has potential but additional, extensive field investigations will be required in areas with different geological and geotechnical conditions.

In conclusion it must also be stated that the quality of some papers submitted to this session does not meet the requirements of an international conference where papers are to be reviewed. The extensive use of computer-based translations has also contributed to a decline of the language standard.

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