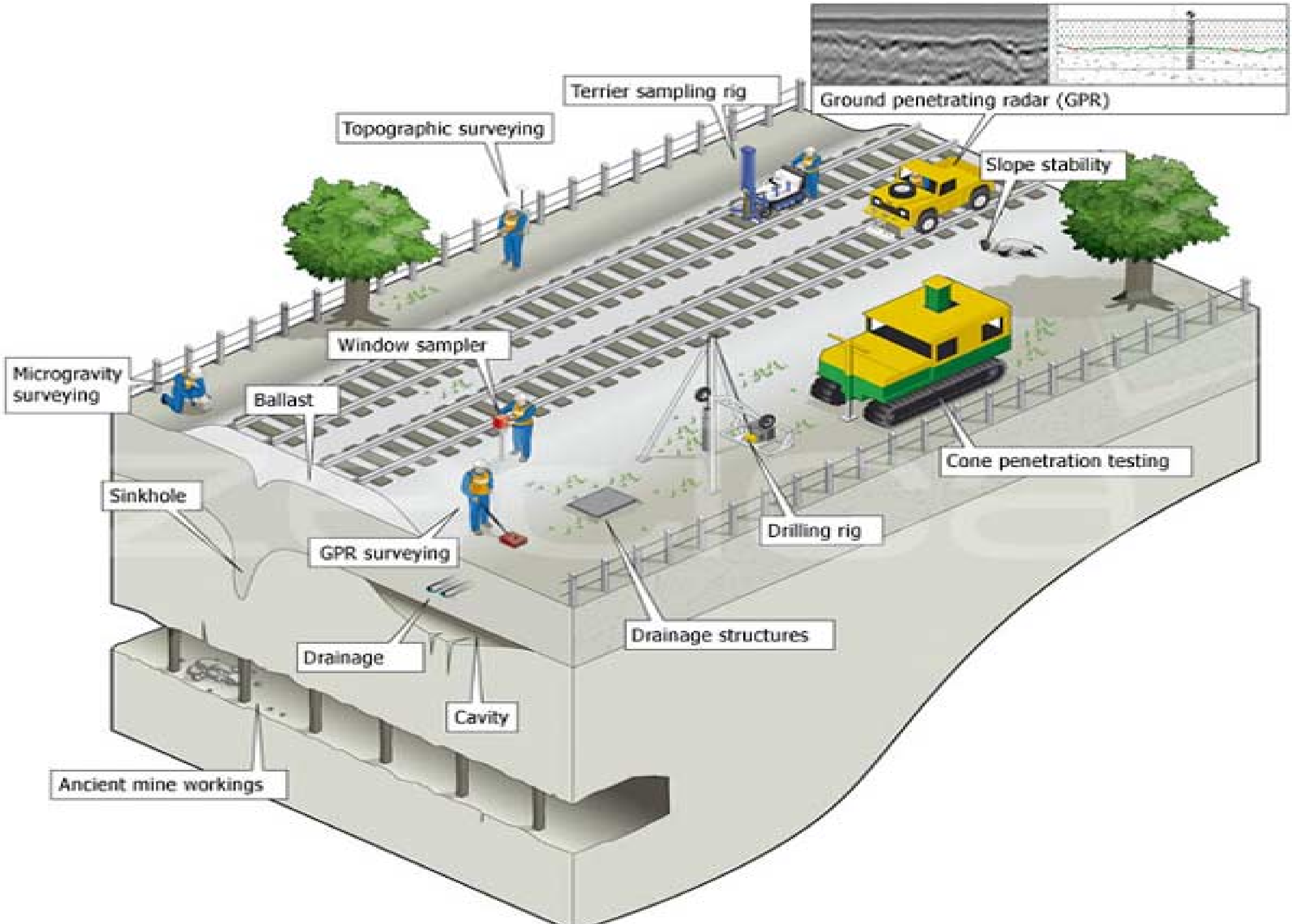
FIELD EVALUATIONS

Methods of Explorations

- **Excavations**
  - **Drilling**
  - **Test Pits**
- **Sampling**
- **Geophysical Testing**
  - **Surface Seismic**
  - **Electrical Resistivity**

FIELD INVESTIGATION



GEOPHYSICAL TESTING

WHAT ?

- Geophysical Exploration consists of making indirect measurements

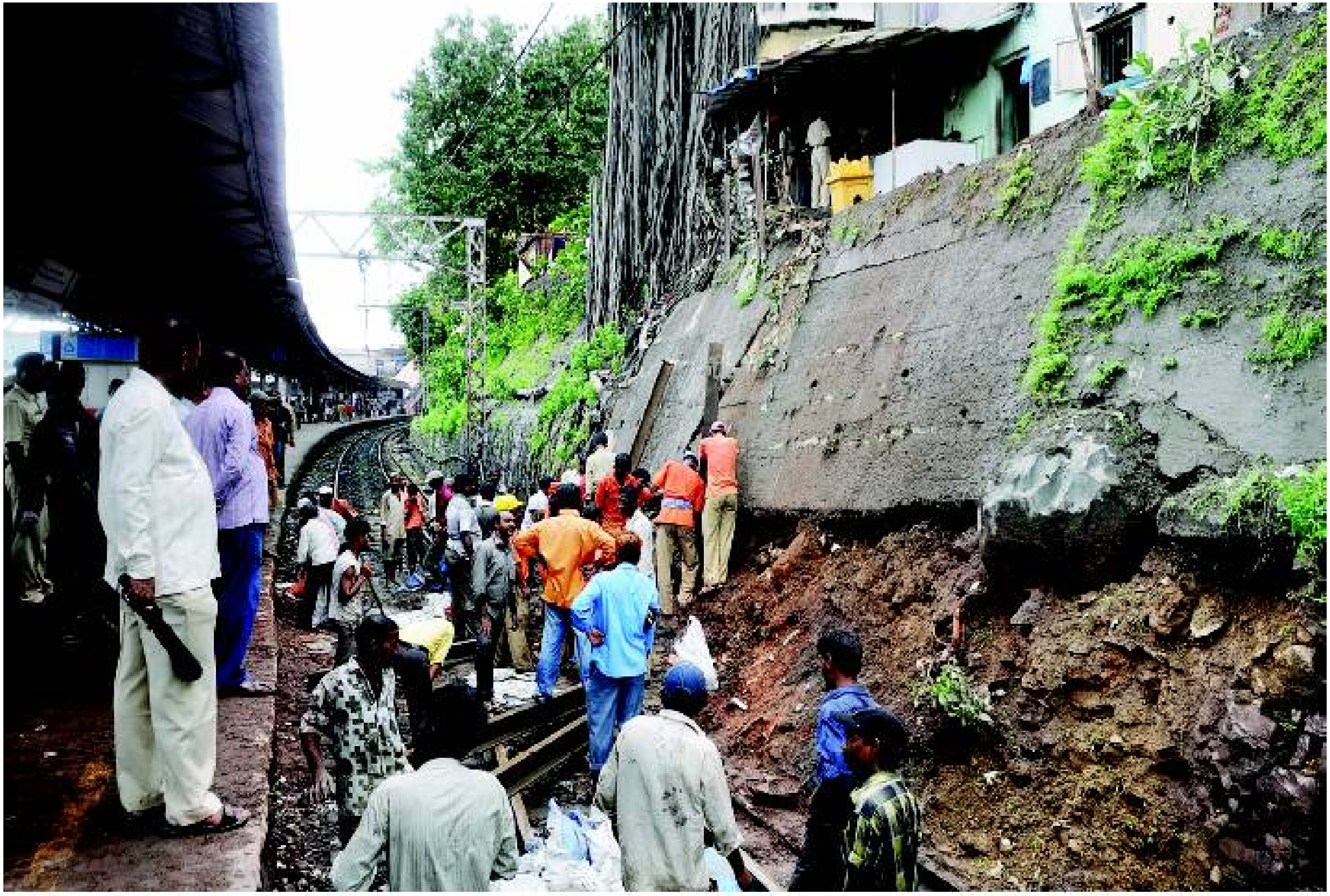
- from the earth’s surface or in borehole

- to obtain subsurface information.

WHY ?

- Requirement of Geotechnical Investigations
  - Grouping of the Subsurface strata with similar Geotechnical Properties
  - Strength
  - Stiffness
- Geophysical Exploration helps in
- *Rapid location and correlation of geological features*
  - Stratigraphy
  - Lithology
  - Discontinuities
  - Ground Water
- *In-situ measurement of*
  - Modulli and Densities

FAILURES



Leaning Tower of Pisa and Sinkholes

HOW ?

General Techniques

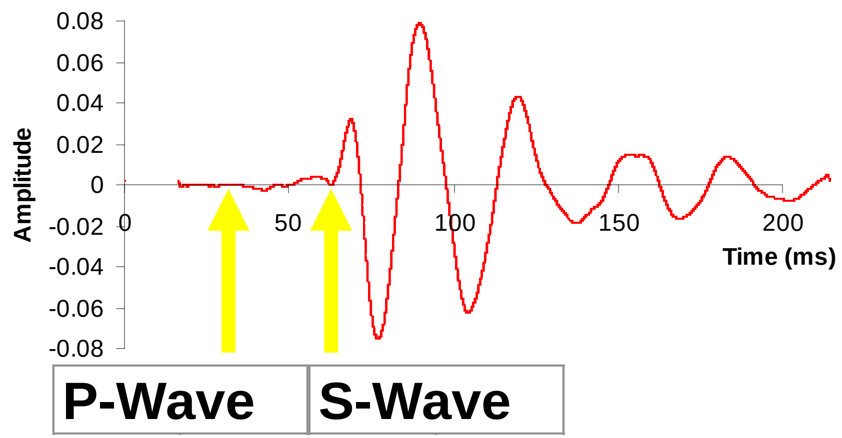
- Seismic ←
- Electrical ←
- Sonic
- Magnetic
- Radar
- Gravity

SEISMIC TECHNIQUES

- ***PRINCIPLE***
  - difference in stiffness of different soil/rock layers
- ***PROCEDURE***
  - An elastic wave is generated in the ground
    - by Impactive force (Falling Weight or Hammer Blow)
    - Explosive Charge
  - Resulting Ground motion is measured using vibration detectors (geophones)
  - Time elapsed will help to evaluate different *Wave Velocities* in different layers

SEISMIC TECHNIQUES

- **_Wave Types_**
  - Longitudinal Waves (P waves)
  - Transverse or Shear Waves (S waves)
  - Rayleigh Waves
  - Love Waves



SEISMIC TECHNIQUES

- ***Methods***

  - **Refraction**
  - **Reflection**
  - **Cross-Hole**
  - **Down-Hole**

SEISMIC METHODS

- Reflection: standard in oil exploration (deep)
- Refraction: for shallow features like depth to bedrock or thickness of the unconsolidated material,
- Also used in deciphering the internal structure of the earth (very deep, need a strong source of vibration like an earthquake)
- Wave/ ray behavior similar to light

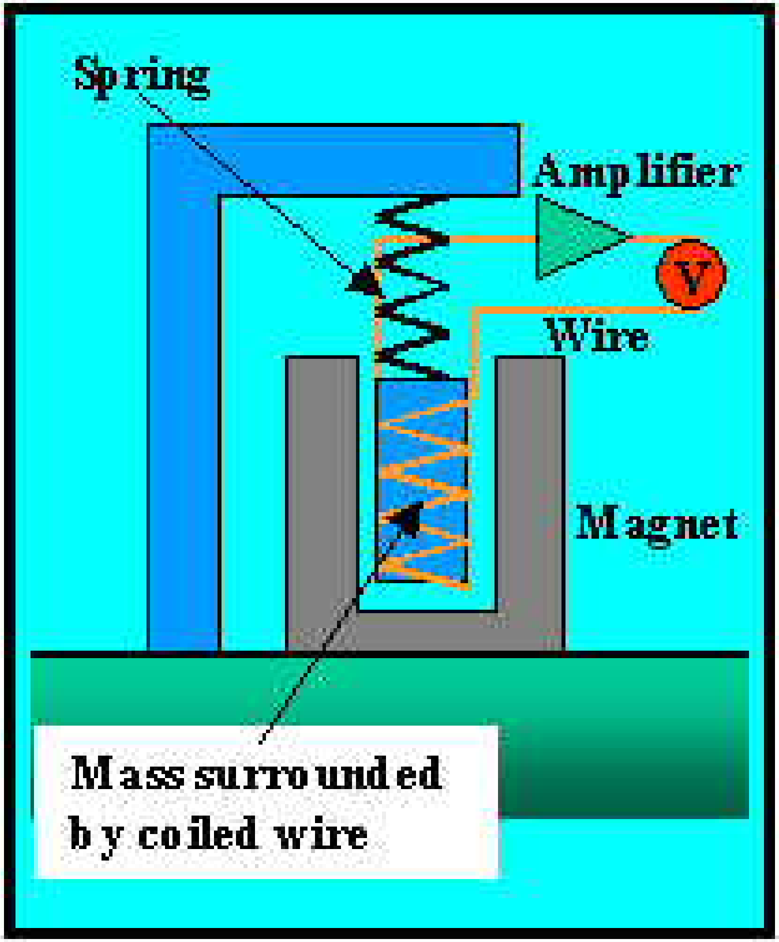
SEISMIC WAVES

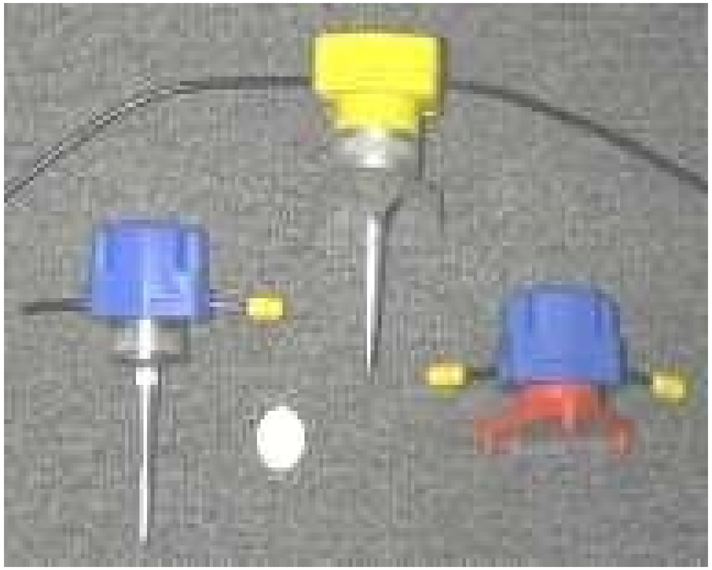
- Surface wave: considered noise
- Body waves: P (compressional) and S (shear)
- Velocity depends on the density of the layers; increases with increasing density
- Incident, reflected, and refracted rays
- Ray gets deflected away from the normal (lighter to a denser medium)
- Critical angle: refracted wave travels along the interface

