GEOPHYSICAL SITE INVESTIGATION TECHNIQUES FOR NEW BRIDGES

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1. INTRODUCTION

Modern bridge construction is inconceivable without high-level site explorations, which play a major role in optimizing the design and costs. Engineering geophysics is an efficient means of subsurface investigation. The merit of application of this low cost aid lies in its ease of deployment and rapidity in providing a reliable knowledge of the underground over a large area, substantiating the requisite geotechnical evaluation studies thereby.

The state-of-the-art non-destructive subsurface geophysical investigations are helpful towards minimizing involvement of the conventional direct invasive exploration methods, aiding in accelerated and economical development of the construction projects.

2. WHAT IS ENGINEERING GEOPHYSICS?

Engineering geophysics is the application of geophysics to geotechnical engineering problems and is used for the following:

1. Subsurface characterization: bedrock depth, rock type, layer boundaries, water table, groundwater flow, locating fractures, weak zones, expansive clays, etc.
2. Engineering properties of Earth materials: stiffness, density, electrical resistivity, porosity, etc.

3. WHY USE ENGINEERING GEOPHYSICS?

A geophysical survey is the most cost-effective and rapid tool to obtain subsurface information. It can be used to select borehole locations and can provide reliable information about the nature and variability of the subsurface between boreholes. Isolated geologic structures cannot be detected by a routine drilling program (Figure 1).

Other advantages of geotechnical geophysics are site accessibility, lightweight instruments and operator safety. Geophysical equipment can be deployed beneath bridges and power lines, in forests, in urban areas, on steep slopes, marshy terrain, on pavements and in other areas not easily accessible to drill rigs.

Most importantly, geophysical surveys can reduce the number of required boreholes. However, engineering geophysics is not a substitute for boring and direct physical testing. It complements cost-effective drilling. Geophysicists refer to borehole information and field geologic maps as "ground truth," and rely on ground truth to constrain and verify all geophysical interpretations.

4. GEOPHYSICAL METHODS OF BRIDGE SITE INVESTIGATIONS

For effective site investigation and characterization few of the obvious geological factors taken into consideration are:

- The type of the rock i.e., igneous, sedimentary or metamorphic
- Depth of bedrock
- Soil profile
- Geological discontinuities
- Groundwater conditions

5. SITE INVESTIGATION FOR NEW BRIDGES

5.1 Seismic refraction surveys

Seismic technique is one of the most developed geophysical techniques, providing vital information on subsurface, crucial for most of the engineering projects. Seismic Refraction surveys

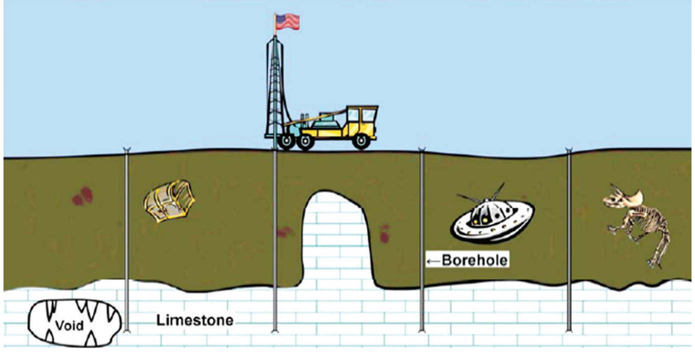

Figure 1: Isolated subsurface features cannot be detected by a routine drilling program.

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Table 1: Applications for Geophysical Testing Methods (after AASHTO, 1988)

