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Estimation of Geotechnical Parameters Using Seismic Measurements

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***Abstract*: This paper overviews the most important geotechnical parameters that need to be taken into consideration when seismic measurements are being collected in different applications.**

***Keywords*: geophysics, geotechnical, seismics.**

1. Introduction

Geophysical methods can be very useful in exploring for oil, and minerals, or for locating buried objects. Most methods in use today were developed five or six decades ago and have not been improved upon greatly since their inception. Each method has its strengths and often important limitations that are imposed by nature and physics. The advantage of geophysical survey techniques is that they do not disturb the site, can usually be performed quickly, and are very cost-effective compared to excavation costs. When they can be used these methods can be very helpful in evaluating the site geologically for delineating areas of interest and eliminating barren ground. Among the more recent tools developed for probing beneath the surface of the earth is ground-penetrating radar.

There are several advantages for the surface geophysical methods than the conventional engineering tools due to the following reasons.

Surface geophysical methods allow subsurface features to be located, mapped, and characterized by making measurements at the surface that respond to physical, electrical, or chemical properties.

These noninvasive measurements can be effectively used to provide reconnaissance to detailed geologic information, guide subsurface sampling and excavation, and provide continuous monitoring.

Surface geophysical methods provide data at a variety of scales, from the regional geologic setting to site-specific geotechnical forensics.

If all sites were simple (horizontally stratified geology with uniform properties), site characterization would be easy. Data from just one boring would be sufficient to characterize the site. However, in most geologic settings, this will not be the case. Even at sites where the geology appears to be uniform, on must be alert to often-subtle variations that can cause significant changes in structural or hydrological properties.

Traditional approaches to subsurface field investigations commonly rely only upon the use of direct sampling methods such as:

- Borings for soil and rock samples.
- Laboratory analysis of discrete soil, rock, and water samples to provide a quantitative assessment of site conditions; and
- Extensive interpolation and extrapolation from a limited number of data points.

Soil and rock sampling programs and the placement of borings are done mainly by educated guesswork. The accuracy and effectiveness of such an approach are heavily dependent on the assumption that subsurface conditions are uniform. Numerous pitfalls are associated with this approach that can result in an incomplete or even erroneous understanding of site conditions. These oversights are the cause of many structural and environmental failures.

In many cases, direct sampling alone is not sufficient to accurately characterize site conditions. This is the primary reason for the application of surface geophysical methods. The geophysical methods encompass a wide range of airborne, surface, marine, and down-hole methods that can be used to significantly improve the accuracy of subsurface investigations. Since surface geophysical measurements can be made relatively quickly, they provide a means to significantly increase data density. In some cases, total site coverage is economically possible. Because of the greater sample density, anomalous conditions are more likely to be detected, resulting in an accurate characterization of subsurface conditions.

Surface geophysical methods, like any other means of measurement, have advantages and limitations. There is no single, universally applicable surface geophysical method, and some methods are quite site-specific in their performance. The methods must be carefully selected based on specific site conditions and project requirements.

There are four major areas where surface geophysical methods may be applied to environmental and engineering problems.

- Assessment of natural geologic and hydrogeologic conditions
- Detection and mapping of contaminant plumes, spills, and leaks
- Detection and mapping of landfills, trenches, buried wastes, drums, or other underground structures and

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utilities; and

- Evaluation of soil and bedrock properties and man-made structures.

The velocity of seismic waves depends mainly on the density of rock, which propagates through it. It increases with increasing density. In sedimentary rock, it increases with the depth of burial, age, and water content. In igneous rocks, it is affected by fracturing or jointing. The velocity variations, therefore, can be interpreted in terms of variations in compactness, porosity, and saturation of rocks, and used to locate interfaces of subsurface layers with velocity contrasts. Shallow geophysical techniques are considered as one of the accurate, cost-effective, and in-situ methods used in engineering site characterization (Abdel Rahman et al, 1994 and El-Behairy et al., 1994). They are alternatives to the conventional geotechnical ones, which are usually tedious and very expensive.

From the engineering point of view, soils are defined as the material overlying the bedrock produced by rock weathering. It is an unconsolidated material of the earth's crust used to build upon or used as a construction material. The seismic method has emerged as a powerful tool in computing the elastic moduli from which their elastic deformation can be estimated, Stumpel (1984); Davis and Taylor (1979).

The advantage of the calculation of the mechanical properties of the foundation rock from in-situ measurements of the seismic wave velocities over that based on the geotechnical measurements carried out in the excavations is apparently due to the amount of stress energy released from the rocks when an excavation is made.

The soundness of rock or soil materials for foundation purposes is a qualitative term. It can be estimated by the average line method, Sjogren et al., (1979) and Abdel -Rahman et al., (1990), where weak zones can be delineated. However, the complete categorization of the rocks or soils, in each area, based on the degree of competence has been established by geotechnical and geophysical tools for instance the N-value, concentration index, stress ratio, and the allowable bearing capacity, De Mello (1971), Imai (1975) and Abdel-Rahman et al., (1990 and 1991).

The calculation of the degree of compaction of soils or the degree of rock consolidation can be easily evaluated when the seismic wave velocities and the density of rocks are known. The P- and SH- wave velocities are used to compute the elastic constants of the three detected subsurface layers including the density, stress ratio, Poisson's ratio, rigidity modulus, Young's modulus (E), and bulk's modulus.

2. Estimation of the Mechanical Properties

A. *Stress Ratio (Si)*

The propagation velocity of seismic waves is proportional to the differential pressure between the sedimentary overburden and the pore-filling fluids. This means that the high fluid pressure formations will have differential pressure and abnormally low seismic velocities. According to Cordier (1985), such formations are said to be sub-compacted or over-pressured zones. These formations occur frequently in recent unconsolidated sedimentary series. For this reason, the case can be represented as the relation between the vertical stresses (S33) at a certain depth and the horizontal stress (S11) due to the pore-filling fluids. The stress ratio can be expressed in terms of the velocity squared ratio.