SEISMIC REFRACTION

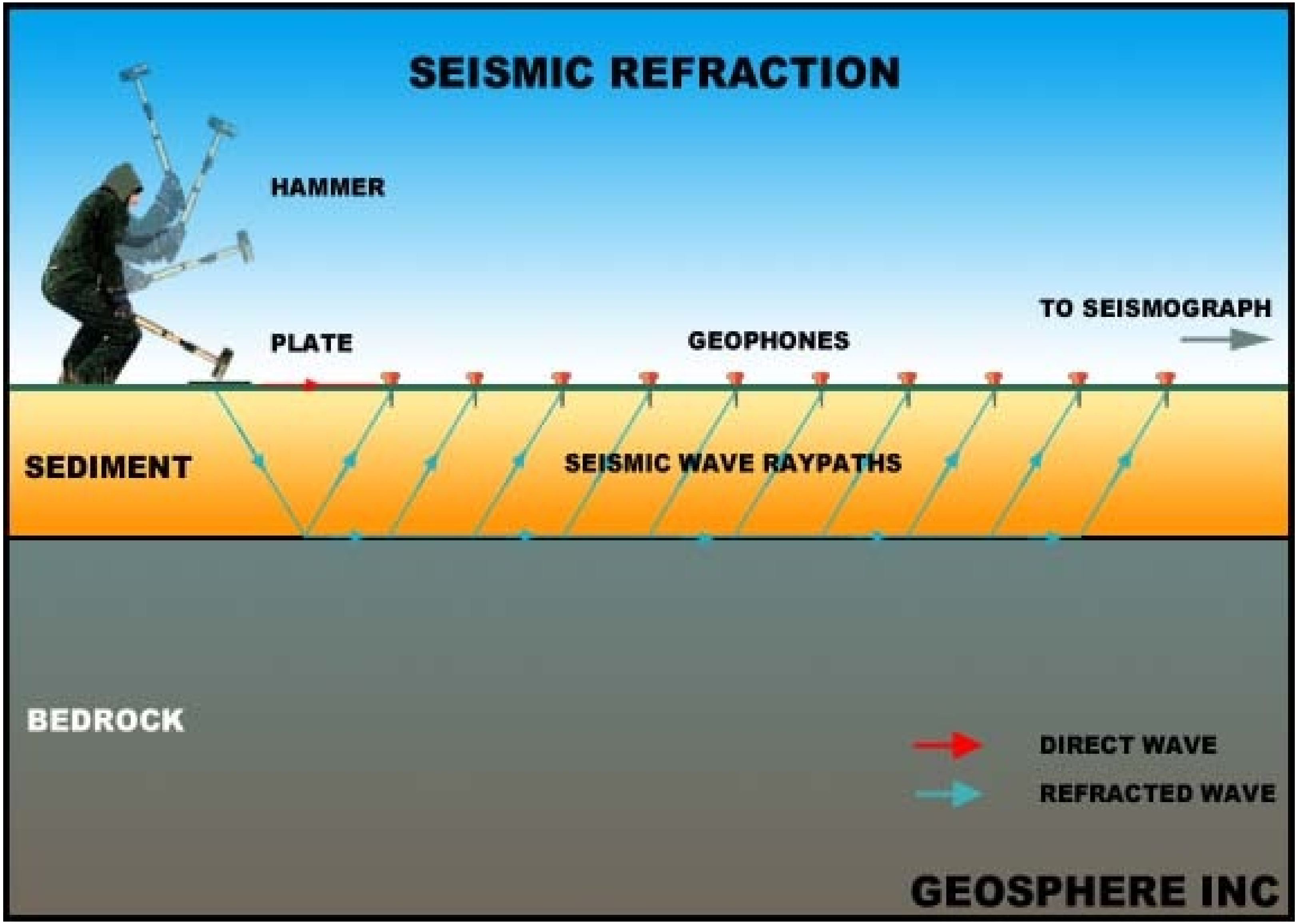
- Energy source: vibration created by a hammer blow or explosive in a drill hole
- Wave propagation: spherical waves in a homogeneous medium, wave fronts
- Rays: perpendicular to wave fronts, shown on diagrams
- Geophone: device that detects vibrations
- Seismograph: device that records the arrival times