GEOLOGICAL CONDITIONS TO BE INVESTIGATED	USEFUL GEOPHYSICAL TECHNIQUES	
	SURFACE	SUBSURFACE
Stratified rock and soil units (depth and thickness of layers)	Seismic Refraction	Seismic Wave Propagation
Depth to Bedrock	Seismic Refraction, Electrical Resistivity, Ground Penetrating Radar	Seismic Wave Propagation
Depth to Groundwater Table	Seismic Refraction, Electrical Resistivity, Ground Penetrating Radar	
Location of Highly Fractured Rock and/or Fault Zone	Electrical Resistivity	Borehole TV Camera
Bedrock Topography (troughs, pinnacles, fault scarp)	Seismic Refraction, Gravity	
Location of Planar Igneous Intrusions	Gravity, Magnetics, Seismic Refraction	
Solution Cavities	Electrical Resistivity, Ground Penetrating Radar, Gravity	Borehole TV Camera
Isolated Pods of Sand, Gravel, or Organic Material	Electrical Resistivity	Seismic Wave Propagation
Permeable Rock and Soil Units	Electrical Resistivity	Seismic Wave Propagation
Topography of Lake, Bay or River Bottoms	Seismic Reflection (acoustic sounding)	
Stratigraphy of Lake, Bay or River Bottom Sediments	Seismic Reflection (acoustic sounding)	
Lateral Changes in Lithology of Rock and Soil Units	Seismic Refraction, Electrical Resistivity	

are routinely carried out for assessment of subsurface conditions prior to engineering projects. An example gradient velocity model, with conventional layered model superimposed has been presented in Figure 2 hereunder:

Based on the velocity model, thickness and topography of overburden, weathered rock and bedrock are easily obtained based on P-wave velocities.

Key features of seismic refraction survey are:

- Precise determination of soil thickness.
- Localization and identification of geological units.
- Great accessibility to rough terrain and remote regions.

Key applications of seismic refraction survey are:

- Bedrock profile, rock quality and depth.
- Thickness of overburden

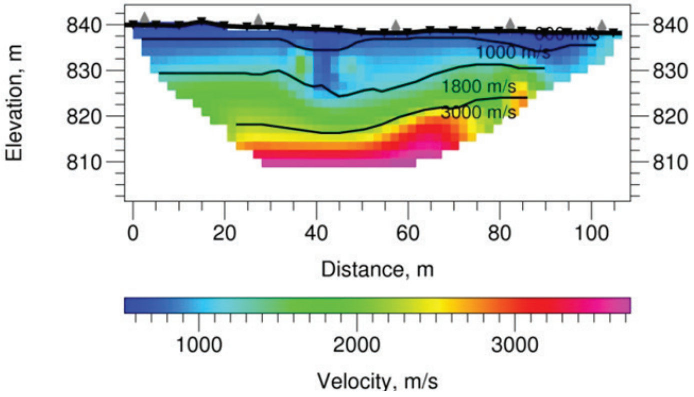

Figure 2: Example of a seismic refraction result (Vp)

- Fractures and weak zones
- Topography of ground water
- Slope stability studies
- Pipeline route studies

Key limitations of seismic refraction survey are:

- Velocity increase with depth is a pre-requisite
- Hidden layer and Blind Zone anomalies

5.2 Electrical resistivity imaging

2D Resistivity Imaging provides the variation in resistivity both along the survey line and with depth. The technique is extremely useful for investigations of important sites to get information on weak zones or buried channels, under the rock interface, which goes undetected in seismic refraction, which terminated at rock interface. Resistivity imaging can also be effectively used to determine rock profile along bridge axis across high current shallow rivers where deployment of hydrophones is not possible restricting use of seismic refraction. In such cases resistivity imaging (Figure 3) can be effectively used to get detailed information of deeper layers.

Key applications of Electrical Resistivity Imaging are:

- Determine the underground water resources
- Bedrock quality and depth measurements
- Dam structure analysis
- Landfill
- Contamination source detection