The stress ratio can introduce a sensitive scale in which soils are classified into soft, compacted, moderate compacted, and compacted.

B. *Poisson's Ratio (ν)*

This ratio represents the lateral extension to longitudinal contraction, in other words, a measure of the geometrical change in the shape of an elastic body. Its value is 0.5 for fluids and it approaches zero for very hard indurate rocks. Negative Poisson's ratio is also recorded for very hard indurate anisotropic rocks. Poisson's ratio (ν) is given in terms of P-wave and S-wave by the relation (Telford et al., 1976) and it has a value of 0.5 for fluids and 0.25 for solids, while weak materials have values higher than 0.45.

C. *Material Competence Coefficient*

The soundness of rock or soil materials for foundation purposes is a qualitative term. It may be estimated by the average line method (Sjogren et al (1984); Abdel Rahman (1991), where weak zones can be delineated. However, the complete categorization of the rocks or soils, in each area, based on the degree of competence has been established by geotechnical and geophysical tools such as the N-value, the settlement index, the degree of competence, and the allowable bearing capacity (De Mello, 1971; Schmertmann, 1975; Imai, 1975 and Abdel Rahman (1990).

The application of these techniques in the investigated area is the subject of the present work. Seismic measurements have been conducted on the area for evaluating the foundation layer for civil engineering purposes and rock mass quality depending upon material elastic parameters. Based on the measurements of compressional and shear wave velocities, elastic moduli and the soundness of rocks or soil materials, including the material index, concentration index, N-value, and ultimate bearing capacity have been calculated:

D. *Material Index (Mi)*

Material index Mi addresses the degree of material competence (Abdel Rahman 1989). It depends mainly on the mineralogic composition and the physical environment under which the rock or soil is situated. So, there is closed relation with material composition, the degree of consolidation, fracturing and jointing, the presence or absence of fluids in pore spaces which affect the elastic moduli. The material index has a direct relation with N-value and an inverse relation with the Poisson's ratio.

E. *Concentration Index (Ci)*

The concentration index describes the degree of material concentration or compaction. The soil compaction status is largely considered, as a measure of the degree of competence for foundation and other civil engineering purposes. It depends on both the elastic moduli of the soil and the pressure distribution at their depth.

F. N-Value

The resistance to penetration by normalized cylindrical bars under standard load, which is geotechnically known as the standard penetration test (SPT), is geophysical evaluated using the following formula (Imai, 1975, and Stuempel et al., 1984):

$$Vs = 89.9 \times N0.341 \tag{1}$$

Where Vs, is the horizontal shear wave velocity.

G. Foundation Material-Bearing Capacity

Evaluation of the foundation material-bearing capacity, for the construction area, is of great importance due to the probability of liquefaction occurrences and/or shear failure. This is, from the general point of view, due to the nature of sediments (soils) prevailing in the area where it is constituted of recent deposits.

The ultimate bearing capacity (Qult) of the foundation material is the maximum load required for shear failure or sand liquefaction. The shear strength is the controlling factor of the ultimate bearing capacity of the soil. The ultimate bearing capacity of the cohesionless soils using the Standard Penetration Test (SPT) can be evaluated using Parry's formula (1977):

$$Qult = 30N \tag{2}$$

Where Qult is the ultimate bearing capacity, and N is the resistance to penetration by normalized cylindrical bars under standard load.

Combining both equations:

$$Qult = 102.932\ (\log Vs - 1.45) \tag{3}$$

By taking the logarithm for both sides of this equation, ultimate bearing capacity can be obtained as follows (Abdel Rahman, 1992):

$$Log\ Qult = 2.932\ (Log\ Vs - 1.45) \tag{4}$$

On the other hand, the allowable bearing capacity is the maximum load to be considered to avoid shear failure or sand liquefaction. Such material indices are of great importance in the study area because of the nature of the Pleistocene and recent deposits, which consist mainly of fine silty clayey sand. The static load of the buildings as well as the natural and artificial dynamic cyclic loading may enhance greatly sand liquefaction and shear failure.

The allowable value (Qa) should be taken into consideration before designing the structures. It can be obtained from the ultimate bearing capacity value by a suitable factor of safety (F), Parry's formula (1977) as:

$$Qa = Qult/ F \tag{5}$$

The factor of safety equals 2 and 3 for the cohesionless and cohesive soils respectively. Also, it can be estimated the Qa using shear wave velocity:

$$Log\ Qa = 2.932 \log Vs - 4.553, \text{ for soft soil} \tag{6}$$
$$Log\ Qa = 2.932 \log Vs - 4.729, \text{ for hard rock} \tag{7}$$

3. Conclusion

In conclusion, the exploration and estimation of geotechnical parameters through seismic measurements represent a crucial advancement in the field of geotechnical engineering. This paper has delved into the significance of seismic methods in providing valuable insights into subsurface soil and rock properties. By harnessing the power of seismic waves, researchers and practitioners can gain a deeper understanding of the geological conditions, enabling more accurate and reliable predictions for construction projects, environmental assessments, and hazard evaluations. As technology continues to evolve, the integration of advanced seismic techniques holds immense promise for enhancing our ability to characterize and quantify geotechnical parameters, ultimately contributing to safer and more sustainable engineering practices. The findings presented in this paper underscore the importance of ongoing research and innovation in seismic-based geotechnical estimation, paving the way for continued advancements in the realm of subsurface exploration and geotechnical engineering.

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