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Seismic Refraction Method

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ABSTRACT

Seismic methods are applied primarily in order to determine quasi-homogeneous zones according to parameters of fragmentation, physical and chemical weathering and deformability of rock masses and cohesionless soil. Applied seismic methods comprise sending impulses underground and registering the resulting refracted arrivals from subsurface interfaces on a number of receivers positioned on or near the surface. Times elapsed from sending to receiving seismic waves depend on depths of studied structures and propagation velocities of seismic waves along paths of their propagation from the source to the refractor (or reflector) to the receiver.

This paper presents two examples of preparation of seismic sections as a basis for geotechnical design of foundations. Both examples are presentations of an optimum program of exploratory boring supplemented by results of deep seismic refraction studies.

Results of geophysical investigations should be included in the data obtained by geological mapping, which will in correlation with drilling results complete the picture of geological structure of terrain and facilitate categorization of materials and rocks for the purpose of developing the engineering and hydrogeological profile as a base for designers in the project execution stage.

INTRODUCTION

Geophysical studies are measurements of physical quantities (resistance, speed of propagation of sound, density, magnetism, conductivity, etc.) aimed at identifying comprehensively the rock mass structure and lithology characteristics to be used in geotechnical studies, water investigations, etc. The big advantage of geophysical methods is that instruments are relatively inexpensive, and investigations are much faster and cheaper than conventional investigations - exploratory drilling.

The applied seismic methods comprise sending impulses underground and registering the consequent arrivals, refracted from subsurface interfaces by a number of detectors laid out at or near the surface. Under the influence of an external impulse, particles of matter in the underground move from their original positions toward each other and collide, and thereby transmit mechanical motion underground from one point to another. In other words, under the influence of an impulse, particles of matter in the underground begin to vibrate in the direction of seismic wave propagation, if waves are longitudinal or P-waves, or perpendicularly to this direction, in case of transverse or S-waves, while not changing their positions in the medium through which the elastic waves propagate and transmit mechanical energy from one point to another (Figure 1). Times elapsed from sending to receiving a seismic wave depend on depths of studied structures and velocities of propagation of seismic waves along paths of their propagation from the source to refractor (or reflector) to receivers [1].

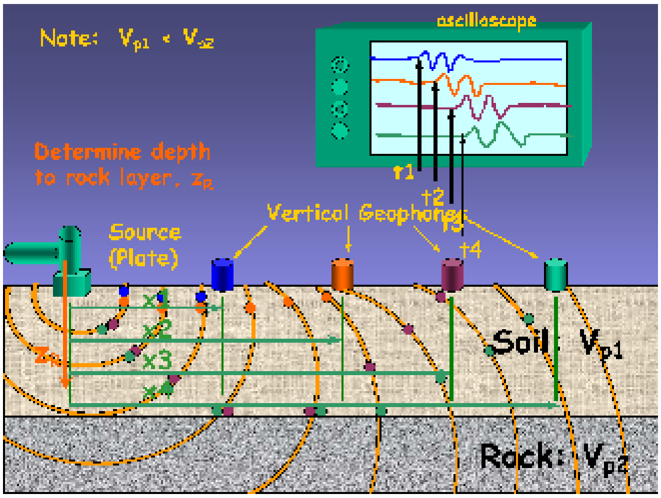

Figure 1 The principle of seismic refraction

To initiate mechanical force, explosives, hammer, weight drop or other source of impulse are used. Successful application of seismic methods is based on the fact that underground layers have different elastic properties and density that directly depend on their lithological composition. Analysis of thus changed properties of seismic waves therefore allows determining the tectonic structure of the underground, lithological composition of underground strata, and in favorable circumstances also directly locating reservoirs of oil and gas.

The x-t coordinate system in Figure 2 shows times of first arrivals of waves [2] to individual geophones from the moment the wave was generated. The points in the diagram are connected, in an ideal case as in Figure 2, and represent two directions of which the first intersects the x-axis at the origin and has the equation:

$$t = \left(\frac{1}{V_1}\right) x \qquad (1)$$

While the second line has the equation:

$$t = \left(\frac{1}{V_2}\right) x + Io \qquad (2)$$

From these equations we determine the velocities V_1 and V_2 of upper and lower seismic media, and calculate depth to first seismic discontinuity.