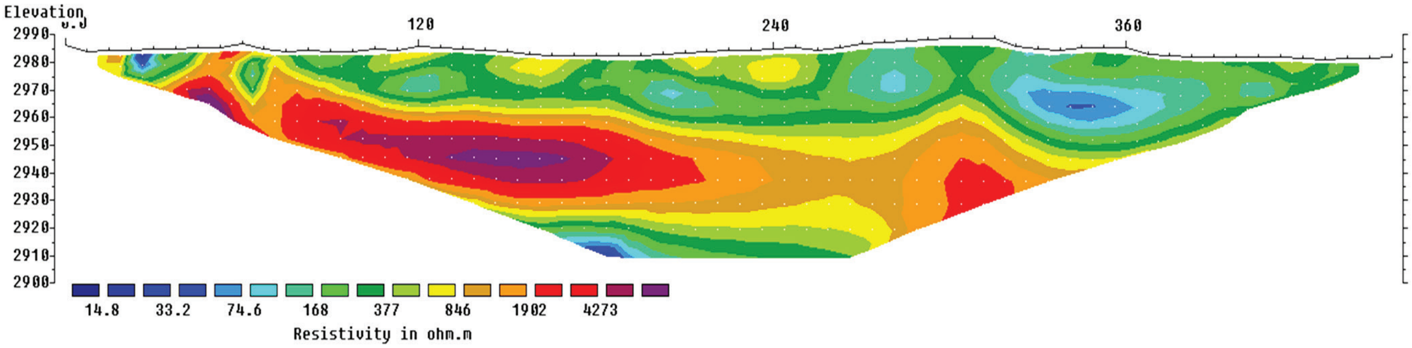

Figure 3: Example electrical resistivity imaging result

Key advantages of Electrical Resistivity Imaging are:

- Excellent 2-dimensional display of ground resistivity.
- Delineation of small features like cavity, contamination plumes, weak zones in structures like dams

Key limitations of Electrical Resistivity Imaging are:

- Good ground contact of electrodes is a must
- Inversion process can produce artefacts

5.3 Multichannel analysis of surface waves (MASW)

MASW analyses the propagation velocities of surface waves, and provides shear-wave velocity (Vs) variations below the surveyed area. Shear-wave velocity (Vs) is one of the elastic constants and closely related to Young's modulus. Under most circumstances, Vs is a direct indicator of the ground strength. After a relatively simple procedure, final Vs information is provided in 1-D, 2-D, and 3-D formats. Figure 4 below shows field data acquisition set up.

Key features of MASW are:

- Quick estimation of shear wave velocity.
- Possible to conduct test in active (with energy source) or passive mode.

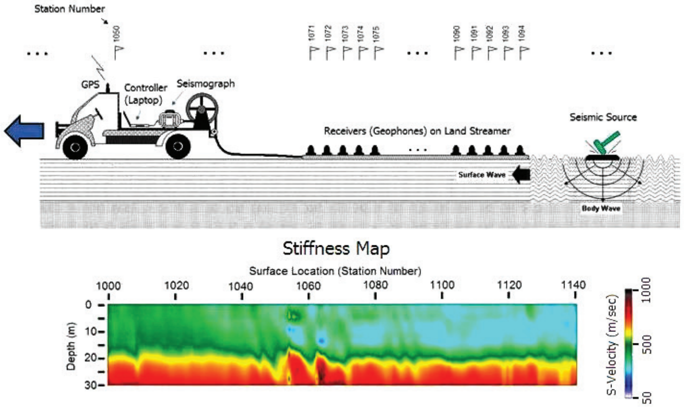

Figure 4: Field setup and results of MAS

Key applications of MASW are:

- Soil stiffness study.
- Vs30 determination
- Detection of voids and cavities

Key limitations of MASW are:

- Provides 1D profiles which are interpolated to create a 2D section
- Ground should be relatively flat for good results

Figure 5 below shows results from MASW.

5.4 Cross-hole seismic surveys

The primary purpose of obtaining cross-hole data is to obtain the most detailed in situ seismic wave velocity profile for site-specific investigations and material Characterization. Cross-hole velocity data are valuable for assessing man-made materials, soil deposits, or rock formations.

The seismic technique determines the compressional (P) and/or shear (S) wave velocity of materials at depths of engineering and environmental concern where the data can be used in problems related to soil mechanics, rock mechanics, foundation studies, and earthquake engineering.