GEOPHONE


Spring
Amplifier
V
Wire
Magnet
Mass surrounded
by coiled wire



SEISMIC REFRACTION

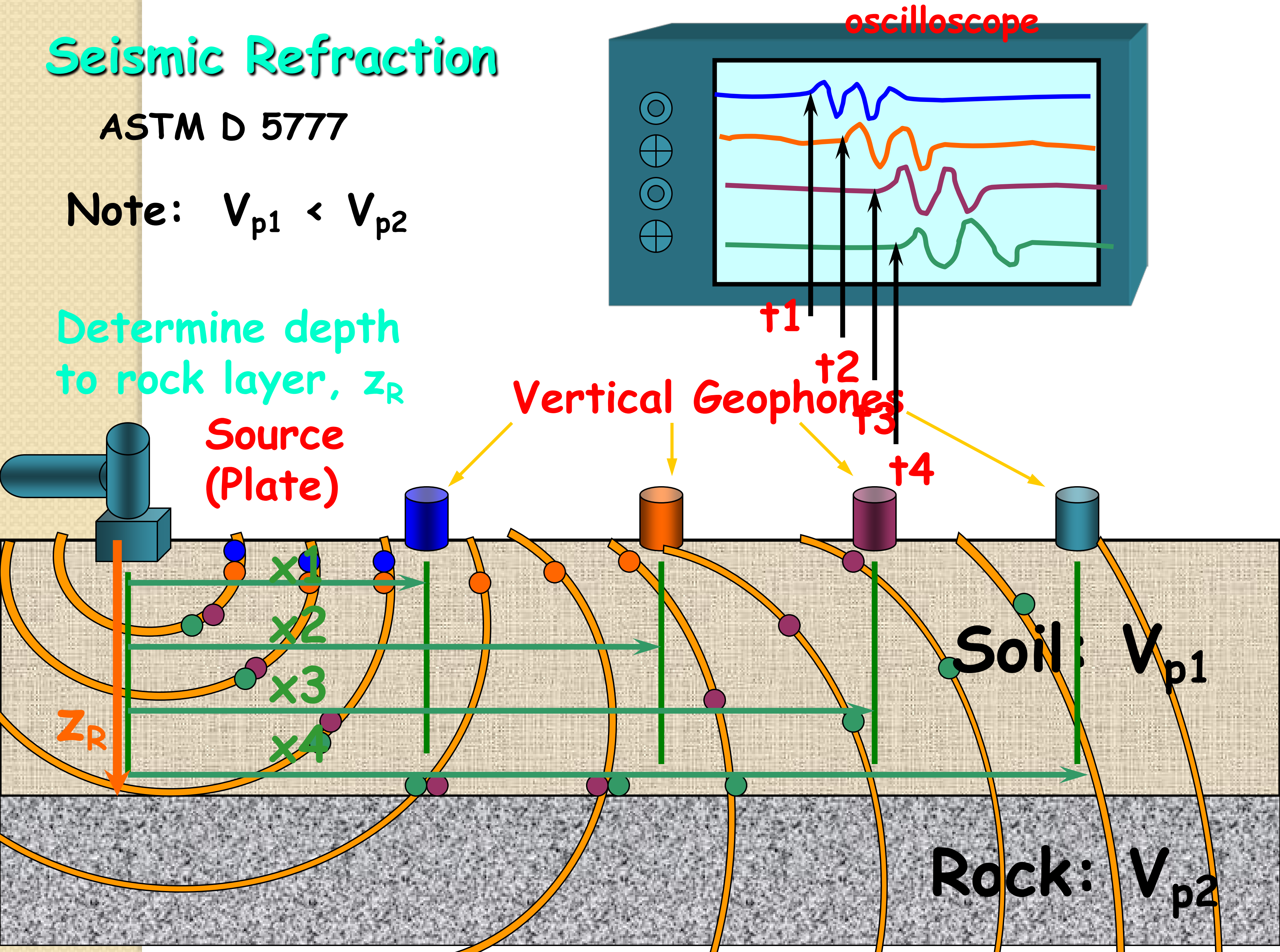


Seismic Refraction

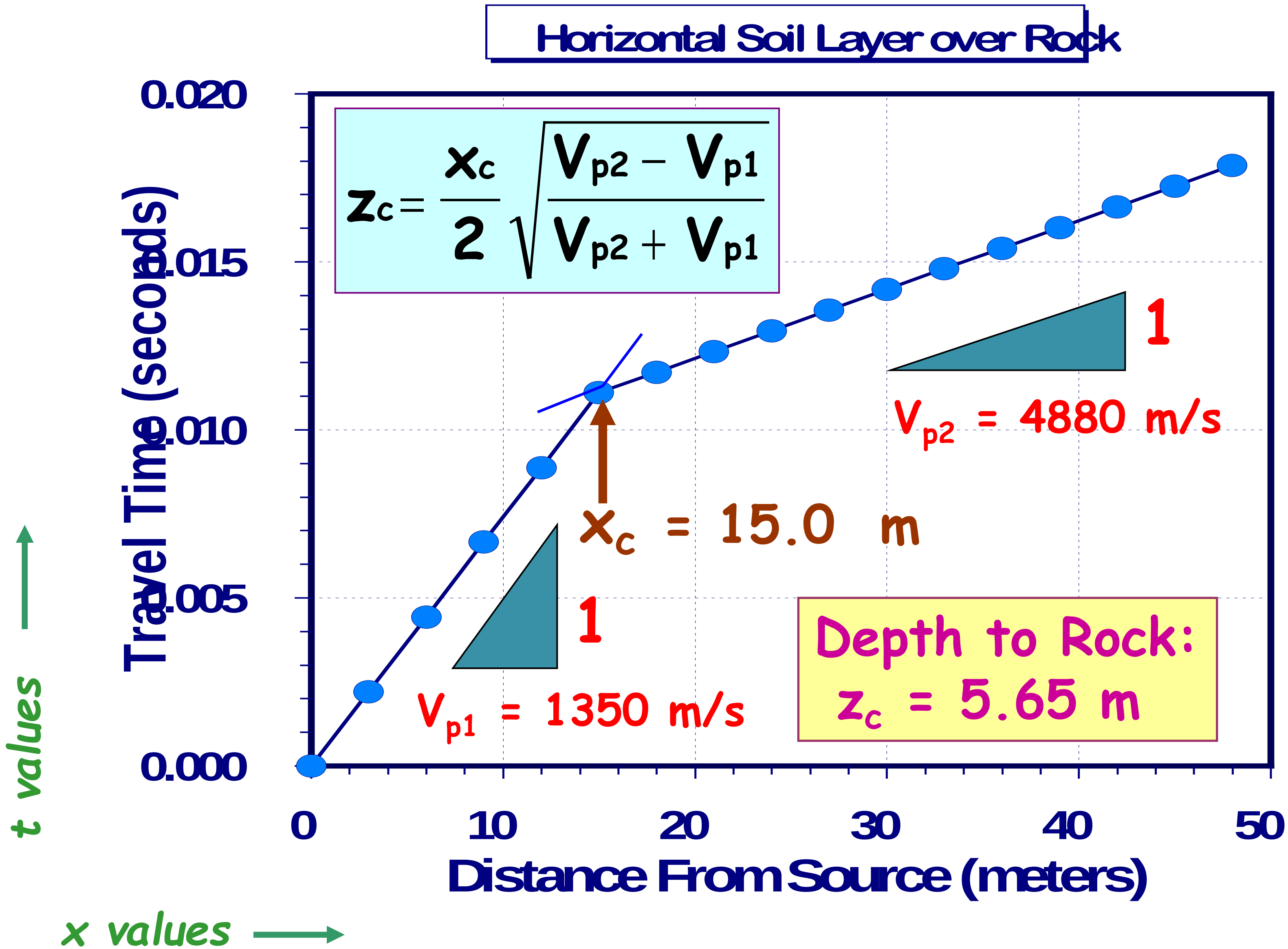
ASTM D 5777

Note: $V_{p1} < V_{p2}$

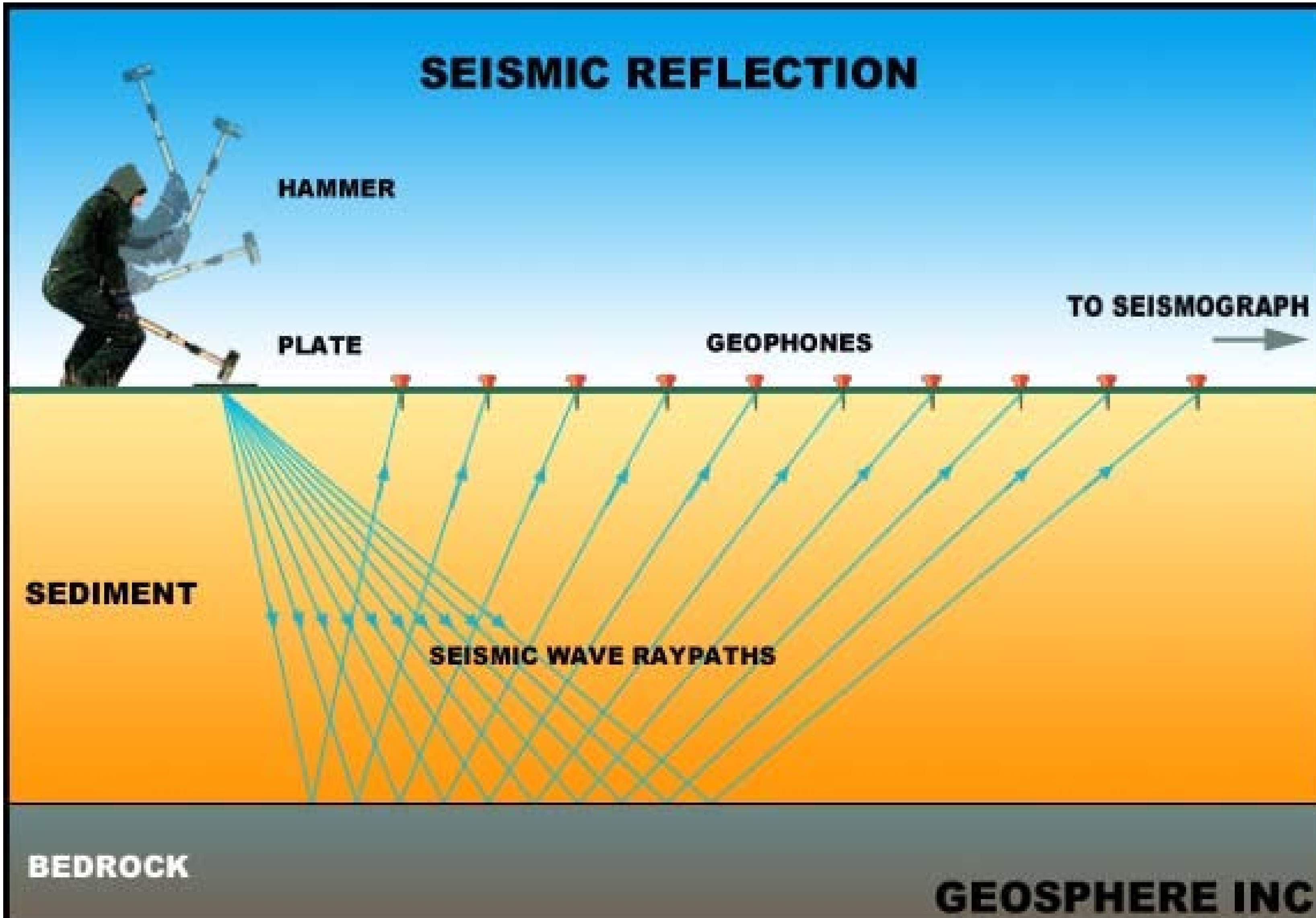
Determine depth to rock layer, z_R



Seismic Refraction



SEISMIC REFLECTION



REFRACTION and REFLECTION

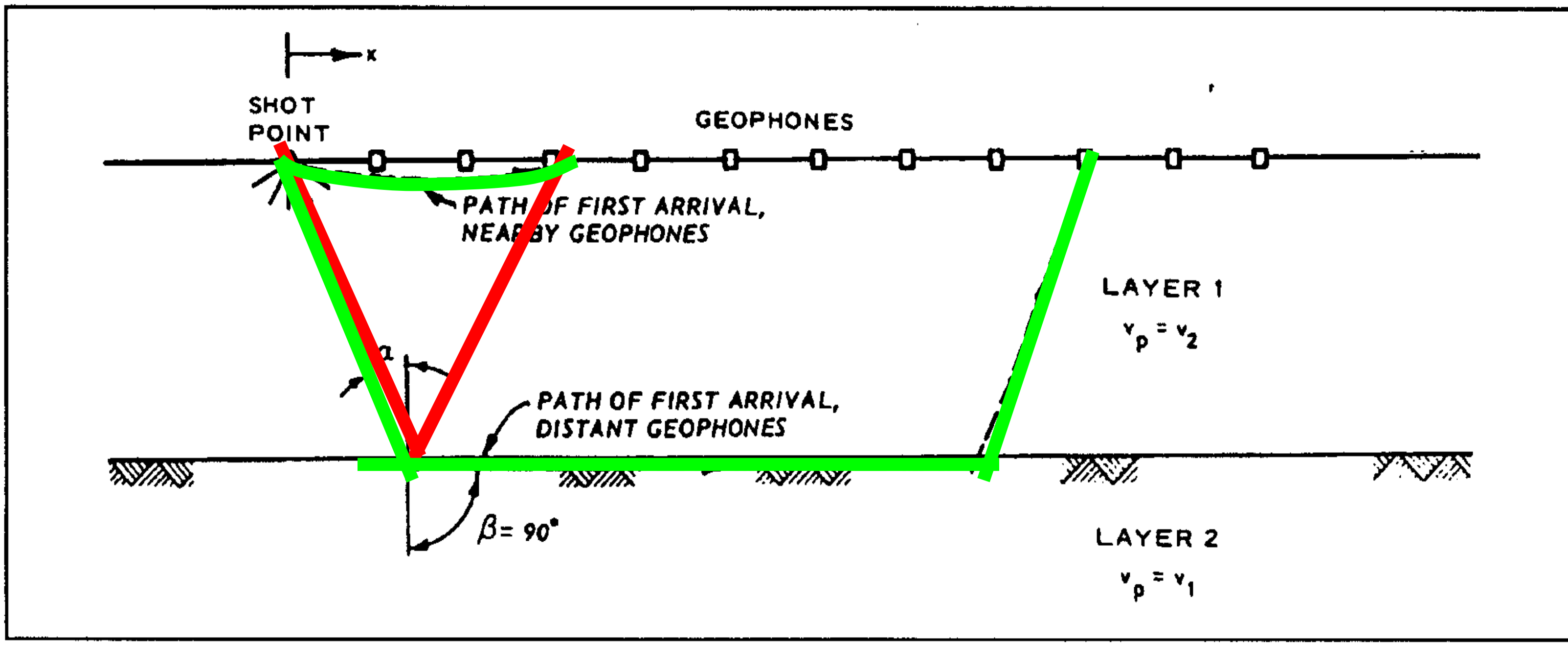
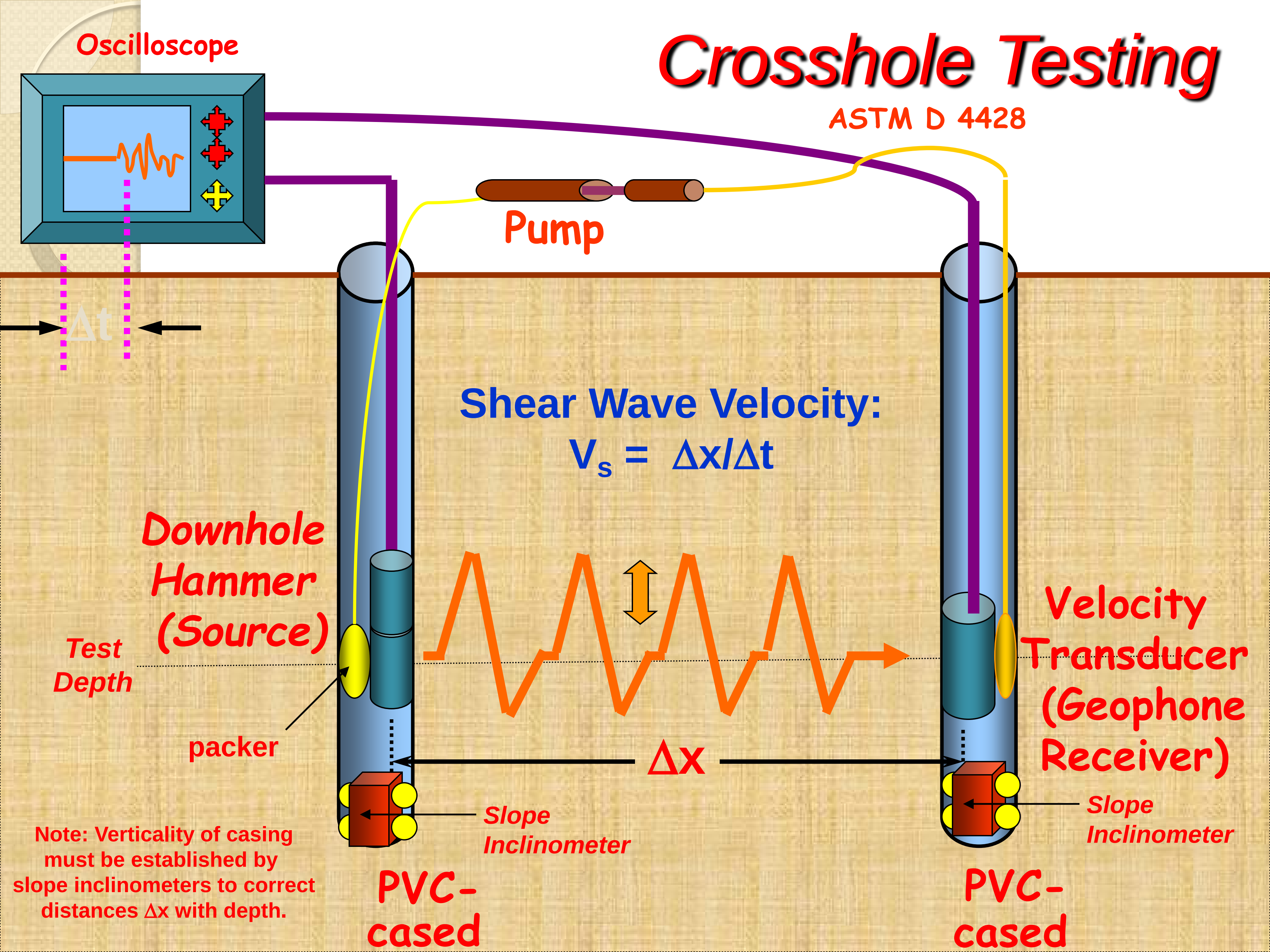