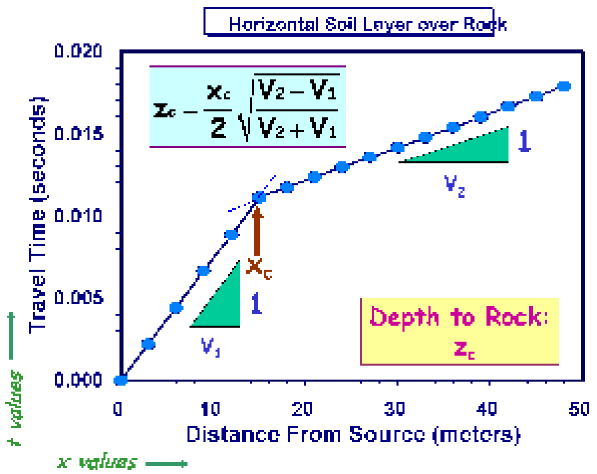

Figure 2 The x-t diagram

Also, by reading the values from the x-t diagram (Figure 2), the depth to the layer can be calculated using the equation:

$$z_c = \frac{x_c}{2}\sqrt{\frac{V_2 - V_1}{V_2 + V_1}} \tag{3}$$

INTERPRETATION OF REFRACTION SEISMIC INVESTIGATIONS

Results of seismic refraction measurements are usually processed on personal computers using the GRM method according to Palmer (Generalized Reciprocal Method, Palmer, 1981 and 1991). Dromocrones of longitudinal waves are obtained by analyzing first arrivals of elastic waves in the S-T diagram [3].

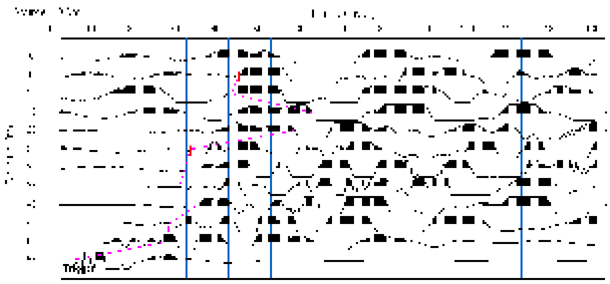

Figure 3 Times of seismic waves passing through the layers

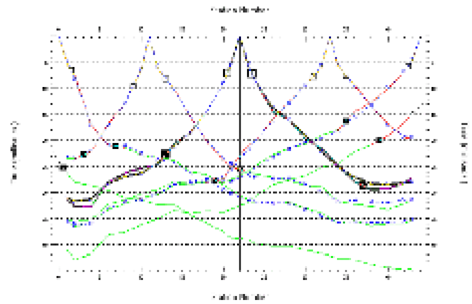

Figure 4 Diagram of passing times of seismic waves

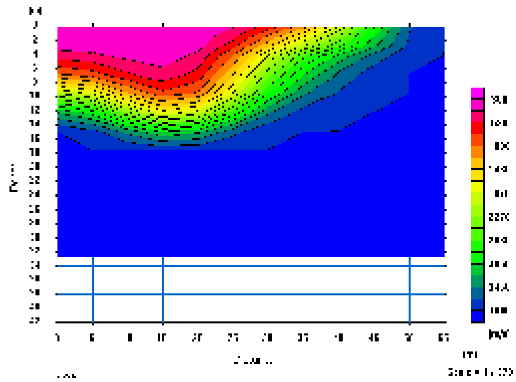

Figure 5 Velocities of seismic waves in depth

A more detailed lithological picture is obtained in combination with geological prospecting and drilling. When data are insufficient for the GRM method, it is possible to use the conventional intercept-time method (ITM) with lower accuracy.

The intercept-time method is based on the transformation of travel time of the refracted wave into the time intercept line (T_i line) for seismic boundaries with different velocity V_r. The transformation contains a reduction in travel time with the velocity V_r and refers to detectors. After the transformation, reverse and partially overlapping refraction with same boundaries should coincide with T_i lines. The method is used for determining the boundaries of layers (depth) and wave analysis [4].