The set-up for cross hole tests include a source hole and 02 receiver holes as shown hereunder:

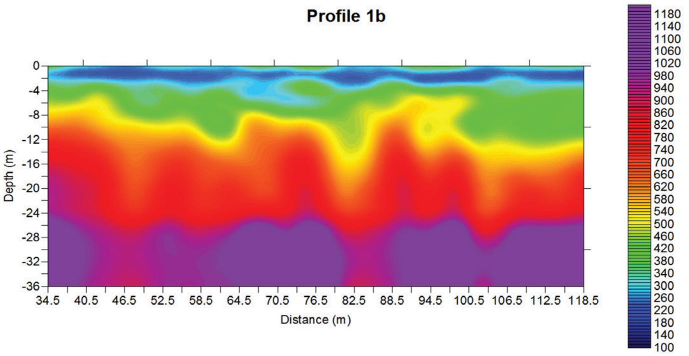

Figure 5: Results for MASW (Vs in m/s)

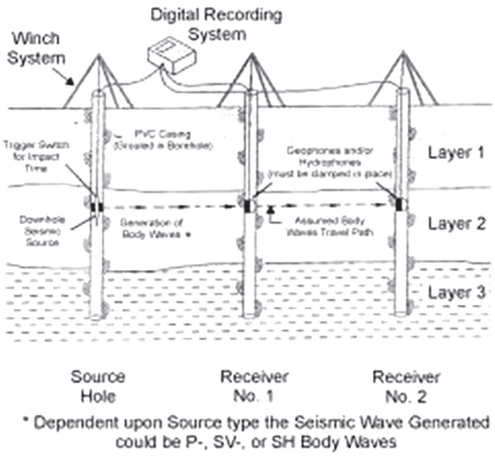

Figure 6: Typical cross-hole setup

The method allows precise determination of P and S wave seismic velocities which leads to determination of Dynamic Elastic Moduli like Poisson's Ration, Young's Modulus, Shear Modulus. Cross-hole method detects even thin anomalous zones in subsurface.

Key features of cross-hole seismic survey are:

- Vp and Vs determination with depth.
- Provides dynamic moduli of site for different layers.
- Cross-hole seismic testing has the definitive advantage of assessing a complex layered velocity structure with alternating high and low relative velocities.

Key applications of cross-hole seismic survey are:

- Liquefaction analysis
- Earthquake site response studies

Key limitations of cross-hole seismic survey are:

- Good borehole preparation is critical for a successful cross-hole survey
- Very large source-receiver borehole spacing creates problems with refractions from layer boundaries received before direct arrivals.

5.5 Ground penetrating radar

Ground Penetrating Radar, also known as GPR, Georadar, Subsurface Interface Radar, Geoprobing Radar, is a totally non-destructive technique to produce a cross section profile of subsurface without any drilling, trenching or ground disturbances. Ground penetrating radar (GPR) profiles are used for evaluating the location and depth of buried objects and to investigate the presence and continuity of natural subsurface conditions and features.

Key application areas of GPR are:

- Geological and hydro-geological investigations including mapping of bedrock topography, water levels, solution features, glacial structures, soils and aggregates.

Figure 7: GPR field work

- Engineering investigations to evaluate piles, bridge decks and river scour.
- Location and evaluation of buried structures including utilities, foundations, reinforcing bars, cavities, tombs, archaeological artifacts, and animal burrows.
- Subsurface mapping for cables, pipes and other buried structures.

Key advantages of GPR are

- Rapid ground coverage- Antenna towed either by hand or from a vehicle.
- High-resolution coverage of the survey area, detecting even small objects.
- On-site interpretation possible due to instant graphic display.

Key limitations of GPR are:

- Data acquisition may be slow over difficult terrain.
- Depth of penetration is limited in materials with high electrical conductivities, like clays.
- Artifacts in the near surface (reinforcing bars, boulders, components of made ground) may scatter the transmitted energy and complicate the received signal and/or reduce depth of penetration.
- Working on principle of reflection, GPR detects the utilities and provides information on depth and location.

6. CONCLUSIONS

Geophysical Methods are non-destructive and can be used individually or in association with one another for the best results of site investigation and post construction condition evaluation of any geotechnical structure like roads, pavements, highways or bridges. The right selection of techniques requires skilled expertise and experience and is the key to successful site exploration or structural integrity assessment.

All major bridge projects where linear water way exceeding 100m, longer elevated corridors, hilly terrains, flyovers in urban limits and all expected difficult sub soil conditions shall be investigated for geophysical studies prior to geotechnical investigations. The borehole locations for the geotechnical investigations shall be optimized for number of bores and depth of investigation based on geophysical studies already carried out.

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