Figure 3-1. Schematic of seismic refraction survey

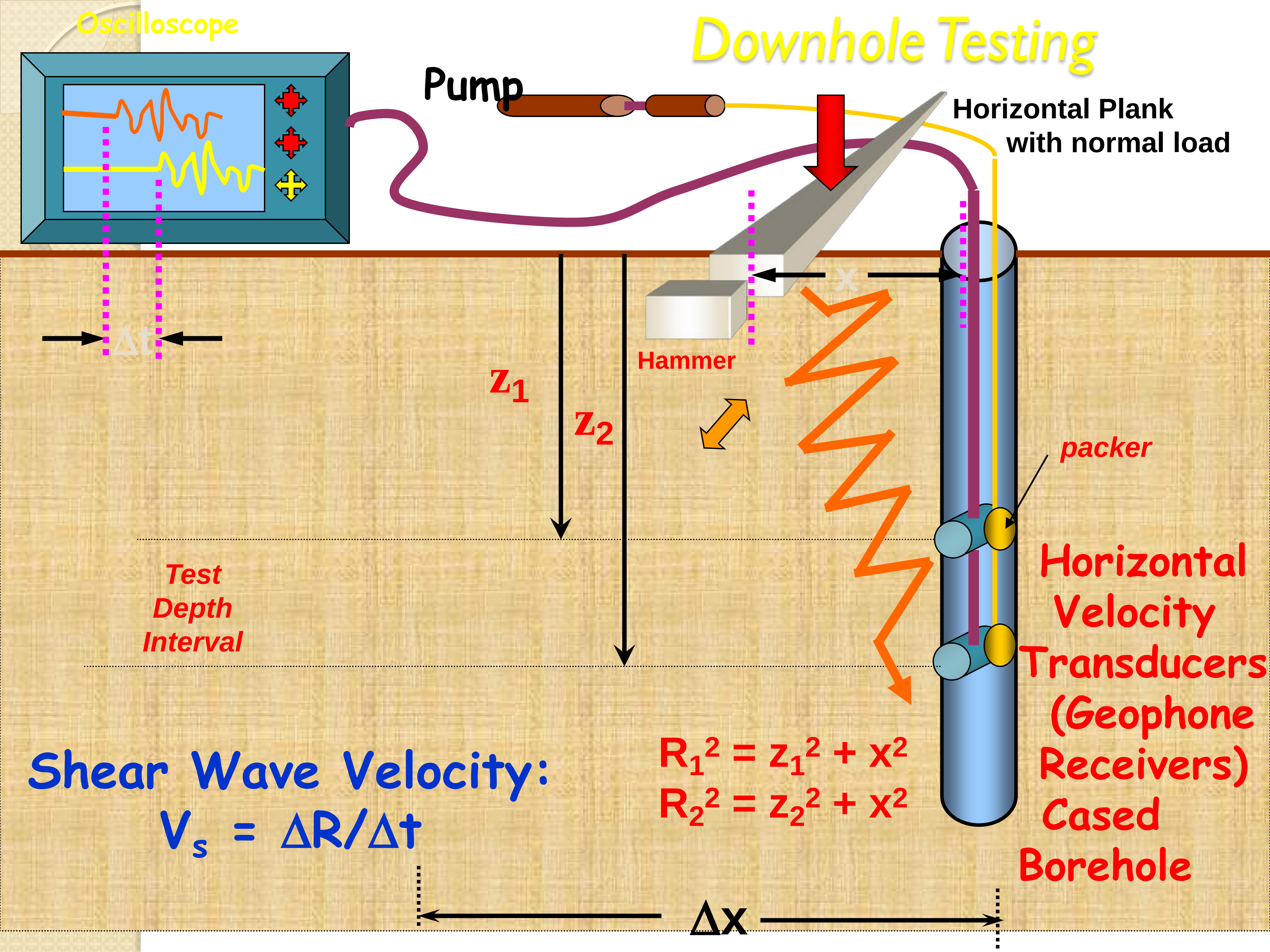
Refracted Wave
Reflected Wave

Crosshole Testing

ASTM D 4428



Note: Verticality of casing must be established by slope inclinometers to correct distances Δx with depth.


Downhole Testing
Oscilloscope
Pump
Horizontal Plank
with normal load
x
Δt
Hammer
z1
z2
packer
Test
Depth
Interval
Horizontal
Velocity
Transducers
(Geophone
Receivers)
Cased
Borehole
$R_1^2 = z_1^2 + x^2$
$R_2^2 = z_2^2 + x^2$
Shear Wave Velocity:
$V_s = \Delta R/\Delta t$
Δx

APPLICATIONS

Table 4-1
Applications of Selected Geophysical and Other Methods for Determination of Engineering Parameters[1]

Method	Basic Measurement	Application	Advantages	Limitations
		Surface		
Refraction seismic	Travel time of compressional waves through subsurface layers	Velocity determination of compression wave through subsurface. Depths to contrasting interfaces and geologic correlation of horizontal layers	Rapid, accurate, and relatively economical technique. Interpretation theory generally straightforward and equipment readily available	Incapable of detecting material of lower velocity underlying higher velocity. Thin stratum sometimes not detectable. Interpretation is not unique
Reflection seismic	Travel time of compressional waves reflected from subsurface layers	Mapping of selected reflector horizons. Depth determinations, fault detection, discontinuities, and other anomalous features	Rapid, thorough coverage of given site area. Data displays highly effective	Even with recent advances in high-resolution, seismic technology applicable to civil works projects is limited in area of resolution
		Borehole		
Uphole/downhole (seismic)	Vertical travel time of compressional and/or shear waves	Velocity determination of vertical P- and/or S-waves. Identification of low-velocity zones	Rapid technique useful to define low-velocity strata. Interpretation straightforward	Care must be exercised to prevent undesirable influence of grouting or casing

(Sheet 2 of 5)

APPLICATIONS

Table 4-2
Numerical Rating of Geophysical Methods to Provide Specific Engineering Parameters[1] Engineering Application

Geophysical Method	Depth to Rock	P-Wave Velocity	S-Wave Velocity	Shear Modulus	Young's Modulus	Poisson's Ratio	Lithology	Material Boundaries Stratigraphy	Dip of Strata	Density	In Situ State of Stress	Temperature	Permeability	Percent Saturation	Ground water Table	Ground water Quality	Ground water Aquifers	Flow Rate and/or Direction	Borehole Diameter	Obstructions	Rippability	Fault Detection	Cavity Detection	Cavity Delineation	Location of Ore Bodies	Borehole Azimuth and Inclination
Surface																										
Refraction (seismic)	4	4	4	4	4	4	1	3	4	2	1	0	0	2	2	0	2	0	0	2	4	3	2	2	3	0
Reflection (seismic)	4	0	0	0	0	0	1	4	4	0	0	0	0	0	2	0	1	0	0	2	0	4	3	3	3	0
Uphole/downhole (seismic)	4	4	4	4	4	4	1	4	0	2	1	0	0	2	2	0	2	0	0	1	2	3	0	2	2	0
Crosshole (seismic)	4	4	4	4	4	4	1	4	2	2	1	0	0	2	2	0	2	0	0	3	2	3	3	2	3	0

(Continued)

[1] Numerical rating refers to applicability of method in terms of current use and future potential:

- 0 = Not considered applicable
- 1 = Limited
- 2 = Used or could be used, but not best approach
- 3 = Excellent potential but not fully developed
- 4 = Generally considered as excellent approach; state of art well developed
- A = In conjunction with other electrical and nuclear logs

[2] Methods not included in EM 1110-1-1802.

[3] Airborne or inhole survey capability not considered.

APPLICATIONS

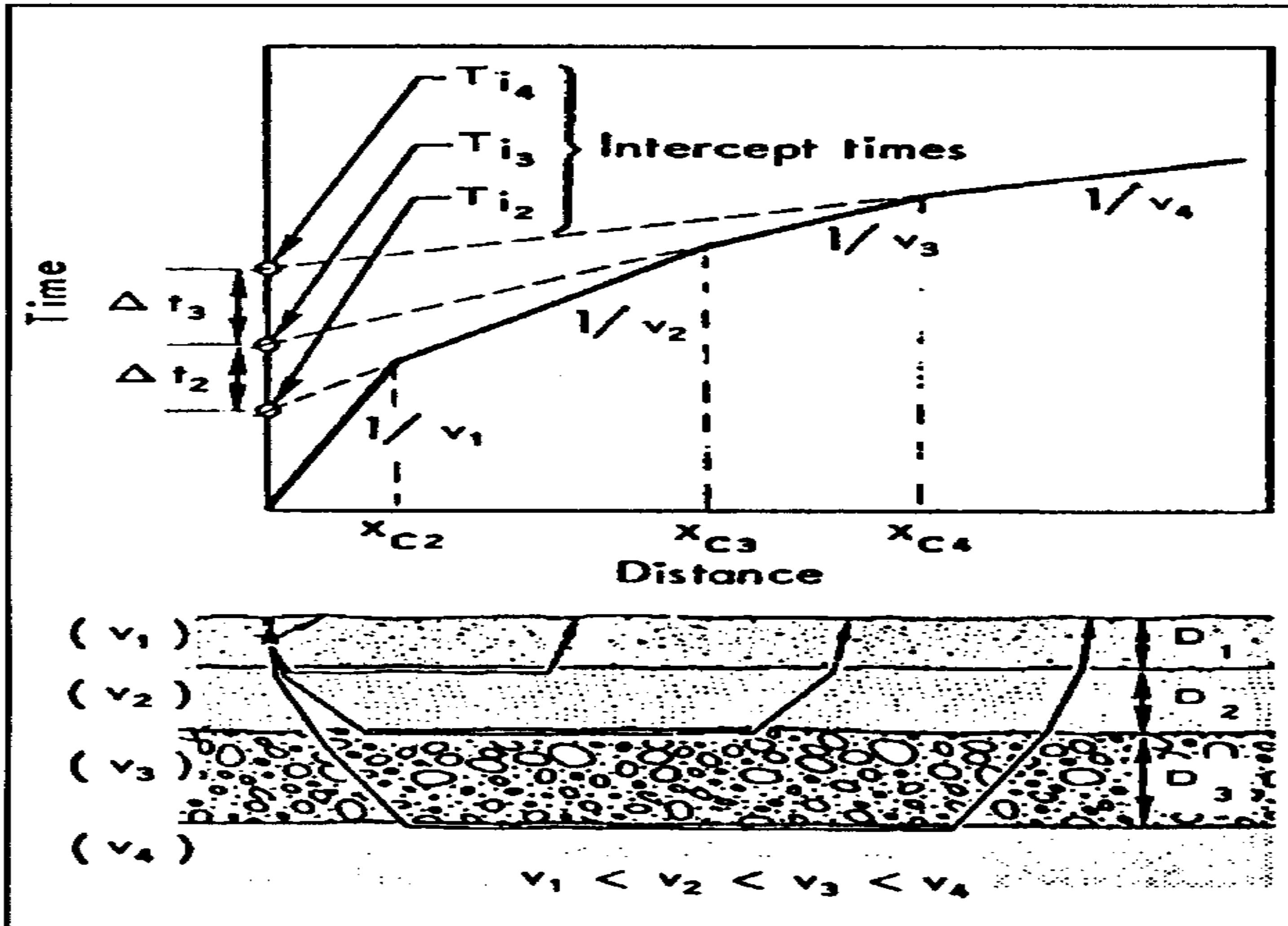


Figure 3-6. Schematic of multiple-layer case and corresponding time-distance curve (Redpath 1973)

APPLICATIONS

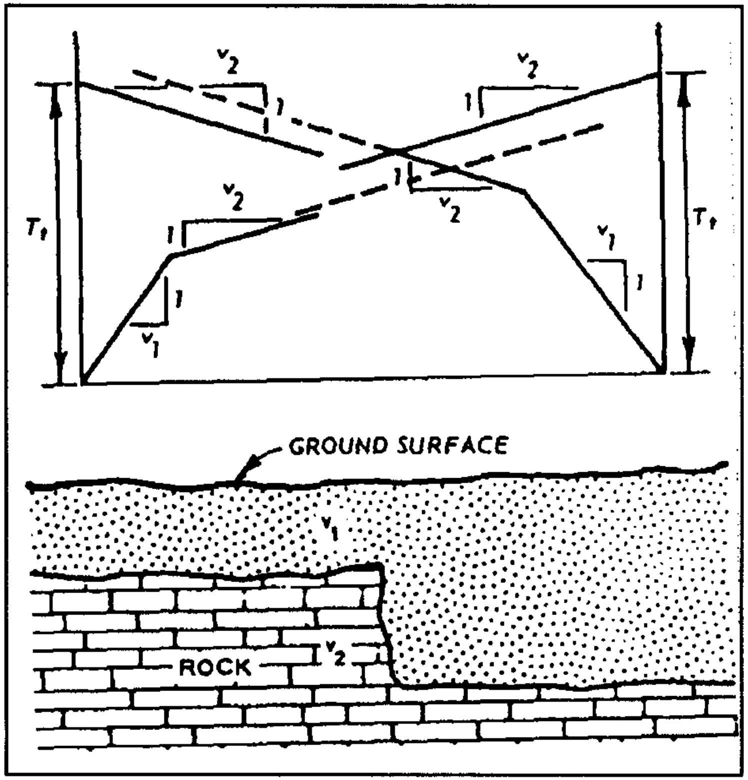


Figure 3-21. Subsurface cliff

the trend of the travel-time curves. One warning about the attempted detection of voids or discontinuities is in order. Fermat's principle says that the discontinuity must extend significantly perpendicular to the profile in order that no fast path detour is present that will minimize the observed delays.

