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RECENT APPLICATIONS OF GEOPHYSICS IN CIVIL ENGINEERING

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Abstract

Geophysical methods are traditionally used in civil engineering practice as subsurface investigation techniques.

Two most commonly employed geophysical methods are electrical resistivity and seismic refraction methods. Recently however, there have been rapid developments of widely varying geophysical techniques that are being used successfully in civil engineering projects. This write up takes an overview of the different geophysical methods as utilized in different civil engineering works with cited examples, without details of geophysics principles governing the method. It also highlights potential use for in highway infrastructure in Nigeria.

1.0 INTRODUCTION

Traditionally within the civil engineering practice, geophysical methods are one among many techniques of subsurface exploration, (Peck, *et al.*, 1974). Other methods include standard penetration test (SPT), cone penetration test (CPT), different drilling methods, and Vane shear test.

Electrical resistivity and seismic refraction are geophysical methods that have found extensive use in the determination of depths to competent layer (bedrock), mapping of rock structures for quarry purposes, and search for groundwater for both construction and potable uses.

Recently however these two methods with other geophysical methods have been widely applied in the design and construction of various civil engineering structures. This write up takes a look at some applications in various branches of civil engineering.

2.0 FOUNDATION INVESTIGATION – DAMSITE INVESTIGATION

In determining the depth to competent stratum to place the base of an earth dam, purely geotechnical investigation often comprises of drilling and boring that will involve obtaining undisturbed sampling of soils at different horizon to depths between 0 to 20m depending on local geology, size of dam, type of dam (earth fill, rock fill, masonry, concrete etc.). The outcome of comprehensive laboratory analysis of such samples in conjunction with other considerations will often guide the Foundation Engineer at which depth to place the dam foundation.

Geophysical seismic refraction method becomes useful in a case like this.

Seismic refraction method utilizes the principles that materials of different densities will give different velocities, when compressional seismic (acoustic) wave passes through them. A case study will illustrate the use of such method.

In a foundation study for Obudu damsite located in Obudu the Northern part of Cross River State, seismic refraction method was employed along with the traditional geotechnical exploratory method (Esu et al.,1996).

Seismic refraction method was able to detect three layers based on average velocity distribution. These layers have seismic velocities ranging from an average of 300m/s for the top layer to 3000m/s for the bottom or third layer. It also estimated within a reasonable degree of accuracy the thicknesses of each of these layers.

Subsequent geotechnical exploratory programme confirmed a first layer made up of clayey/silty sands and a third layer made up of fresh (basement) rock. The second layer consists of a mixture of weathered rocks (gravels), sands and clayey sands.

3.0 SLOPE STABILITY ANALYSIS AND LANDSLIDE EVALUATION

Slope stability analysis forms a near routine work for highway engineers as road alignment often cuts through hills.

The stability analyses of slopes associated with such a cut are usually carried out to assure safety.

For hills with a reasonably homogenous soil the analysis requires basic strength parameters (C - Φ), unit weights, and fairly accurate geometrical details of the hill namely, angle of slope, vertical height of hill, lateral extent of hill, water flow regime.

Factors predisposing a slope to failure can be summarized as:

- The presence of stronger strata within a softer hill mass and vice versa.
- The presence of a hard stratum at the base of a slope.
- If the potential failure plane to the horizontal is more than the angle of internal friction of the soil.
- If a release surface that provides negligible resistance to sliding is present.

Within the traditional geotechnical practice, the methods available for analysis can usually be broadly divided into two based on assumptions of homogenous and non-homogenous soils.

For homogenous soil, the majority of the methods can be categorized as limit equilibrium or mass method while, for non-homogenous soil the method of slices is employed. Within the two generalized methods, failure plane is assumed and available forces are analyzed resulting in a factor of safety for a slope. This process is iterative until an adequate factor of safety (at least 2) is realized.

Two dimensional and three dimensional (2D and 3D) electrical resistivity method and their variants, for example 2D – laterally constraint electrical resistivity, and induced polarization methods can be used to map potential failure surfaces distinctly and hence help in refining the accuracy in defining potential failure surfaces for the stability analysis.

Seismic refraction can define angle of slope of potential failure surfaces. The two methods above will refine slope stability analysis and produce more true to life results. Example of cases where geophysical methods were employed in slope stability analysis was where it was used to investigate failures of some hill cuts along highway alignment that has been in service but experiences slope failures at some sections. The slopes were designed geotechnically, but still fail. due to limitations of geotechnical method in fairly heterogeneous slope materials. A case study in question is from Jordanian- Iranian Highway,(Bafayneh and Al-Diabet, ,2002). Others cases where geophysics was employed in solving slope stability problems are Micheals (1999), Mohammed *et al.*, (2007).

4.0 HIGHWAY PAVEMENT

Geophysics, of recent finds so numerous applications in highway pavement either as part of tools for quality control during construction or in investigating state of the pavement after construction for example pavement failures.

In quality assurance and quality control, traditional or modified forms of geophysical methods are often employed.

In determining thickness and strength parameter, (for example Young's modulus) of different layers within a highway pavement; modified forms of geophysical methods have been developed. For example, Nazarian, et al, (1993), and Gucunski and Maher (2002) reports on the Seismic Pavement Analyzer (SPA). Another one is the Falling Weight Deflectometer (FWD). The former was developed by the American Federal Highway Administration, while the later is actively used by the agency; National Cooperative Highway and Research Program (NCHRP) Synthesis 381, (2008). The FWD was also evaluated and adopted by the European Union members (COST 336, 1998).

Both are used in determining different strength parameters (young's and shear modulus), thicknesses and densities of different layers of highway pavements.

