Engineering Geology

Unit – 4 Part – 2

Principles of Geophysical exploration methods for Subsurface Investigation

The geophysical exploration methods are subdivided into two major methods, i.e.,

1. Electrical Resistivity Method
2. Siesmic Refraction Method

Electrical Resistivity Methods

The electrical resistivity method is used to map the subsurface electrical resistivity structure, which is interpreted by the geophysicist to determine geologic structure and/or physical properties of the geologic materials. The electrical resistivity of a geologic unit or target is measured in ohmmeters, and is a function of porosity, permeability, water saturation and the concentration of dissolved solids in pore fluids within the subsurface. Electrical resistivity methods measure the bulk resistivity of the subsurface as do electromagnetic methods.

The electrical geophysical methods are used to determine the electrical resistivity of the earth's subsurface. Thus, electrical methods are employed for those applications in which a knowledge of resistivity or the resistivity distribution will solve or shed light on the problem at hand. The resolution, depth, and areal extent of investigation are functions of the particular electrical method employed. Once resistivity data have been acquired, the resistivity distribution of the subsurface can be interpreted in terms of soil characteristics and/or rock type and geological structure. Resistivity data are usually integrated with other geophysical results and with surface and subsurface geological data to arrive at an interpretation.

Electrical methods can be broadly classified into two groups: those using a controlled (human-generated) energy source and those using naturally occurring electrical or electromagnetic energy as a source. The controlled source methods are most commonly used for shallow investigations, from characterizing surficial materials to investigating resistivities down to depths as great as 1 to 2 km, although greater depths of investigation are possible with some techniques and under some conditions. The natural source methods are applicable from depths of tens of meters to great depths well beyond those of interest to hydrocarbon development.

Controlled source methods

Controlled source methods use generated currents or electromagnetic fields as energy sources. An advantage is the control over energy levels and the attendant positive effects on signal to noise ratio in areas of high cultural noise. A disadvantage of controlled source methods is that the complex nature of the source field geometry (the geometry of the electromagnetic field or currents induced with the earth by the transmitter) may present quantitative interpretation problems in areas of complex geology.

In the ***DC method***, a current (usually a very low frequency square wave and not actually direct current) is injected into the earth through a pair of current electrodes, and the resulting potential field is mapped. Various geometries of current and potential electrodes have been employed, with the choice primarily based upon the depth and geometry of the survey target. The measured surface potential field is interpreted in terms of the subsurface resistivity distribution through modeling and inversion techniques.[2] *Induced polarization* (*IP*) and *complex resistivity* (*CR*) techniques are special cases of the DC method in which the induced potential field is measured and interpreted in terms of mineralogy and/or soil characteristics. IP and CR have been applied with some success to hydrocarbon exploration through the measurement of geochemical alteration halos that have been found to be related to reservoirs under some conditions.

In the ***electromagnetic* (*EM*) *method*,** an electromagnetic field is produced on or above the surface of the ground. This primary EM field induces currents in subsurface conductors. The induced currents in turn reradiate secondary EM fields. These secondary fields can be detected on or above the surface as either a distortion in the primary field (frequency domain methods) or as they decay following the turning off of the primary field (time domain methods). Both loops and grounded wires are used to generate the source field. Resistivities are calculated from the observed electromagnetic field data using modeling and inversion techniques.

EM techniques have been adapted to a variety of surface and airborne configuration, with the airborne instruments generally limited in penetration to 100 to 200 m. Airborne electromagnetic surveys have proven very effective for mapping the shallow resistivity distribution, leading to cost-effective surveys over large areas. Surface loop or grounded wire systems are applicable to depths well in excess of 1 km, although high power transmitters are required as depth increases. The resolution attainable is normally considered as a percentage of penetration depth, such that absolute resolution decreases with depth.

In the ***controlled source magnetotelluric*** (***CSMT***) *method*, a low frequency electromagnetic wave is generated, and the electrical and magnetic fields are measured at some distance from the transmitter. The wave impedance of the electromagnetic wave at the receiver is calculated from the electrical and magnetic field values as a function of frequency and then interpreted in terms of the subsurface resistivity distribution. Depths of penetration in excess of 1 to 2 km are attainable under suitable conditions.

