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SITE CHARACTERIZATION IN ROAD AND RAIL TRANSPORTATION PROJECTS

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Abstract

The understanding of soil characteristics and conditions in geotechnical engineering depends on the scope and quality of geotechnical investigation works. Roads and railways are line structures, thus it is irrational and almost impossible to carry out geotechnical investigation works to the extent which would allow for reliable defining of characteristics and condition of basic structural material. Such materials can significantly vary along the transportation routes, depending on the complexity of geological formations. The design of transportation routes requires a different approach which implies that a design process is not completed in the design office basing on the results of concluded geotechnical investigation works. The studies aiming to define soil condition and characteristics are an integral part of the design process which is going to continue during the execution of the works.

Geotechnical investigation works for transportation structures are intended to collect data on soil and rock mass along potential and selected transportation route, essential for a detailed description of basic properties of soil, rock, and ground waters, and for a reliable determination of characteristic values for a geotechnical design. Geotechnical works are preceded by seismotectonic, geophysical, geologic and hydro geologic investigations. With regard to the line character and potential long distances of transportation structures, the site investigations gets more and more important. Soil and rock are investigated in natural surroundings, on a large mass. There is no need to apply expensive methods to get samples for laboratory testings. It is possible to obtain continual data on soil and rock according to depth. Testing procedures are fast, comparatively cheap, and simple in most cases.

The paper deals with different approaches and methods of determining the strength and stiffness parameters for geotechnical design and construction of roads and railways. The paper highlights Croatian experience gained in construction of modern transportation routes over the last fifteen years.

Keywords: site characterisation, soil, rock, geotechnical engineering

1 Introduction

Roads and railways consist of a series of geotechnical structures such as cuts, embankments and tunnels. The use of different construction and basic structural materials accounts for essential differences in designing geotechnical structures in contrast to other civil engineering facilities. The usual designing in construction starts with defining the loading, for which, further on, the type of structural material and construction are being determined. Structural material, such as concrete, reinforced concrete, steel or brick can be either produced or it can be selected from nature - such as wood or stone. Production or selection enable control over structural material’s quality allowing very narrow deviation limits. The strength and deformability of structural materials are determined, so that the selection of the structure and

estimation of exact costs present the final part of the design worked out in the design office. According to such a design the erected structure will be stable enough.
With the necessary structural material such as rock mass or soil, i.e. natural material of the transportation facility zone, the geotechnical structures designer on transportation projects does not have a choice of basic structural material. The Eurocode 7, Chapter 2, Design Basics states that the essential knowledge of soil characteristics and conditions is vital to the design of geotechnical structures. The knowledge depends on the scope and quality of geotechnical investigation works. Such understanding and control of works' execution are more significant for fulfilling fundamental requirements than the accuracy of computational model and partial factors.
The selection of the transportation route greatly impacts construction and maintenance costs. The determination of the transportation route is followed by introducing geotechnical design which starts with investigation. The aim is to create a geotechnical model of the rock mass or the soil for the future transportation facility. The basics of geotechnical model are contained in an engineering and geological model presenting a systematic description of the medium, its structure and condition. The scientific discipline covering research, procedures and geology tools – an engineering geology – is used for developing engineering and geological model. It implies structural geology, stratigraphy, geomorphology, hydrogeology, mineralogy, petrography, etc. Geotechnical engineers develop a geotechnical model on the basis of engineering-geological model. Creation of the model involves application of research in soil or rock mechanics dealing with studying physical and mechanical soil or rock mass characteristics such as strength, deformability, and porosity. A geotechnical engineer involves in his (her) work a classification of basic materials, laboratory investigation, in situ research, theories and laws of soil or rock mass behavior, discontinuity and rock mass for empirical and numerical analysis of geotechnical structures. A geotechnical model represents actually a quantitative upgrade of engineering and geological model, which is mostly of descriptive, i.e. of qualitative character.

2 Site investigation in soil

The investigation of soil characteristics in field (in situ) has always been of special interest for geotechnical practice. Its advantages over laboratory investigation imply the testing of soil in its natural surroundings, in large masses. There is no need to obtain undisturbed samples for laboratory investigation implementing expensive methods. Also, the soils which can be sampled in some complicated way or in no way at all, have been investigated, making it possible to obtain continuous data on soil according to depths. The investigation procedures are quick, relatively inexpensive and mostly simple [1].
In Croatian geotechnical practice the standard penetration test - SPT and cone penetration test - CPT are most often used for the design of transportation routes in soil.

2.1 Standard Penetration Test, SPT

Standard penetration test (SPT) is the most widespread and the simplest "in situ" test for the investigation of density, strength and stiffness of non coherent soils and soft rocks. It is often applied for checking consistency of coherent soil and for estimation of liquefaction occurrence due to an earthquake in saturated incoherent soils. The test can be performed during site investigation (borings) in boreholes. In this method the standardized penetration knife of 50mm outer diameter is being fixed to the series of boring rods instead of boring tools. The experiment consists of counting strokes (N) with 63,5kg weight falling from the 760mm height, needed to enact 300mm penetration after the initial 150mm penetration (Figure 1) [2].