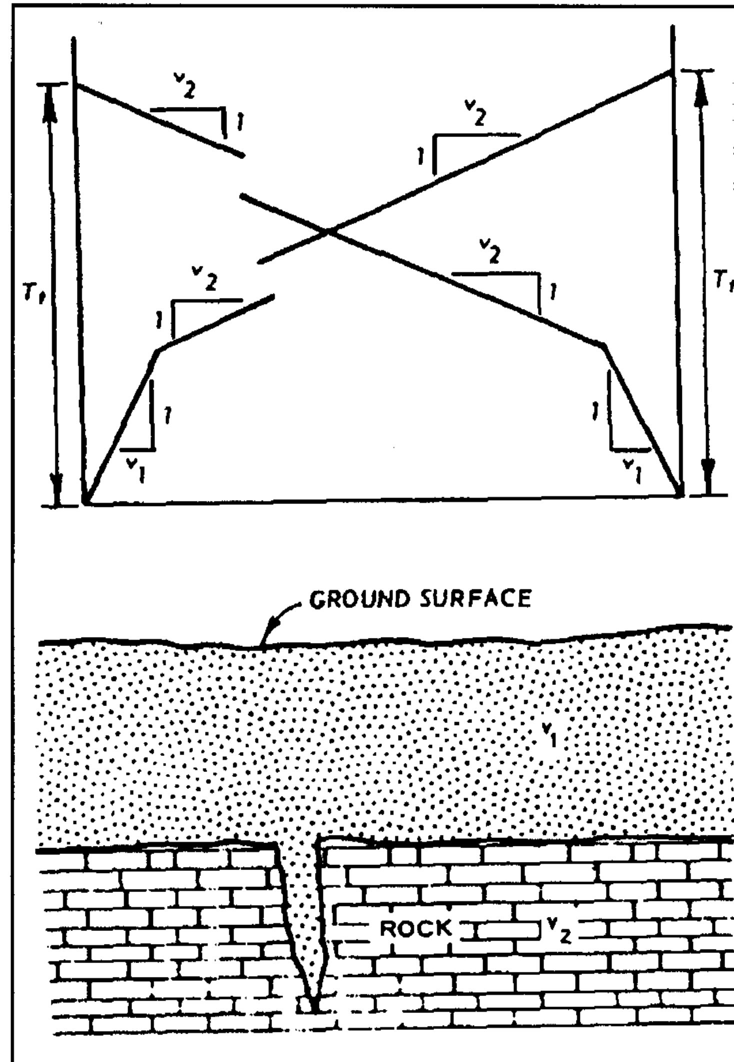


Figure 3-22. Offset in time-distance plot due to discontinuity in rock surface

APPLICATIONS

Table 3-1
Typical/Representative Field Values of V_P, ρ_b and ν for Various Materials

Material	V_P (m/s)	$\rho_{b,dry}$ (mg/m³)	ν
Air	330		
Damp loam	300-750		
Dry sand	450-900	1.6-2.0	0.3-0.35
Clay	900-1,800	1.3-1.8	~0.5
Fresh, shallow water	1,430-1,490	1.0	
Saturated, loose sand	1,500		
Basal/ lodgement till	1,700-2,300	2.3	
Rock			0.15-0.25
Weathered igneous and metamorphic rock	450-3,700		
Weathered sedimentary rock	600-3,000		
Shale	800-3,700		
Sandstone	2,200-4,000	1.9-2.7	
Metamorphic rock	2,400-6,000		
Unweathered basalt	2,600-4,300	2.2-3.0	
Dolostone and limestone	4,300-6,700	2.5-3.0	
Unweathered granite	4,800-6,700	2.6-3.1	
Steel	6,000		

APPLICATIONS

- **Vp and Vs**

$$\nu = [(V_P/V_S)^2 - 2]/\{2[(V_P/V_S)^2 - 1]\} \quad (3\text{-}1)$$

$$E = \rho_b V_P^2 (1-2\nu)(1+\nu)/(1-\nu) \quad (3\text{-}2)$$

$$G = E/[2(1+\nu)] \quad (3\text{-}3)$$

$$\rho_b = G/V_S^2 \quad (3\text{-}4)$$

LIMITATION

- **In case of Saturated Media ?**
- **Waves will pass through water (1500 m/s) and not through the soil structure**

LIMITATIONS- SEISMIC REFRACTION

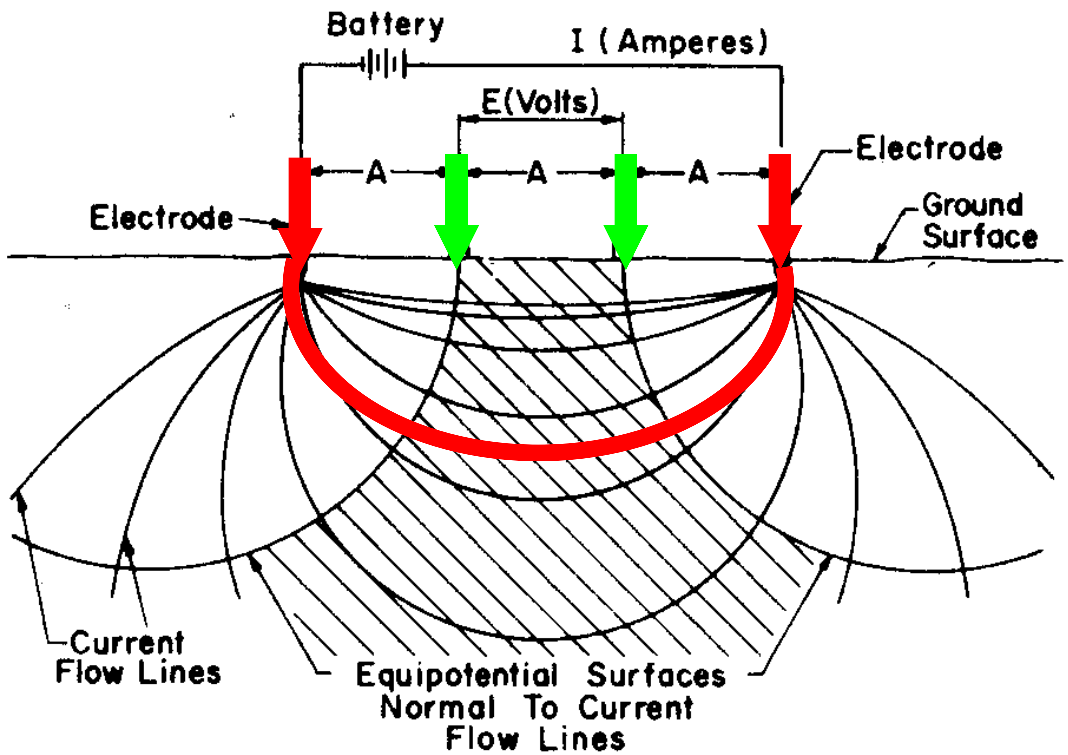
- Seismic refraction method: density of the layers must increase with depth

  $V_3 > V_2 > V_1$ (if $V_2 < V_1$ and $V_3 > V_1$ then V_2 will not be "seen" by seis. refraction
- The ray bends towards the normal when going from denser (V_1) to lighter (V_2) medium; refracted into the earth
- When going from a lighter to denser medium the ray is refracted back to the surface

ELECTRICAL TECHNIQUES

- ***PRINCIPLE***
  - difference in electrical Resistivity of different soil/rock layers
- ***PROCEDURE***
  - An electrical current is made to flow through the ground under an electrical potential
  - Resulting Apparent Resistivity of the Ground is measured.

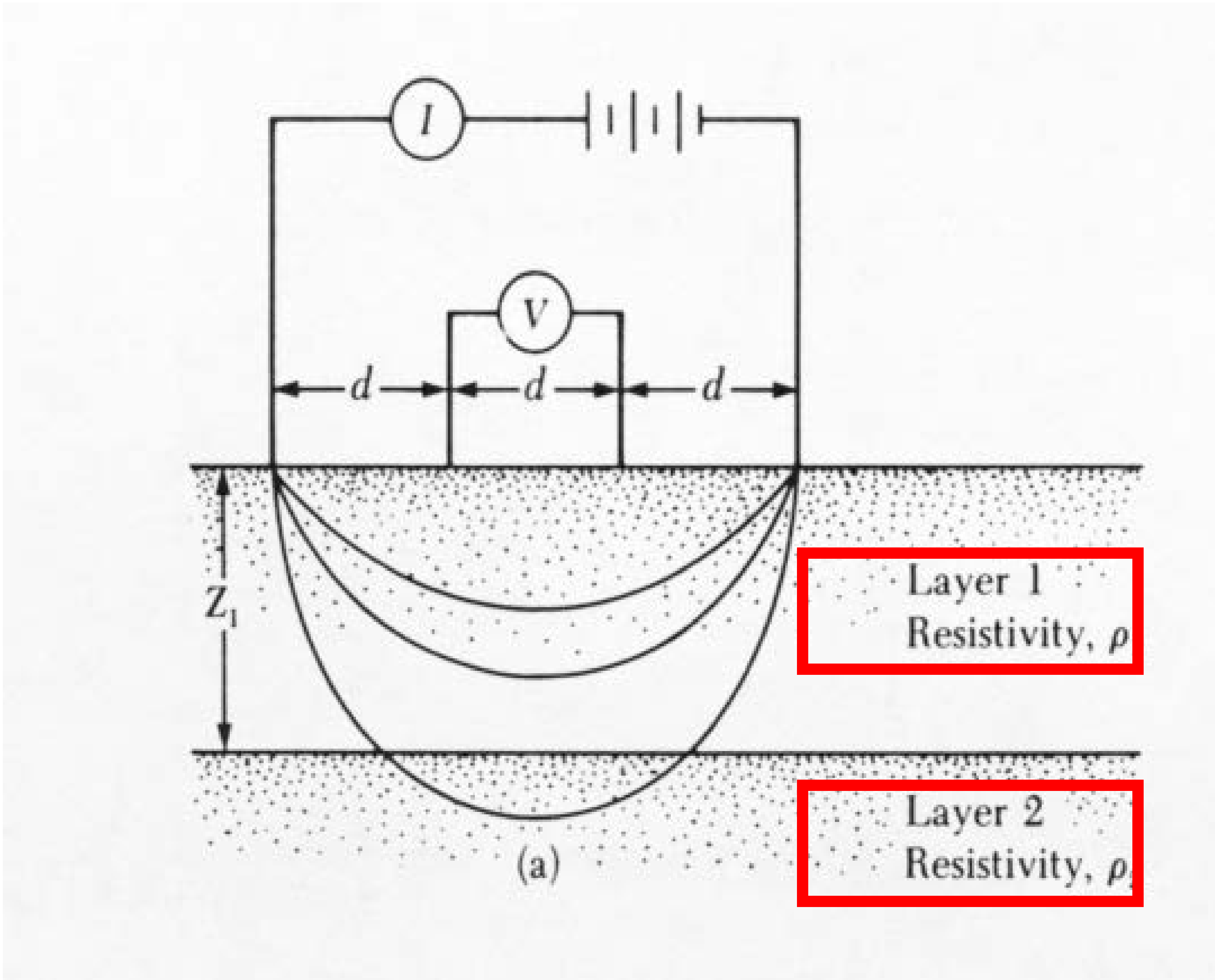
THEORY OF MEASUREMENTS



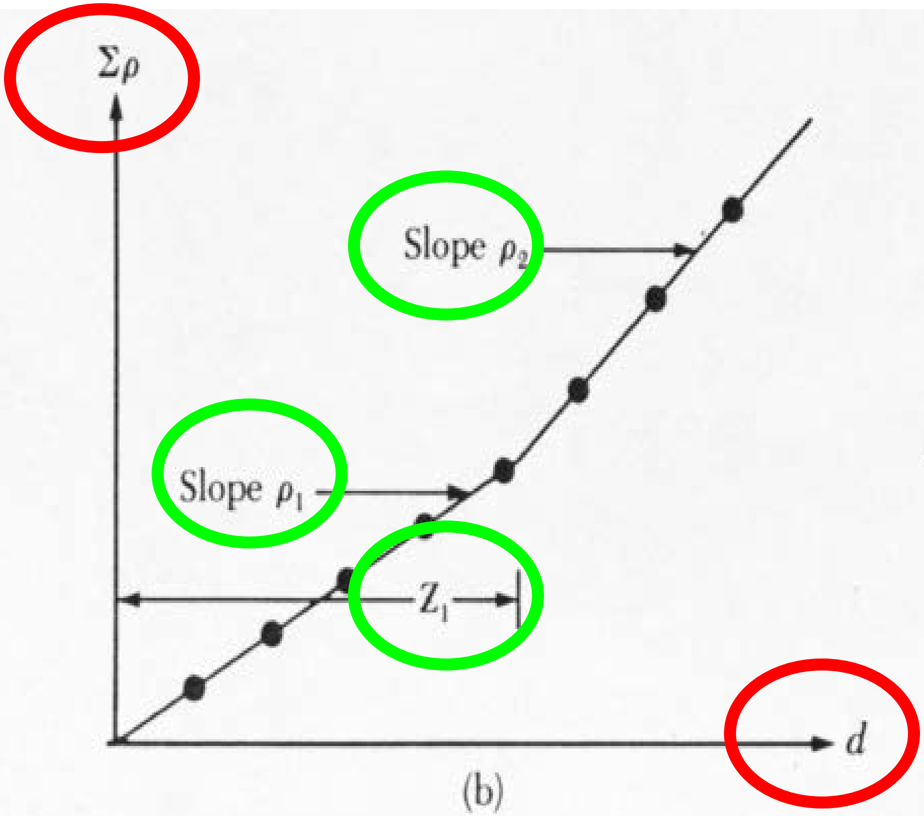
Apparent Resistivity, ρ, = $\frac{2\pi AE}{I}$

Fig. 1.2 Diagram showing theory of earth resistivity methods. (*After U.S. Army Corps of Engineers.*)