Ground probing radar (***GPR***) is used for detailed investigations of the shallow subsurface. An extremely short pulse is generated and transmitted into the earth and reflections are received from interfaces between materials of differing resistivity and dielectrical constant. GPR instrumentation is sophisticated but highly portable. Depth of penetration is limited from less than 0.3 m in silty soils to over 100 m in permafrost, freshwater-saturated sand, and some very low porosity rocks. Successful applications include the measurement of ice thickness, the location of cracks in ice, permafrost studies, the detailed mapping of the bedrock surface, the examination of soil stratification, and the mapping of contaminant plumes in the shallow subsurface. An important application of GPR is locating buried pipes, tanks, and other objects that reflect the radar pulse

Advantages

A principal advantage of the electrical resistivity method is that quantitative modeling is possible using either computer software or published master curves. The resulting models can provide accurate estimates of depth, thickness and electrical resistivity of subsurface layers. The layered electrical resistivities can then be used to estimate the electrical resistivity of the saturating fluid, which is related to the total concentration of dissolved solids in the fluid.

Limitations

Limitations of using the electrical resistivity method in ground water pollution investigations are largely due to site characteristics, rather than in any inherent limitations of the method. Typically, sites are located in industrial areas that contain an abundance of broad-spectrum electrical noise. In conducting an electrical resistivity survey, the voltages are relayed to the receiver over long wires that are grounded at each end. These wires act as an antenna receiving the radiated electrical noise that in turn degrades the quality of the measured voltages. Electrical resistivity surveys require a fairly large area, far removed from power lines and grounded metallic structures such as metal fences, pipelines and railroad tracks. This requirement precludes using this technique at many ground water pollution sites.

Seismic Refraction Method

Seismic refraction is a geophysical principle (see refraction) governed by Snell's Law. Used in the fields of engineering geology, geotechnical engineering and exploration geophysics, seismic refraction traverses (seismic lines) are performed using a seismograph(s) and/or geophone(s), in an array and an energy source. The seismic refraction method utilizes the refraction of seismic waves on geologic layers and rock/soil units in order to characterize the subsurface geologic conditions and geologic structure.

The methods depend on the fact that seismic waves have differing velocities in different types of soil (or rock): in addition, the waves are refracted when they cross the boundary between different types (or conditions) of soil or rock. The methods enable the general soil types and the approximate depth to strata boundaries, or to bedrock, to be determined.

Seismic P-Wave Behavior

P-waves traveling through rock are analogous to sound waves traveling through air. The speed a P-wave propagates through a medium depends on the physical properties (i.e. rigidity, density, saturation) and degree of homogeneity of the rock. Spherical wave fronts emanate from a source, as well as ray paths. Ray paths travel normal to the spherical wave surface. For seismic refraction discussion, it is useful to imagine seismic waves as ray paths.

When a ray encounters an inhomogeneity in its travels, for example a lithological contact with another rock, the incident ray transforms into several new rays. A reflected wave enters and exits at the same angle measured to the normal of the boundary - angle of incidence equals angle of reflection.

From **Snell's Law**, a ray path is dependent on the wave velocities through different layers. For refraction seismology, the critical angle is the most important angle value to understand. If angle (r) equals 90 degrees, then the refracted wave propagates along the boundary interface. One can solve for the critical angle (i_c) by calculating inverse sine of (V1/V2). As the critically refracted wave propagates along the boundary, according to Huygen's Theory of Wavelets, the primary critically refracted wave acts as a source for new secondary wave fronts and ray paths. These secondary ray paths exit at the critical angle.

S-Wave Refraction (Shear Wave Refraction)

S-wave refraction evaluates the shear wave generated by the seismic source located at a known distance from the array. The wave is generated by horizontally striking an object on the ground surface to induce the shear wave. Since the shear wave is the second fastest wave, it is sometimes referred to as the secondary wave. When compared to the compression wave, the shear wave is approximately one-half (but may vary significantly from this estimate) the velocity depending on the medium.