

## Geophysical Exploration

Seismic refraction survey  
 Cross hole seismic survey  
 Resistivity survey

Suitable for investigating large areas  
 Provide rapid results  
 Results should be confirmed by information from borings or pits

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## Seismic Refraction Survey

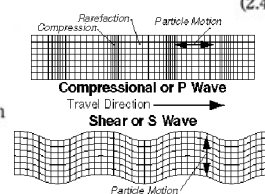
Seismic refraction surveys are useful in obtaining preliminary information about the thickness of the layering of various soils and the depth to rock or hard soil at a site. Refraction surveys are conducted by impacting the surface, as at point *A* in Figure 2.44a, and observing the first arrival of the disturbance (stress waves) at several other points (e.g., *B*, *C*, *D*, ...). The impact can be created by a hammer blow or by a small explosive charge. The first arrival of disturbance waves at various points can be recorded by geophones.

The impact on the ground surface creates two types of stress wave: *P waves* (or plane waves) and *S waves* (or shear waves). The *P waves* travel faster than *S waves*; hence the first arrival of disturbance waves will be related to the velocities of the *P waves* in various layers. The velocity of *P waves* in a medium is

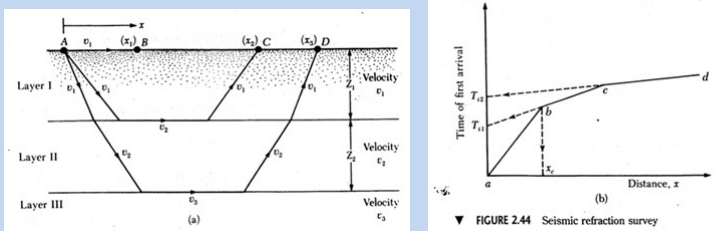
$$v = \sqrt{\frac{E}{\left(\frac{\gamma}{g}\right)(1-2\mu)(1+\mu)}} \quad (2.48)$$

where  $E$  = modulus of elasticity of the medium  
 $\gamma$  = unit weight of the medium  
 $g$  = acceleration due to gravity  
 $\mu$  = Poisson's ratio

To determine the velocity,  $v$ , of *P waves* in various layers and the thicknesses of those layers, use the following procedure.



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1. Obtain the times of first arrival,  $t_1, t_2, t_3, \dots$ , at various distances,  $x_1, x_2, x_3, \dots$ , from the point of impact.
2. Plot a graph of time,  $t$ , against distance,  $x$ . The graph will look like the one shown in Figure 2.44b.
3. Determine the slopes of the lines  $ab, bc, cd, \dots$ .  

$$\text{Slope of } ab = \frac{1}{v_1} \quad \text{Slope of } bc = \frac{1}{v_2} \quad \text{Slope of } cd = \frac{1}{v_3}$$
 where  $v_1, v_2, v_3, \dots$  are the  $P$ -wave velocities in layers I, II, III,  $\dots$ , respectively (Figure 2.44a)
4. Determine the thickness of the top layer as  

$$Z_1 = \frac{1}{2} \sqrt{\frac{v_2 - v_1}{v_2 + v_1}} x_c \quad (2.49)$$
 The value of  $x_c$  can be obtained from the plot, as shown in Figure 2.44b.
5. Determine the thickness of the second layer,  $Z_2$ , shown in Figure 2.44a, as  

$$Z_2 = \frac{1}{2} \left[ T_{R2} - 2Z_1 \frac{\sqrt{v_3^2 - v_1^2}}{v_3 v_1} \right] \frac{v_2 v_3}{\sqrt{v_3^2 - v_2^2}} \quad (2.50)$$
 where  $T_{R2}$  is the time intercept of the line  $cd$  in Figure 2.44b extended backward

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In analyzing the results of a refraction survey, two limitations need to be kept in mind:

1. The basic equations for the refraction survey — that is, Eqs. (2.49) and (2.50) — are based on the assumption that the  $P$ -wave velocity  $v_1 < v_2 < v_3 < \dots$ .
2. When a soil is saturated below the water table, the  $P$ -wave velocity may be deceptive.  $P$  waves can travel with a velocity of about 1500 m/sec (5000 ft/sec) through water. For dry, loose soils, the velocity may be well below 1500 m/sec. However, in a saturated condition, the waves will travel through water present in the void spaces with a velocity of about 1500 m/sec (5000 ft/sec). If the presence of groundwater has not been detected, the  $P$ -wave velocity may be erroneously interpreted to indicate a stronger material (e.g., sandstone) than actually present *in situ*. In general, geophysical interpretations should always be verified by the results obtained from borings.

▼ TABLE 2.10 Range of  $P$ -Wave Velocity in Various Soils and Rocks

Type of soil or rock	P-wave velocity	
	m/sec	ft/sec
<i>Soil</i>		
Sand, dry silt, and fine-grained top soil	200–1,000	650–3,300
Alluvium	500–2,000	1,650–6,600
Compacted clays, clayey gravel, and dense clayey sand	1,000–2,500	3,300–8,200
Loess	250–750	800–2,450
<i>Rock</i>		
Slate and shale	2,500–5,000	8,200–16,400
Sandstone	1,500–5,000	4,900–16,400
Granite	4,000–6,000	13,100–19,700
Sound limestone	5,000–10,000	16,400–32,800

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### Cross-Hole Seismic Survey