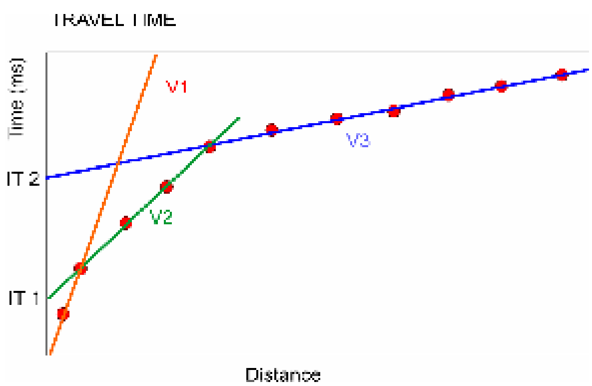

Figure 6 The diagram for the IT method

DEVELOPMENT OF SEISMIC MODELS FOR GEOTECHNICAL DESIGN

In the following, we present two examples of preparation of seismic sections as a basis for geotechnical design of foundations. Both examples are illustrations of optimum program of exploratory boring supplemented by results of deep seismic refraction studies, which largely satisfies geotechnical needs in conforming to construction design requirements. Besides, we should emphasize their big role, supported by other geophysical methods, in the preparation of prognostic engineering geophysical profiles in the stage of project design as well as remediation solutions during excavation and preparation for construction of foundations of structures.

Example 1

Seismic geophysical surveys were conducted as part of geotechnical investigation works in abutment and column locations of the Biakuse Viaduct, column site S-10, Highway Zagreb-Split-Dubrovnik, section Dugopolje-Bisko. The separated depth profile of the refraction section of the column site S-10 contains interpretations of seismic recordings obtained by the inverse Delta-t-V method. Isolines of longitudinal wave velocities are shown in the range 0-5000 m/s with the increment of 100 m/s. Illustrations are supplemented by lithological description with the legend taken from the determination of the exploratory borehole [5]. The type and quality of rock is determined by this lithological description, and is additionally spatially defined up to depths of approximately 15 meters by velocities of seismic waves. Fault zones and intervals of highly fractured rock in the base are marked by dashed lines, Figure 7.

The depth section shows the distribution of P-waves propagation velocities based on which the type and quality of the material in the shallow underground can be estimated, especially in the surface zone and upper weathering zone. Locations where larger fault systems were found and associated zones of wider fracture systems are marked by dashed lines on the seismic sections. Limestones registered in the ground are occasionally accompanied by occurrences of tectonic breccias, which follow one another along the faults observed on the refraction sections. The geotechnical section made on the basis of geological mapping and seismic investigation data collected from the S10 column site is compared with the diagram of P-waves velocity pattern of the same site [5]. The diagram of velocity dependence on depth points at the conclusion that the subsurface is characterized by a thicker weathering zone, 2-4 meters. In connection with the occurrence of faults zones and developed fracture systems, intervals of fractured carbonate rock mass with appearance of scattered breccias and higher degree of karstification are observed at larger depths, Figure 8.

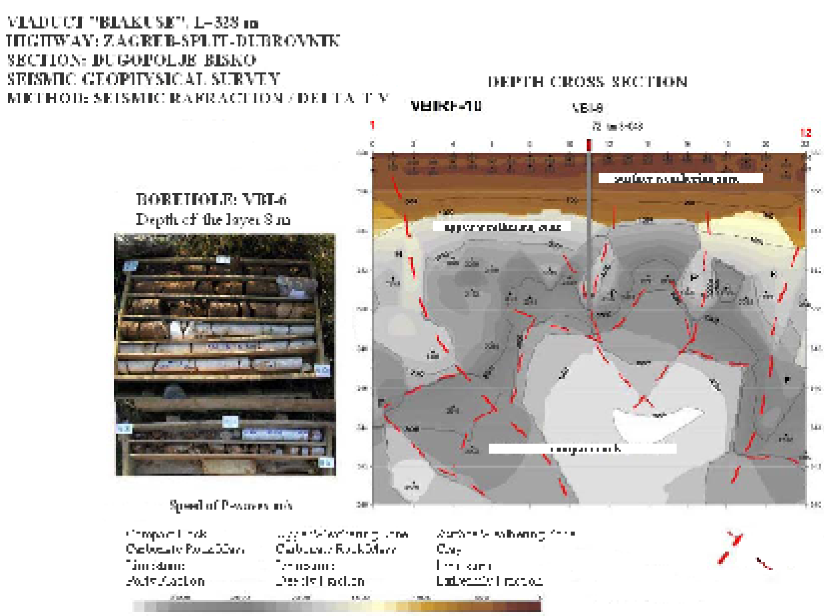

Figure 7 The seismic depth section and borehole at the S10 column site, the Biakuse Viaduct