Figure 1 SPT procedure

For many soil types SPT provides basics for the forecasting of soil characteristics and potential soil behavior. The application of standard penetration test in solving geotechnical problems can be divided into two groups: solving by direct methods (investigation results are being taken (in this case N) where the required value is being directly determined (e.g. settlement or allowed bearing capacity) and the other type – solving by indirect methods (applying test results to obtain geotechnical parameters (e.g. soil stiffness or soil strength), further used for determining of a required value. Today, there are many half-empirical correlations used to evaluate geotechnical parameters from the N strokes number in SPT test for various soil types. Those correlations vary in reliability and application. Due to dynamic nature of SPT interpretation, the geotechnical parameters mostly for non coherent soils are being obtained, with penetration conducted in drainage conditions [2].

2.2 Cone Penetration Test, CPT

CPT is performed with a special probe driven into the soil at a given speed (2cm/s). The resistance to pushing into the soil at the probe's tip and friction on the probe's sleeve activated during the installation is being continuously measured. In addition to the resistivity to installation and friction on the sleeve, the data on seismic waves (SCPT) can be collected, and the pore pressure (CPTU) and temperature in the probe's vicinity can be measured as well (Figure 2).

Figure 2 Procedure of conducting CPT

Although the CPT is in first instance limited to soft soils, it can be utilized in stiff and extremely stiff soil, in case we apply state-of-the-art and bigger boring equipment with firmer probes' tips. In some cases CPT can even be used in soft rocks [1].

The results of CPT investigation are used for: evaluation of the soil profile, evaluation of the soil type, evaluation of the stiffness parameters and soil strength parameters, evaluation of the consolidation coefficient and porosity, evaluation of pore pressure, pre-consolidation coefficient, and establishment of intermediate CPTU correlations with the laboratory tests results. Nowadays, there are numerous half empirical correlations to evaluate geotechnical parameters from measurements obtained in CPT tests for various soil types. Those correlations vary in reliability and application. CPT experiment is being implemented for determination of profile and soil classification in the case when classification diagrams are used. The granulometric soil contents cannot be deduced in this case, but soil mechanical characteristics can be determined.

3 Site investigation in rocks

Site investigation in rock mass includes considerably larger volume of rock material than laboratory samples. Some of them can represent rock mass behaviour. The radial loading tests carried out in 1:1 diameter in excavated tunnels are potentially the most reliable method for determining rock mass stiffness. However, such investigations are very expensive and of long duration. Because of the results interpretations based on assumptions, the site investigations rarely provide high reliability [3]. Clerici [4] concluded that site investigations should not aim at determining absolute module values, but the area they cover.
Croatian geotechnical practice usually prefers plate loading tests and dilatometer with transportation facilities design in rock mass.

3.1 Plate Loading Test

The plate loading test comprises the rock mass volume of approximately 2 m^3 [5]. It is based on defining a deformation module by measuring rock mass displacements induced by loading with flexible or stiff round plate of corresponding diameter (Figure 3).

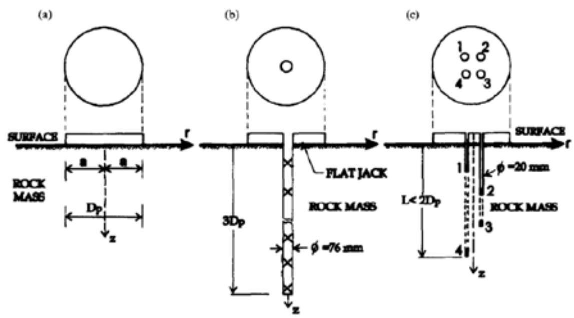

Figure 3 Plate loading on the field surface: (a) displacement measurement on the surface in the plate's centre (b) displacement measurement in the plate's centre according to depth, (c) displacement measurement on several positions according to depth [8]

For the foundation works plate loading is conducted on the field surface. In the foundation works' cases where the understanding of stiffness variations with depth is required the plate loading investigations are applied in large diameter boreholes, conducted at different depths. For underground structures design, which requires the knowledge of stiffness at great depths, tests are performed in test tunnels or galleries. The plate loading test often provides ambiguous results due to disturbances in rock mass, and because of the assumption of linear elastic behaviour of rock mass on the occasion of module interpretation. Boyle [6] points out that

quite often deformation modules are obtained, being several times larger than the modules of intact rock in laboratory tests, which is physically impossible.
Rocha and Silva [7] showed through numerous plate loading tests in test tunnels that they obtained in 30% of cases twice varied results for the plates at a distance smaller than 3m.