The velocity of shear waves created as the result of an impact to a given soil layer can be effectively determined by *cross-hole seismic survey* (Stokoe and Woods, 1972). The principle of this technique is illustrated in Figure 2.46, which shows two holes drilled into the ground at distance  $L$  apart. A vertical impulse is created at the bottom of one borehole by means of an impulse rod. The shear waves thus generated are recorded by a vertically sensitive transducer. The velocity of shear waves,  $v_s$ , can be calculated as

$$v_s = \frac{L}{t} \quad (2.51)$$

where  $t$  = travel time of shear waves

The shear modulus of the soil at the depth of the test can be determined from  $v_s$  as

$$v_s = \sqrt{\frac{G}{(\gamma/g)}} \quad \text{where } G = \text{shear modulus of soil}$$

$$G = \frac{v_s^2 \gamma}{g} \quad (2.52) \quad \begin{array}{l} \gamma = \text{soil unit weight} \\ g = \text{acceleration due to gravity} \end{array}$$

The values of shear modulus are useful in the design of foundations to support vibrating machinery and the like.

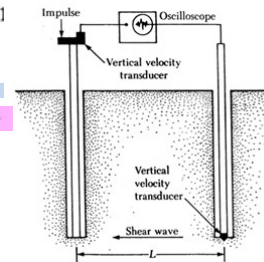


FIGURE 2.46 Cross-hole method of seismic survey

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### Electrical Resistivity Survey

Based on the fact that different types of soil and rock material has significantly different resistivity (an electrical property) that varies with water content, composition etc.

The electrical resistivity,  $\rho$ , of any conducting material having a length  $L$  and an area of cross section  $A$  can be defined as

$$\rho = \frac{RA}{L} \quad (2.53) \quad \text{where } R = \text{electrical resistance}$$

The unit of resistivity is generally expressed as *ohm · centimeter* or *ohm · meter*.

The resistivity of various soils depends primarily on the moisture content and also on the concentration of dissolved ions. Saturated clays have a very low resistivity; in contrast, dry soils and rocks have a high resistivity. The range of resistivity generally encountered in various soils and rocks is given in Table 2.11.

TABLE 2.11 Representative Values of Resistivity

Material	Resistivity (ohm · m)
Sand	500–1500
Clays, saturated silt	0–100
Clayey sand	200–500
Gravel	1500–4000
Weathered rock	1500–2500
Sound rock	>5000

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The most common procedure for measuring electrical resistivity of a soil profile makes use of four electrodes that are driven into the ground and spaced equally along a straight line. It is generally referred to as the *Wenner method* (Figure 2.47a). The two outside electrodes are used to send an electrical current,  $I$ , (usually a dc current with nonpolarizing potential electrodes) into the ground. The electrical current is typically in the range of 50–100 milliamperes. The voltage drop,  $V$ , is measured between the two inside electrodes. If the soil profile is homogeneous, its electrical resistivity is  $\rho = \frac{2\pi dV}{I}$ . (2.54)

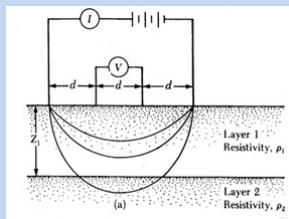
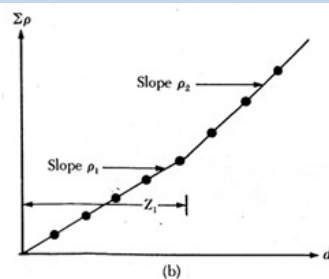


FIGURE 2.47 Electrical resistivity survey: (a) Wenner method;

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In most cases, the soil profile may consist of various layers with different resistivities and Eq. (2.54) will yield the *apparent resistivity*. To obtain the *actual resistivity* of various layers and their thicknesses, an empirical method may be used. It involves conducting tests at various electrode spacings (that is,  $d$  is changed). The sum of the apparent resistivities,  $\Sigma\rho$ , is plotted against the spacing  $d$ , as shown in Figure 2.47b. The plot thus obtained has relatively straight segments. The slopes of these straight segments give the resistivity of individual layers. The thicknesses of various layers can be estimated as shown in Figure 2.47b.



▼ FIGURE 2.47 Electrical resistivity survey: (b) empirical method for determination of resistivity and thickness of each layer

Electrical Resistivity Survey is particularly useful in locating  
gravel deposits within sand layer  
Water table  
Zones of soft material etc.

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### Subsoil Exploration Report

Geotechnical Engineering/c.Venkatramaiah/p.751

A good soil exploration report should comprise of the following:

1. The scope of the investigation
2. A description of the proposed structure for which the subsoil exploration has been conducted
3. A description of the location of the site, including structure(s) nearby, drainage conditions of the site, nature of vegetation on the site and surrounding it, and any other feature(s) unique to the site
4. Geological setting of the site
5. Details of the field exploration — that is, number of borings, depths of borings, type of boring, and so on
6. General description of the subsoil conditions as determined from soil specimens and from related laboratory tests, standard penetration resistance and cone penetration resistance, and so on
7. Water-table conditions
8. Foundation recommendations, including the type of foundation recommended, allowable bearing pressure, and any special construction procedure that may be needed; alternative foundation design procedures should also be discussed in this portion of the report
9. Conclusions and limitations of the investigations

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The following graphical presentations should be attached to the report:

1. Site location map
2. A plan view of the location of the borings with respect to the proposed structures and those existing nearby
3. Boring logs
4. Laboratory test results
5. Other special graphical presentations

The exploration reports should be well planned and documented. They will help in answering questions and solving foundation problems that may arise later during design and construction.

If the recommended types of foundation requires any special attention during construction phase, like dewatering and/or bracing, it should be so stated and the client should be cautioned about the problems that might arise during construction phase.

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