APPARENT RESISTIVITY



EVALUATIONS



▼ **FIGURE 2.39** Electrical resistivity survey: (a) Wenner method; (b) empirical method for determination of resistivity and thickness of each layer

DIFFERENT CONFIGURATIONS

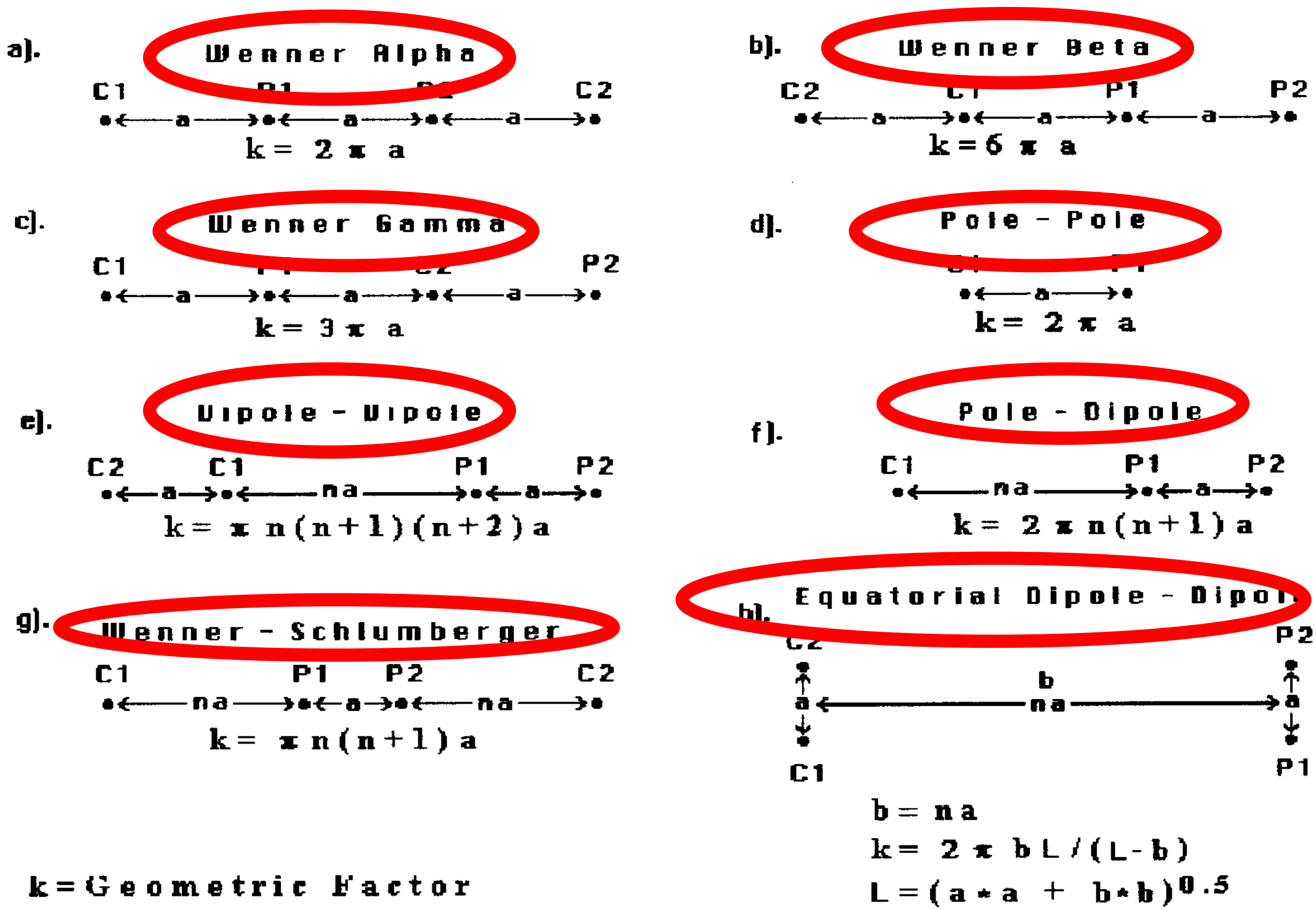


Figure 2. Common arrays used in resistivity surveys and their geometric factors.

DIFFERENT MODELS

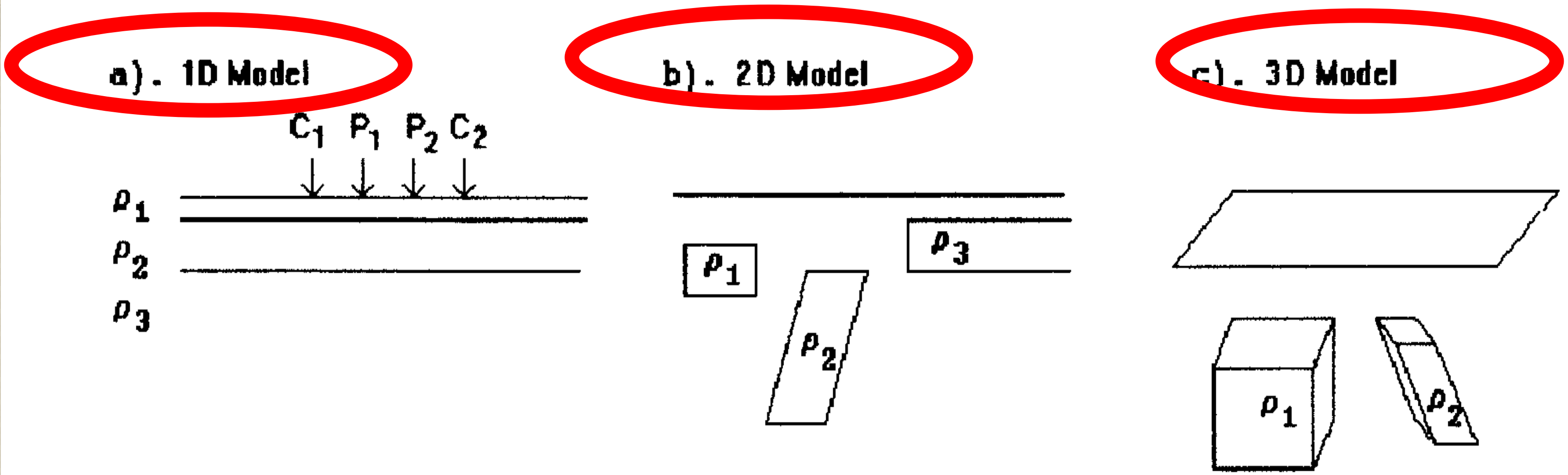
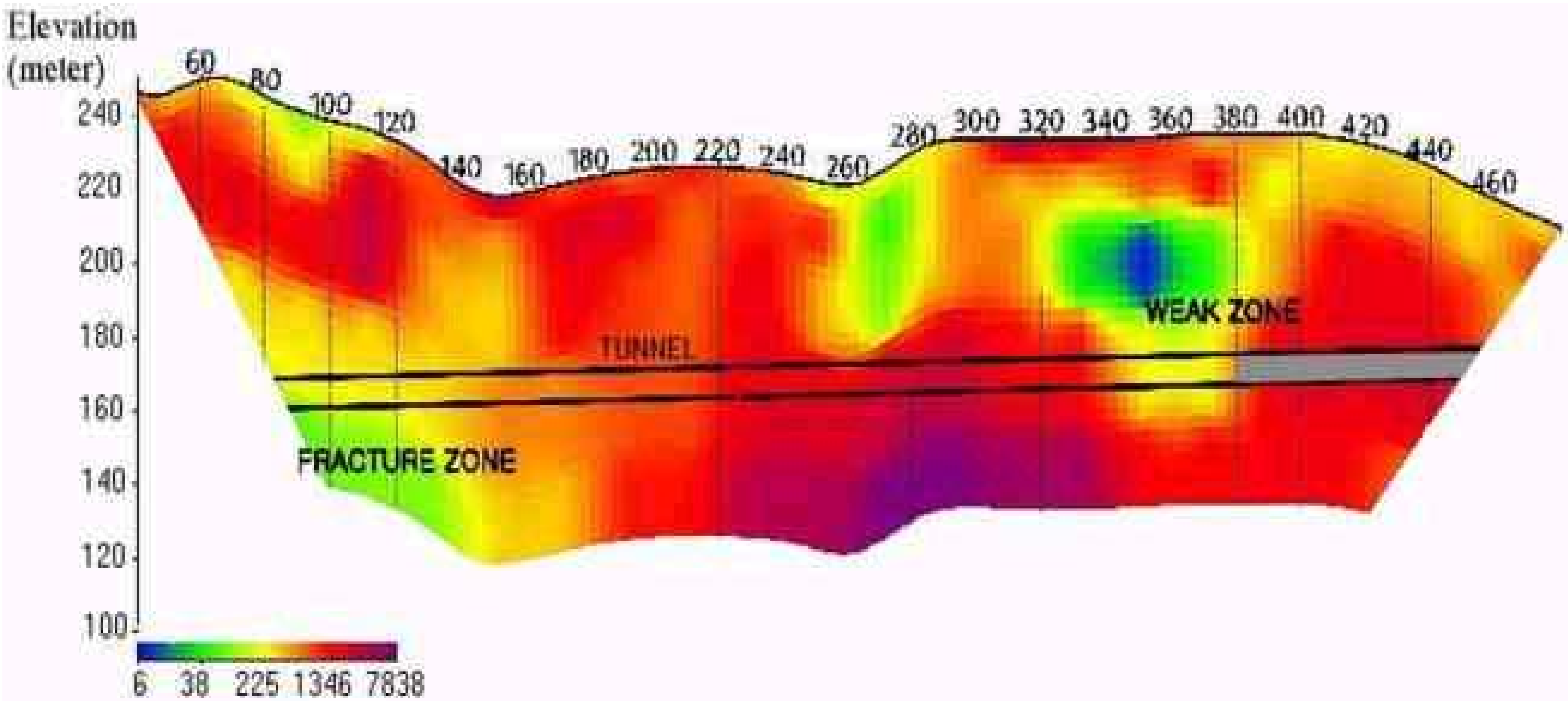
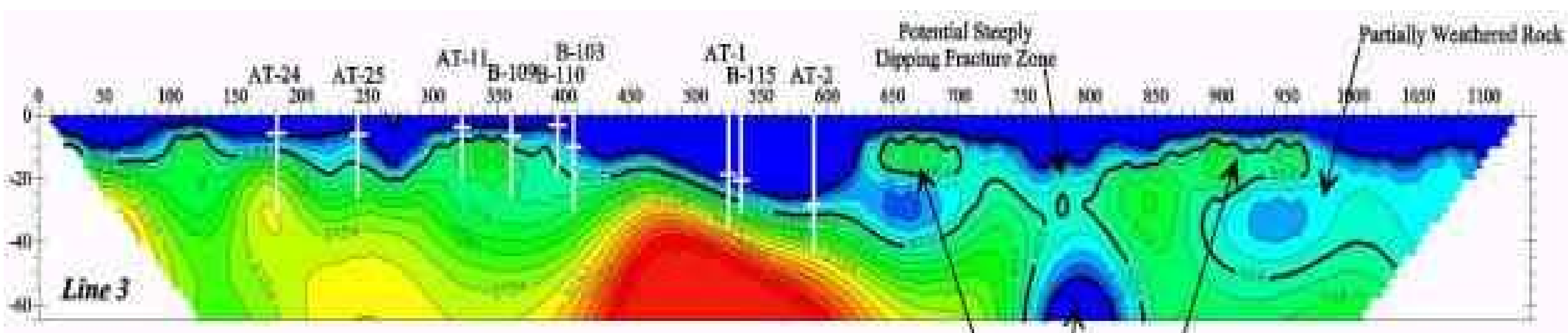


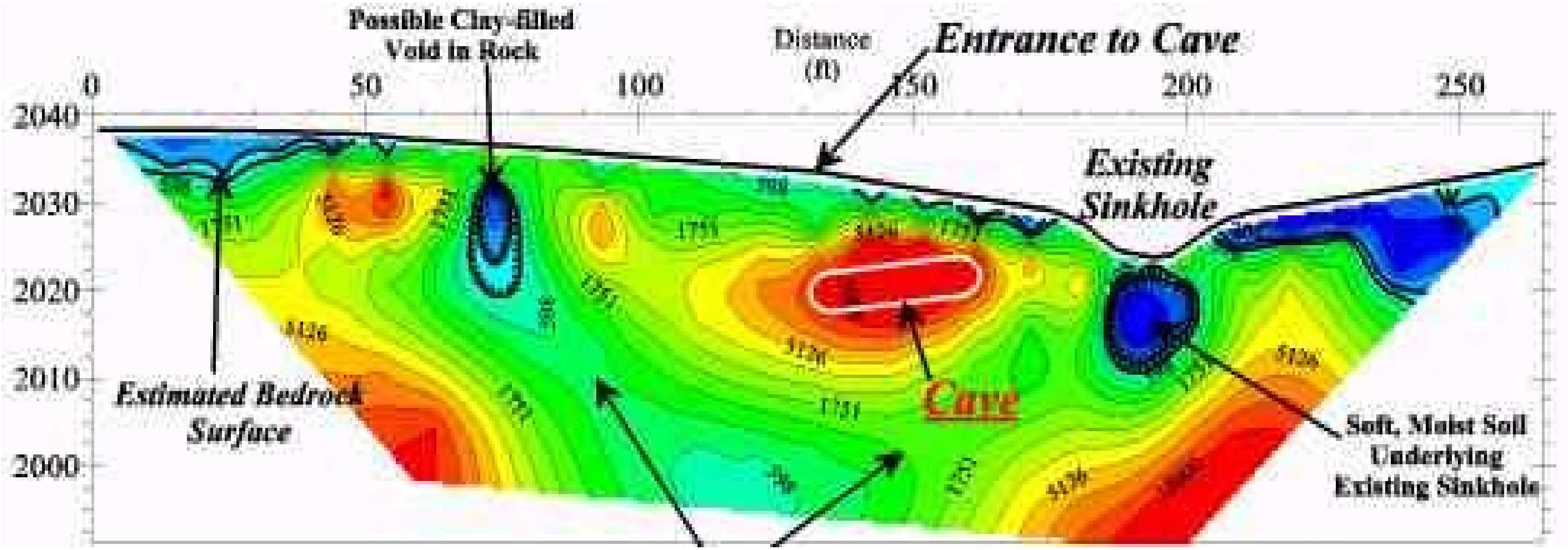
Figure 3. The three different models used in the interpretation of resistivity measurements.