3.2 Dilatometer

Investigations with flexible and stiff dilatometer cover the volume of approximately 0,1 m^3 [5]. They base on the measurement of borehole's diameter alteration caused by radial spreading of dilatometer probe installed on a given depth (Figure 4). The advantage of dilatometer investigations includes the possibility of comparatively quickly performing several tests in just one borehole to obtain in that way a distribution of deformation characteristics of the rock mass according to depth. Because of extremely small volume of rock mass treated, those tests can not represent the rock mass, which significantly reduces the test's usability and value [9]. Deformation modules obtained in dilatometer tests should be connected with results of other field investigations and thus enable the application of dilatometer on the rock mass of large diameter. However, in practice it is not always operable [3]

Figure 4 Flexible dilatometer

4 Seismic geophysical investigation

Seismic investigations are applied to define elastic wave velovity profile by depth. The waves velocities are directly connected with elastic stiffness properties of material through which they penetrate. They take place on the field surface and pertain to the group of non destructive investigations. Seismic methods are being established on elastic waves spreading through the soil, i.e. rock, generated by impulse or controlled vibrations on the field surface.

4.1 Seismic refraction and seismic reflexion

Seismic refraction measures the spreading periods of breaking i.e. refracted waves through soil or rock. The method is applicable in cases when the waves spreading velocity increases with depth. If it does not happen, there is no wave refraction, and the method is unusable.
Seismic reflexion measures spreading periods of rejected, i.e. of reflected waves through the soil or rock. The condition of increase in the waves spreading velocity with depth need not be satisfied for the application of seismic reflexion [10]. The method is to be applied specifically for determining the bedrock structure, i.e. the layers depth and inclination of boundary surfaces, particularly at greater depths.
Both refraction and reflexion seismic methods have advantages and drawbacks. Refraction yields far better results at lower depths, whereas is reflexion clearly advantageous at greater depths. The zones of weathering, characteristic of karst sediments can be successfully detec-

ted by refraction, whereas the underminings - such as faults, caverns and similar formations are being detected by reflexion. Reflexion effectively makes up for the refraction's drawback in detecting velocity inversions, in case where the upper layers are stiffer than the lower ones. In Croatian geotechnical practice the hybrid seismic method has been applied lately including independently obtained results of seismic refraction and reflexion into a unique profile. Such a profile enables geologists and geotechnical engineers to get significantly better insight into engineering and geological profile in question [11].

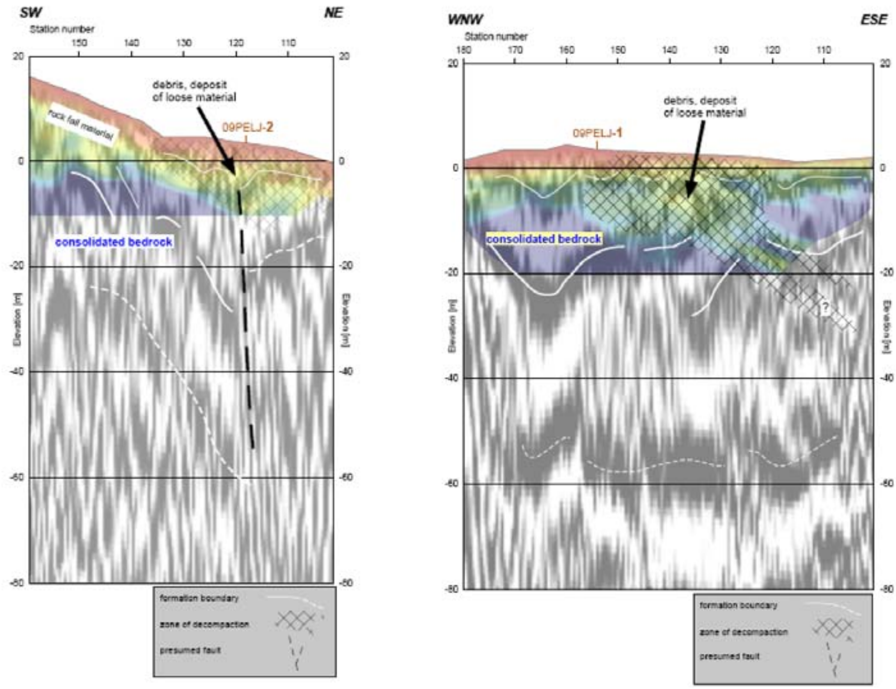

Figure 5 Results of hybrid seismic method investigation on the Pelješac bridge

The Figure 5 shows the results of hybrid seismic method investigation. The method was carried out for the foundation work of the S17 Pelješac bridge pier by the Faculty of Civil Engineering in Zagreb in cooperation with the Zürich based "Geo-expert" company. The investigation was conducted on two profiles, 09PELJ-1, 60m long and 09PELJ-2, 80m long, which are nearly vertical. The investigation on the 09PELJ-1 profile pointed to the potential position of the fault in the north-east direction connected with the heaping of fragments and weak material, which was clearly recognized. The 09PELJ-2 profile runs along the fault, which is identified as the zone of incompacted material. Such zones have been identified due to reduction of seismic waves' velocity in this area.

5 Conclusion

Roads and railways are line structures. It is both irrational and generally unfeasible to carry out geotechnical investigation works which would enable to precisely define the characteristics and conditions of basic structural material. The materials are likely to vary to a considerable extent along the transportation route depending on the complexity of geologic formations. With regard to the line character and most likely great lengths of transportation structures, the field investigation works are becoming increasingly significant.

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