The two are based on seismic principles, the advantage of these tools over traditional sample coring, and laboratory analyses is that the measurements covers sections of road directly as against the representative coring procedure of traditional methods.

Density monitoring especially during construction is not only limited to the two equipments above, ground penetrating radar (GPR) and infrared thermocouple tester are also routinely used, including nuclear density tester, (Willet and Ruster, 2002; Myers *et al.*, 2001).

In investigating pavement failures, seismic and electrical methods have been widely applied. For example Rucker (2006), used seismic refraction in conjunction with seismic microtremor; to investigate a highway pavement failure along Highway 'NM 128' near Carlsbad, New Mexico in U.S.A. The highway traverses through a Karst (limestone) area. It is in this section of the highway that a major subsidence of the highway pavement occurred. Seismic refraction was able to detect a cavity caused by dissolution of limestone at about 9.0m depth under the pavement in this area of subsidence.

5.0 TUNNEL PLANNING AND DESIGN

In planning a new route tunnel or expanding an existing one, there is the need to know the ground conditions along the proposed alignment. With an initial preliminary sizing of the tunnel traditional geotechnical methods will call for preliminary soil sampling at the appropriate depths along the proposed tunnel alignment, followed by laboratory analysis. The results of the laboratory analysis are now employed to make preliminary computations of stresses (both geostatic and structural on the tunnel) potential groundwater flow pattern (if groundwater is encountered), and areas on the tunnel alignment that needs further or detailed geotechnical investigation. The interpretation of a preliminary geotechnical investigation and subsequent decision to carry out detailed geotechnical work depends to a great deal on experience and depth of knowledge of local soil variations and behaviour.

As an alternative a number of geophysical methods can first be employed to study the alignment and plan where the geotechnical sampling should be carried out. A case study will illustrate the above.

In a planning procedure to increase the capacity of 1.8 kilometer long Mount Carmel tunnel in Utah, U.S.A, Armstrong *et al.* (2009); utilized seismic reflection method as a first step in characterizing the alignment.

The technique involves analyzing seismic signals for multiple sources and receiver locations. From which reflector zones within the rock mass that might corresponds to voids, fracture zones, or significant changes in geologic structure are identified.

The civil engineering design team on the project verified this analysis by comparing the images with known ground supports and voids.

The nondestructive seismic reflection method provided rapid characterization of large tunnel segments as well as identification of structural 'targets' warranting more detailed investigation.

6.0 BRIDGE STRUCTURAL SYSTEMS

A number of geophysical methods have various applications in both quality assurance/quality control and condition monitoring of the state of bridge structural systems.

6.1 Application to Substructure

A number of geophysical methods are used in evaluating the condition or integrity of foundations of bridge structural systems. These include:

- Cross hole Sonic Logging (CSL)
- Crosshole Sonic Logging Tomogram (CSLT)
- Gamma-gamma Density Logging (GDL)
- UltraSeismic (US) Profiling
- Ultrasonic Pulse Velocity(UPV)

The first and the last methods are discussed here.

Cross hole sonic logging was developed for integrity testing of concrete foundation such as drilled shafts, slurry wall and auger drilled, casts pile. It allows accurate determinations of soil intrusions or other anomalies throughout the shaft.

Various degrees of defects can be detected by the method with high precision (Finno and Champy,1997; Haramy and Mekic-Stall, 2000).

The UPV method is used for computing ultrasonic pulse velocity of structural concrete, and can be used for assessing integrity of structural concrete elements of up to 7.50m thick with two-side access, (Amir,2002). It can also be used to predict the strength of early stage concrete and as a relative indication of concrete quality.

6.2 Application to Superstructure.

Geophysical methods have been utilized for both Quality Assurance and Quality Control(QA/QC) of Bridge Decks during construction.. Examples are;

- Ground Penetrating Radar (GPR).
- Impact Echo (IE).
- Spectral Analysis of Surface Waves (SASW) and Ultrasonic Surface Waves Methods
- Spectral Analysis of Surface Waves (SASW) and Impact Echo (IE) combined.

One of the major problem in Quality Assurance and Quality Control of bridge desk construction is to ascertain that reinforcement are at specific spacing to each other and appropriate depth, and the thickness of cover to reinforcement is within acceptable limit. While coring traditionally is used to check thickness of concrete to reinforcement ; the position of the reinforcement are invariably "assumed" to be where they are before concrete placement, that is they have not been shifted during and after concrete placement. This may not necessarily be true. Roberts (2002), reports that Ground Penetrating Radar (GPR) with high frequency (1.5GHz) shielded and ground coupled antennae can be used with high degree of accuracy to ascertain reinforcement positions and concrete cover. The GPR is said to image the structure and concrete cover thickness can be ascertained to within 0.25cm accuracy, and reinforcement spacing to within accuracy 0.5cm,

Other Geophysical methods that are employed to check bar quality and bonding to concrete within a bridge deck includes;

- Half Cell Potential.
- Linear Polarization Resistance (LPR).
- Galvanostatic Pulse Techniques.
- Electrochemical Noise.
- Magnetic Field Disturbance (MFD).

7. SUMMARY

Numerous geophysical methods as applied to civil engineering structures represent major advancement to civil engineering practice in general. The a of application of such methods to structures or facilities in Nigeria will go a long way to ensure efficient monitoring and behaviour or performance of such facilities before, during, and after design and the construction processes. Most bridges that forms part of our highway infrastructure were constructed from 1970 upwards as part of both post civil war reconstruction efforts and development plans. They are therefore more than 30years old. The use of geophysical methods to check the conditions of the substructure and superstructure will reveal their structural states that will allow adequate planning for required maintenance to prevent collapse.

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