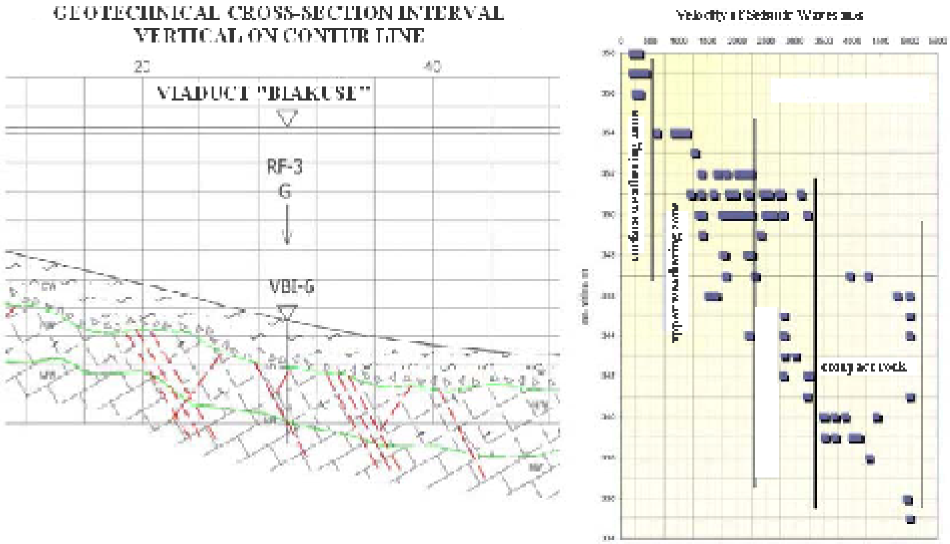

Figure 8 Parallel view of the geotechnical section and the velocity diagram

Example 2

In order to define geomechanical properties of soil required for the construction of a business structure in Mostar, geophysical investigations were carried out at the project site. Seismic studies were performed using the method of seismic refraction at three profiles in total (Figure 9).

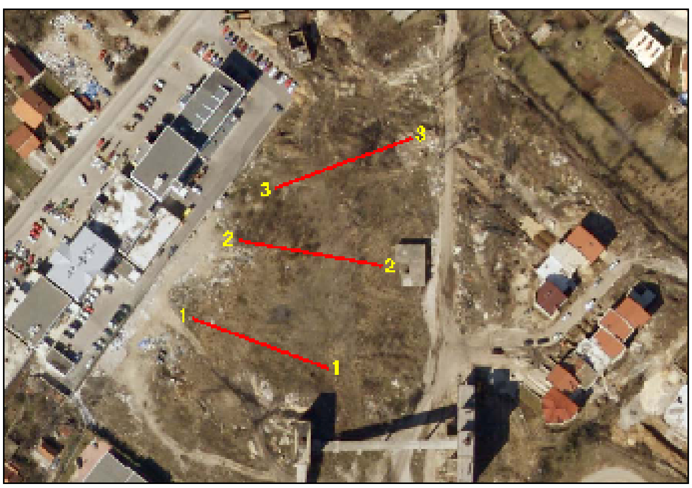

Figure 9 The studied profiles indicated on the lot

The objective of these investigations was to determine the most accurate possible spatial distribution of geomechanical media under the entire design structure and their geomechanical properties. Data were digitally processed on a computer, and the results are time and depth sections along measurement lines for the total of three profiles. They define boundaries of zones with different geomechanical properties underground [6].