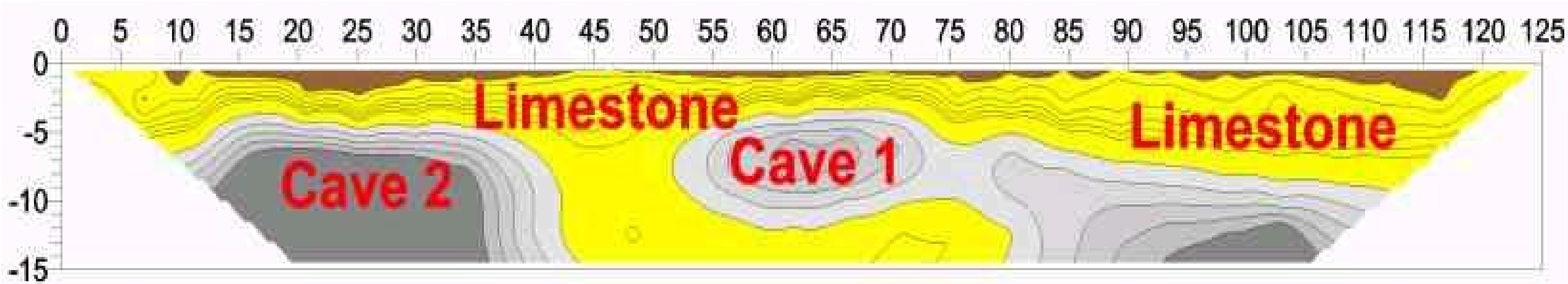
2-D MODELS


Elevation
(meter)
240
220
200
180
160
140
120
100
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
WEAK ZONE
TUNNEL
FRACTURE ZONE
6
38
225
1346
7838

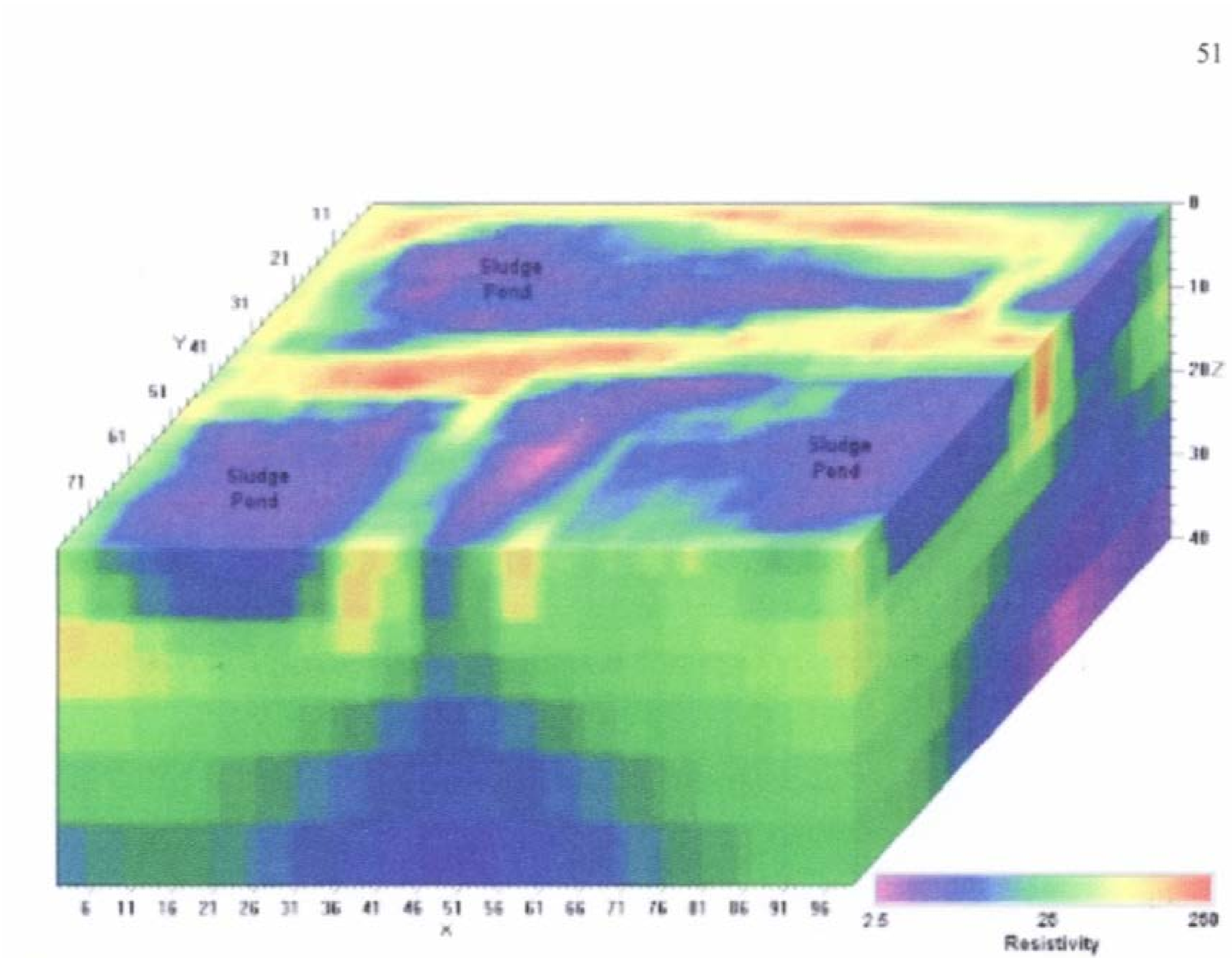

Potential Steeply
Dipping Fracture Zone
Partially Weathered Rock
AT-24
AT-25
AT-11
B-109
B-103
B-110
AT-1
B-115
AT-2
Line 3

2-D MODELS


Possible Clay-filled Void in Rock
Distance (ft)
Entrance to Cave
0
50
100
150
200
250
2040
2030
2020
2010
2000
Existing Sinkhole
Estimated Bedrock Surface
Cave
Soft, Moist Soil Underlying Existing Sinkhole


0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125
0
-5
-10
-15
Limestone
Cave 1
Cave 2
Limestone

3-D MODEL


51
Sludge Pond
Sludge Pond
Sludge Pond
Y
11 21 31 41 51 61 71
X
6 11 16 21 26 31 36 41 46 51 56 61 66 71 76 81 86 91 96
Z
0 10 20 30 40
2.5
25
250
Resistivity

APPLICATIONS

Table 4-1 (Continued)

Method	Basic Measurement	Application	Advantages	Limitations
Surface (Continued)				
Electrical resistivity	Electrical resistance of a volume of material between probes	Complementary to refraction seismic. Quarry rock, ground water, sand and gravel prospecting. River bottom studies and cavity detection	Economical nondestructive technique. Can detect large bodies of “soft” materials	Lateral changes in calculated resistance often interpreted incorrectly as depth related; hence, for this and other reasons, depth determinations can be grossly in error. Should be used in conjunction with other methods, e.g., seismic

Table 4-2
Numerical Rating of Geophysical Methods to Provide Specific Engineering Parameters[1] Engineering Application

Geophysical Method	Depth to Rock	P-Wave Velocity	S-Wave Velocity	Shear Modulus	Young's Modulus	Poisson's Ratio	Lithology	Material Boundaries Stratigraphy	Dip of Strata	Density	In Situ State of Stress	Temperature	Permeability	Percent Saturation	Ground water Table	Ground water Quality	Ground water Aquifers	Flow Rate and/or Direction	Borehole Diameter	Obstructions	Rippability	Fault Detection	Cavity Detection	Cavity Delineation	Location of Ore Bodies	Borehole Azimuth and Inclination
Electrical resistivity	3	0	0	0	0	0	1	3	2	0	0	0	2	1	4	0	4	2	0	3	2	0	4	4	4	0

APPLICATIONS

Table 1. Resistivities of some common rocks, minerals and chemicals.

Material	Resistivity (Ω•m)	Conductivity (Siemen/m)
Igneous and Metamorphic Rocks		
Granite	$5x10^{3}$ - 10^{6}	10^{-6} - $2x10^{-4}$
Basalt	10^{3} - 10^{6}	10^{-6} - 10^{-3}
Slate	$6x10^{2}$ - $4x10^{7}$	$2.5x10^{-8}$ - $1.7x10^{-3}$
Marble	10^{2} - $2.5x10^{8}$	$4x10^{-9}$ - 10^{-2}
Quartzite	10^{2} - $2x10^{8}$	$5x10^{-9}$ - 10^{-2}
Sedimentary Rocks		
Sandstone	8 - $4x10^{3}$	$2.5x10^{-4}$ - 0.125
Shale	20 - $2x10^{3}$	$5x10^{-4}$ - 0.05
Limestone	50 - $4x10^{2}$	$2.5x10^{-3}$ - 0.02
Soils and waters		
Clay	1 - 100	0.01 - 1
Alluvium	10 - 800	$1.25 x10^{-3}$ - 0.1
Groundwater (fresh)	10 - 100	0.01 - 0.1
Sea water	0.2	5
Chemicals		
Iron	$9.074x10^{-8}$	$1.102x10^{7}$
0.01 M Potassium chloride	0.708	1.413
0.01 M Sodium chloride	0.843	1.185
0.01 M acetic acid	6.13	0.163
Xylene	$6.998x10^{16}$	$1.429x10^{-17}$

SUBGRADE CONSTRUCTION

- **Construction Principles**
- **Construction Equipment**
- **Construction Processes**

SUBGRADE CONSTRUCTION

- **What is SUBGRADE Construction ?**
- **Compaction**
  - **Objectives**
  - **Factors**
  - **Mechanism**
  - **Created Fabric and Structure**
  - **Effect on Engineering Properties**
    - **Strength**
    - **Stiffness**
    - **Stability**

SUBGRADE CONSTRUCTION

- 1. Establishment of Grade Line
  - Natural Ground (Cut)
  - Embankment (Fill)
- 2. Compaction

SUBGRADE CONSTRUCTION

1. Establishment of Grade Line

- The subgrade line should be established
  - to obtain the optimum natural support for the pavement
  - consistent with economic utilization of available materials
  - traffic requirements
- **a . Balancing Cut and Fill:** Optimizing subgrade support and drainage should take precedence over balancing cut and fill.

SUBGRADE CONSTRUCTION

b . Ground Water: The subgrade line will be above the flood plain and a minimum of 2 feet above wet season ground water level . Where not practicable, provide for permanent lowering of water table by drainage.

- **c . Rock:** Rock excavation is to be avoided for economic reasons . Where excavation of rock is unavoidable, undercut to provide for full depth of base course under surface courses .

SUBGRADE CONSTRUCTION

2. COMPACTION

PURPOSE:

- In engineering practice the soils at a given site do not often meet the ideal requirements or the intended purpose.
- They may be weak, highly compressible, or have a higher/lower permeability than desirable from an engineering or economic point of view.
- It would seem reasonable in such instances to simply relocate the structure or facility. However, considerations other than geotechnical often govern the location of a structure, and the engineer is forced to design for the site at hand.
- One possibility is to adapt and design according to the geotechnical conditions at the site.

SUBGRADE CONSTRUCTION

2. COMPACTION

PURPOSE:

- Another possibility is to try to stabilize or improve the engineering properties of the soils at the site. Depending on the circumstances, this second approach may be the most economical solution to the problem.