Interpretation of results of example 2

Refraction section 1-1

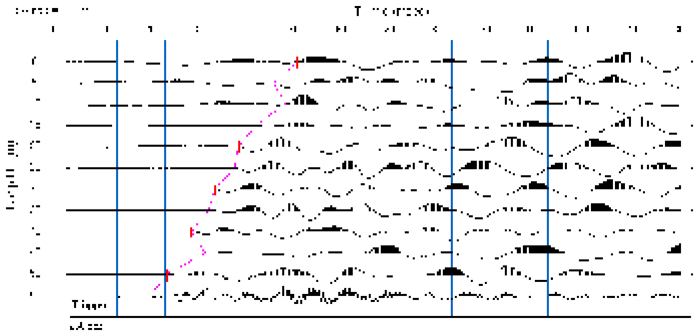

Figure 10 Times of seismic waves passing through the layer 1

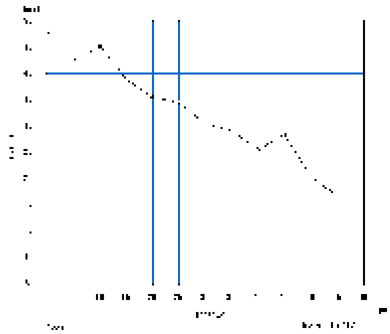

Figure 11 Diagram of passage times of seismic waves

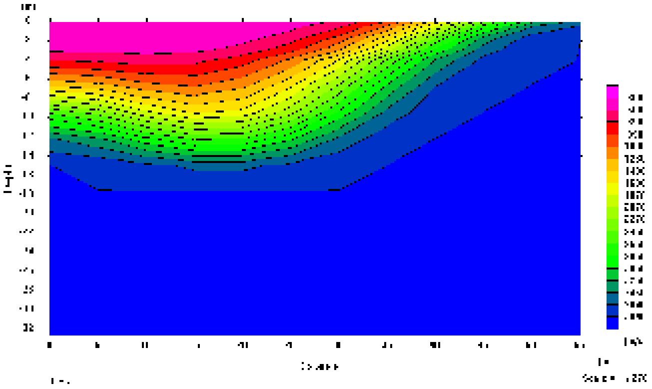

Figure 12 Velocities of seismic waves in depth

The refraction seismic investigations defined zones with different elastic and geomechanical properties (Figure 10). Geomechanical properties, defined on the basis of recorded velocities of seismic (transverse and longitudinal) waves, are clearly indicative of medium- and high-bearing materials (Figure11 and Figure 12).

The obtained data indicate a relatively uniform geomechanical structure of the terrain, and the interpretation of lithology is given on the basis of drilling carried out in the wider area [6].

CONDITIONS AND LIMITATIONS

Successful application of the seismic refraction method in determining the boundaries of different media in depth requires the presence of what is called the normal sequence of velocities, which means that the materials with higher elastic wave velocities should occur under those with lower velocities [2]. In the opposite case, it is not possible to achieve total refraction of waves along the discontinuity surface. Velocity inversion is quite a normal occurrence, e.g. due to presence of caverns in karst, in fractured limestones under compact flysch marls under limestones, in different densities and saturations of sedimentary series etc.; in such cases the method does not give accurate results over depth, but its use is justified because it may well determine the thickness of the first, commonly found, weathering zone of the lowest-velocity material.

The method is best used to provide detailed information along layers, where geological profile is not complicated, or where establishing lithological or structural changes in sound rock is required [4]. For such information the method provides good results, although it is relatively expensive if explosives are used as the energy source. Presence of significant noise, such as the noise on highways, may compromise the reading and may result in inaccurate data [3].

CONCLUSION

Seismic methods are applied primarily in order to determine quasi-homogeneous zones according to parameters of fragmentation, physical and chemical weathering and deformability of rock masses and cohesionless soil.

They are also used in combination with static methods for testing deformability and resistance parameters in shear. Geophysical (seismic and geoelectrical) surveys are the basis for preparation of engineering geological profiles and models with quasi-homogeneous zones separated in terms of the parameters of longitudinal wave velocity, modulus of elasticity, and electrical resistance Ω (ohm).

The primary use of seismic refraction is for determining the depth and structure of bedrock. Seismic velocity depends on elasticity and density of the material through which energy passes; seismic refraction provides data on strength of materials and therefore can be used as a means of assessing rock quality. The technique has been successfully employed in establishing depth and strength of overburden rock and describing areas containing groundwater.

Results of geophysical investigations should be included in the data obtained by geological mapping, which will in correlation with drilling results complete the picture of geological structure of terrain and facilitate categorization of materials and rocks for the purpose of developing the engineering and hydrogeological profile as a basis for designers in the project execution stage.

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