SUBGRADE CONSTRUCTION

- Stabilization Methods are generally classified as:

- **Mechanical** ← **COMPACTION**
- **Physical**
- **Chemical**
- **Thermal**
- **Electrical**

EQUIPMENT REQUIRED

Clearing & Grubbing	Tractor Dozer, Rooter/Ripper
Excavation	Shovels, Dozers, Draglines, Scrapers
Transportation	Scrapers, Trucks, Dumpers
Spreading	Grader, Dozer
Watering	Tankers, Sprinklers
Compaction	Rollers of Different Types

COMPACTION

Objectives of Compaction

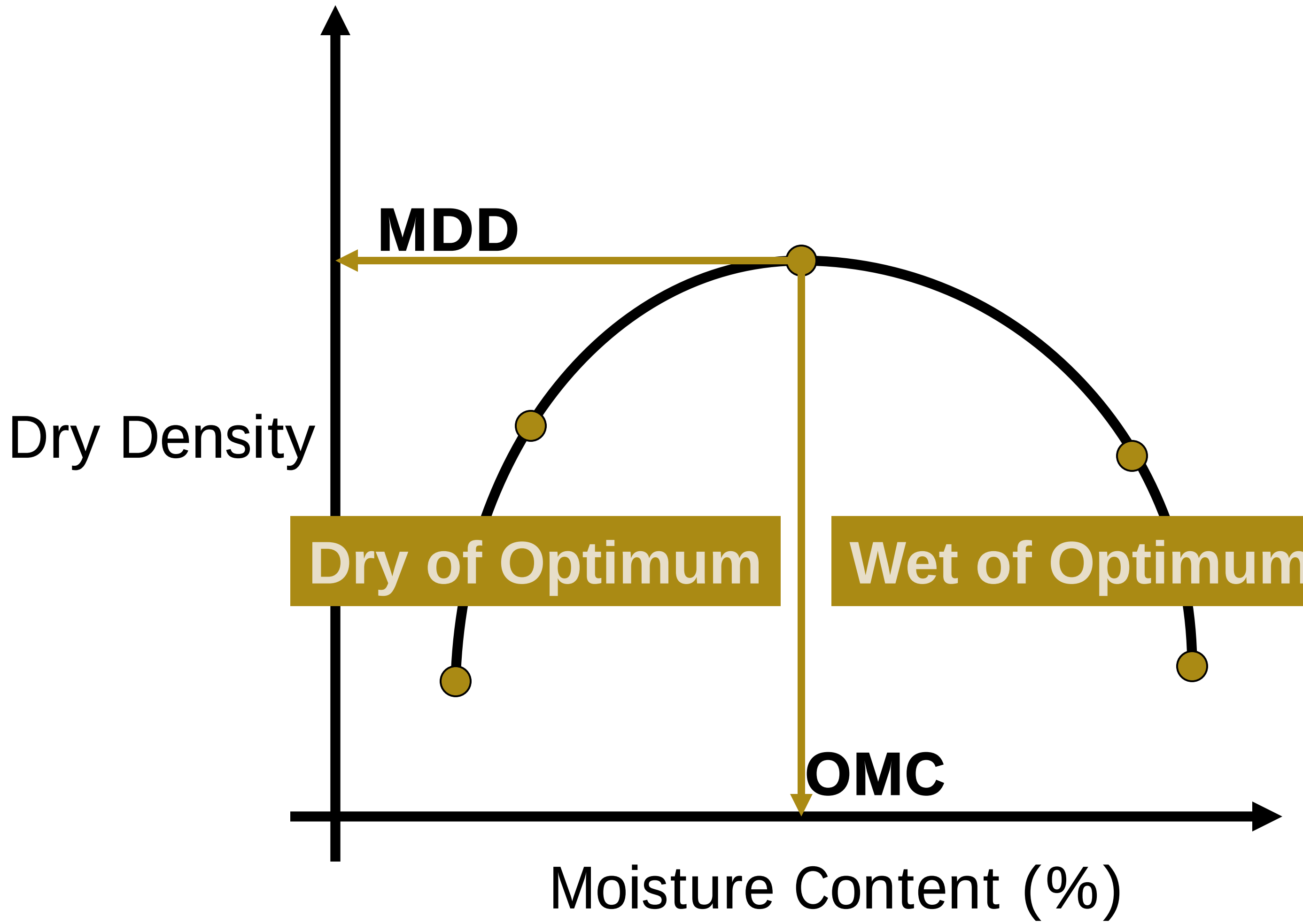
- Detrimental settlements can be reduced or prevented.
- Soil strength increases and slope stability can be improved.
- Bearing capacity of pavement subgrades can be improved.
- Undesirable volume changes, for example, caused by frost action, swelling, and shrinkage may be controlled.

COMPACTION

- **Compaction is a function of four variables:**

- **Dry Density**
- **Water Content**
- **Compactive Effort/Type**
- **Soil Type**
  - ***gradation, presence of clay minerals, etc.***

PROCTOR COMPACTION TEST



SUBGRADE COMPACTION

- **Natural Subgrade**
- Compact at Grade Level to a depth of
- Compact from the surface (cohesionless soils except silts) .
- Remove, process to desired water content, replace in lifts, and compact .

- **Embankment**
- Once borrow material has been transported to the fill area, bull-dozers, front loaders, and motor graders, called blades, spread the material to the desired layer or lift thickness.
- Lift thickness may range from 150 to 500 mm (6 to 18 in.) or so, depending on the size and type of compaction equipment and on the maximum grain size of the fill.

COMPACTION ACHIEVEMENT

- NUMBER OF PASSES
- ?
- SPEED
- ?

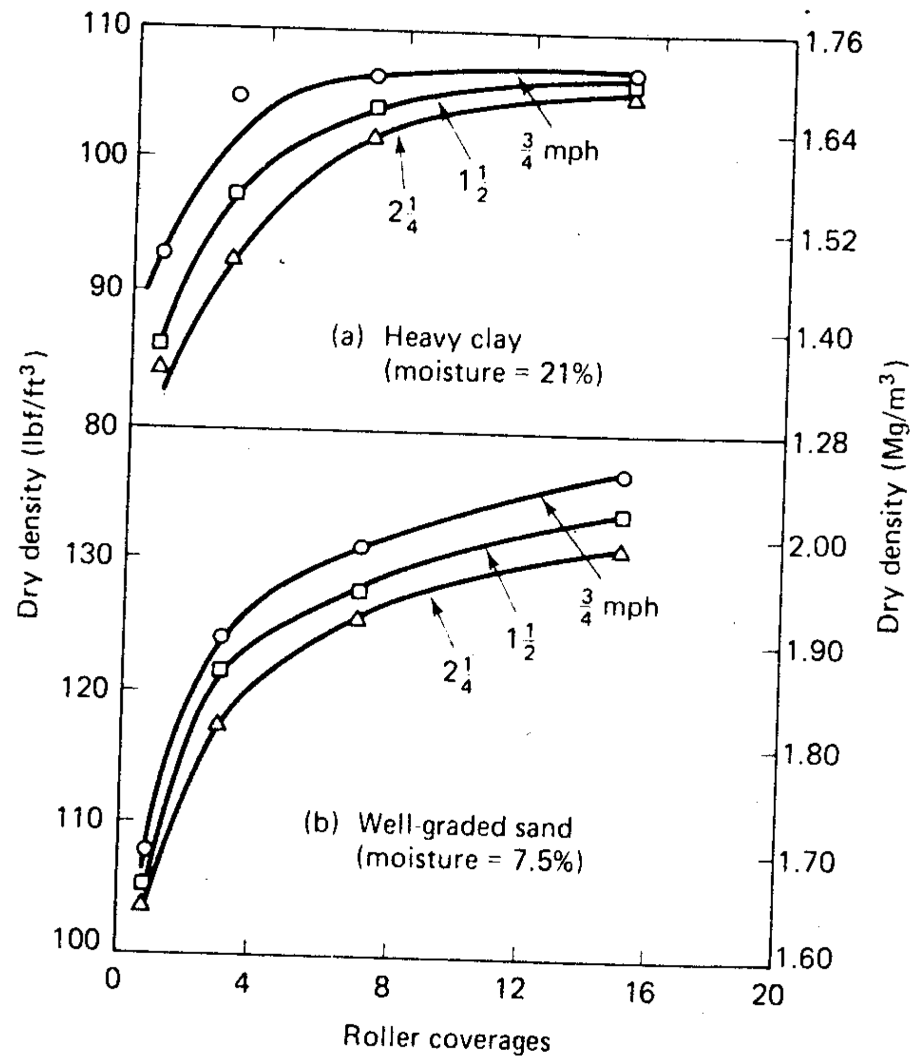


Fig. 5.18 Effect of roller travel speed on amount of compaction with 7700 kg (17,000 lb) towed vibratory roller (after Parsons, et al., 1962, as cited by Selig and Yoo, 1977).

COMPACTION ACHIEVEMENT

COMPACTION DEPTH (Lift Thickness)

- **Cohesive Soils**
  - Compacted By Pressure, Kneading,....
- **Cohesionless Soils**
  - Compacted by Vibrations

COMPACTION ACHIEVEMENT

- **Compaction Depth (Lift Thickness)**

- **Cohesive Soils**
- **Depends on**
  - Pressure
  - Impact
  - Vibration (if any)
  - Initial Density of Soil

COMPACTION ACHIEVEMENT

- **Cohesionless Soils**

- Difference Between Compaction Characteristics
- Compaction Pressure
- Vibration Frequency

COMPACTION ACHIEVEMENT

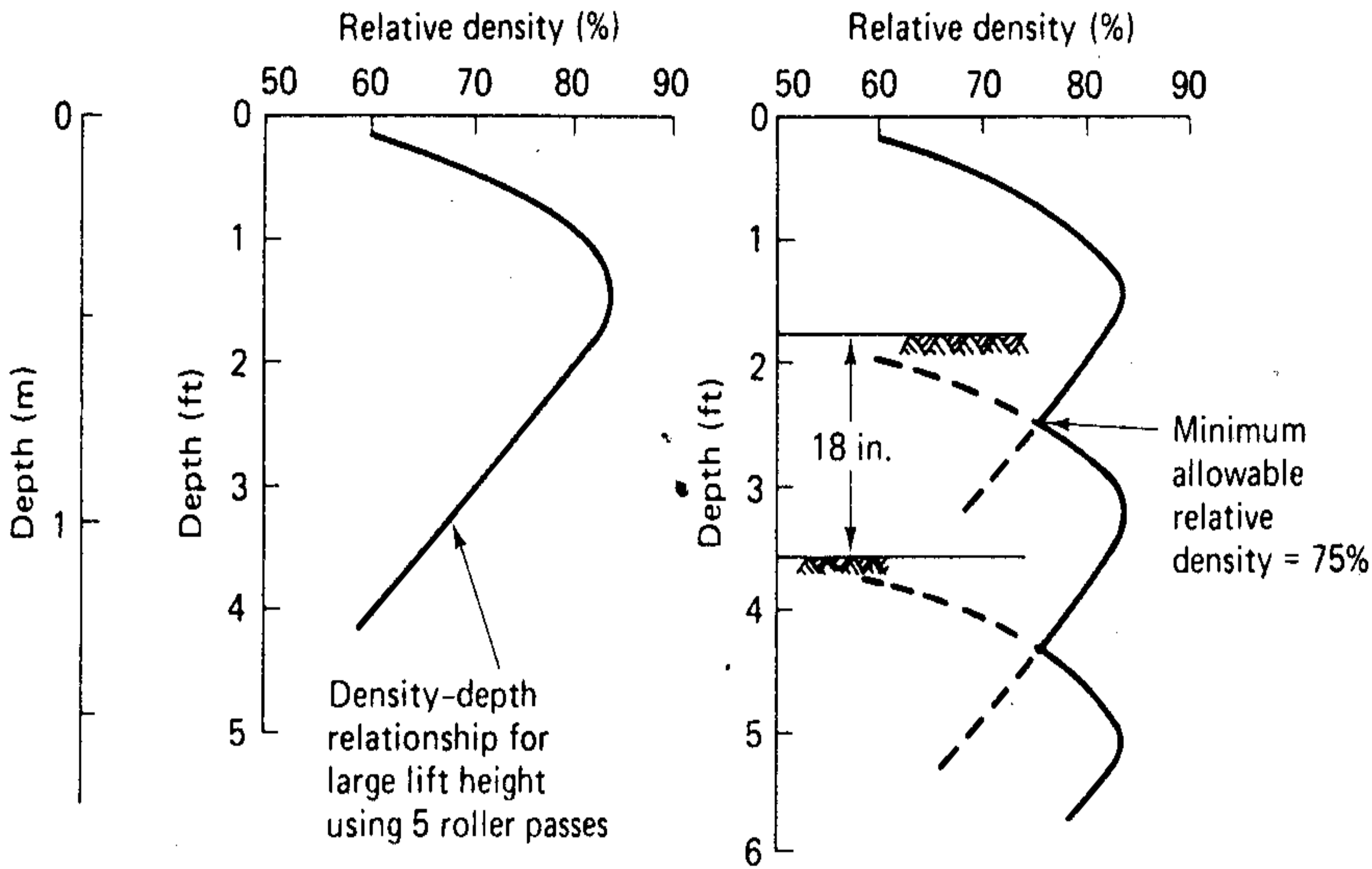


Fig. Ex. 5.2 Approximate method for determining lift height required to achieve a minimum compacted relative density of 75% with five roller passes, using data for a large lift height (after D'Appolonia, et al., 1969).

Thanks