PAVEMENT MATERIALS

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Lecturer CED, INU

COURSE HEADS

- SUBGRADE
  - NATURAL
  - STABILIZED
- SUBBASE
- BASE COURSE
  - UNBOUND
  - BOUND
- SURFACE COURSES

SEQUENCE

- <u>SUBGRADE</u>

- MATERIAL CLASSIFICATION/IDENTIFICATION
- INVESTIGATION
- MATERIAL EVALUATION
- MATERIAL SELECTION
- CONSTRUCTION OF SUBGRADE
- QA/QC
- POST CONSTRUCTION INVESTIGATION

SUBGRADE INVESTIGATIONS

- <u>**SOIL INVESTIGATIONS ?**</u>

- A COMPLETE PICTURE OF <u>***SUBSURFACE CONDITIONS***</u>
  - AS FAR AS POSSIBLE

- <u>**SUBSURFACE CONDITIONS**</u>
- SOIL/ROCK STRATA (TYPE, LAYERS, THICKNESS, EXTENT)
  - <u>***TO DEPTH OF SIGNIFICANCE***</u>
- HYDROLOGICAL CONDITIONS
- ENGINEERING PROPERTIES
  - STRENGTH, DENSITY, MOISTURE, COMPRESSIBILITY, STABILITY (FROST, EXPANSION), PERMEABILITY, CAPILLARITY

FIELD EVALUATIONS

- **<u>METHODS OF EXPLORATIONS</u>**

- **EXCAVATIONS**
  - **DRILLING**
  - **TEST PITS**
- **SAMPLING**

Ref. to Geotechnical Site Investigation and Instrumentation
(Previous Course)

- **GEOPHYSICAL TESTING**
  - **SURFACE SEISMIC**
  - **ELECTRICAL RESISTIVITY**
    - *<u>(DRILLING, SAMPLING, TESTING) (VIDEOS)</u>*

GEOPHYSICAL TESTING

BRIEF INTRODUCTION

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**

HOW ?

- ***GENERAL TECHNIQUES***

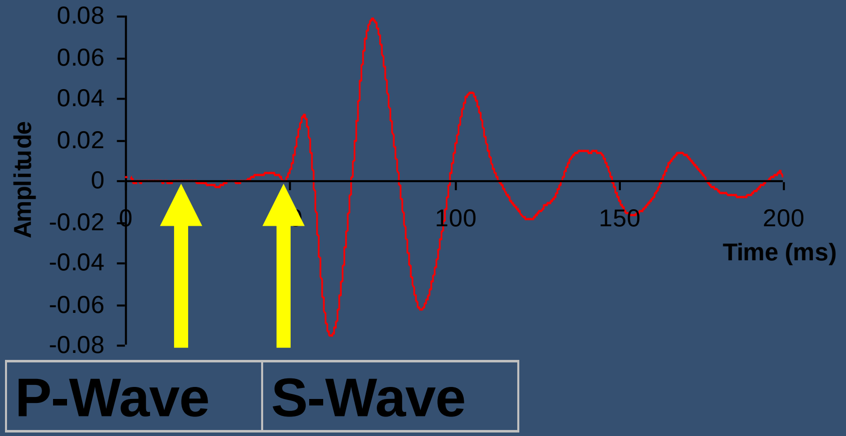
    - SEISMIC
    - ELECTRICAL
    - SONIC
    - MAGNETIC
    - RADAR
    - GRAVITY

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***

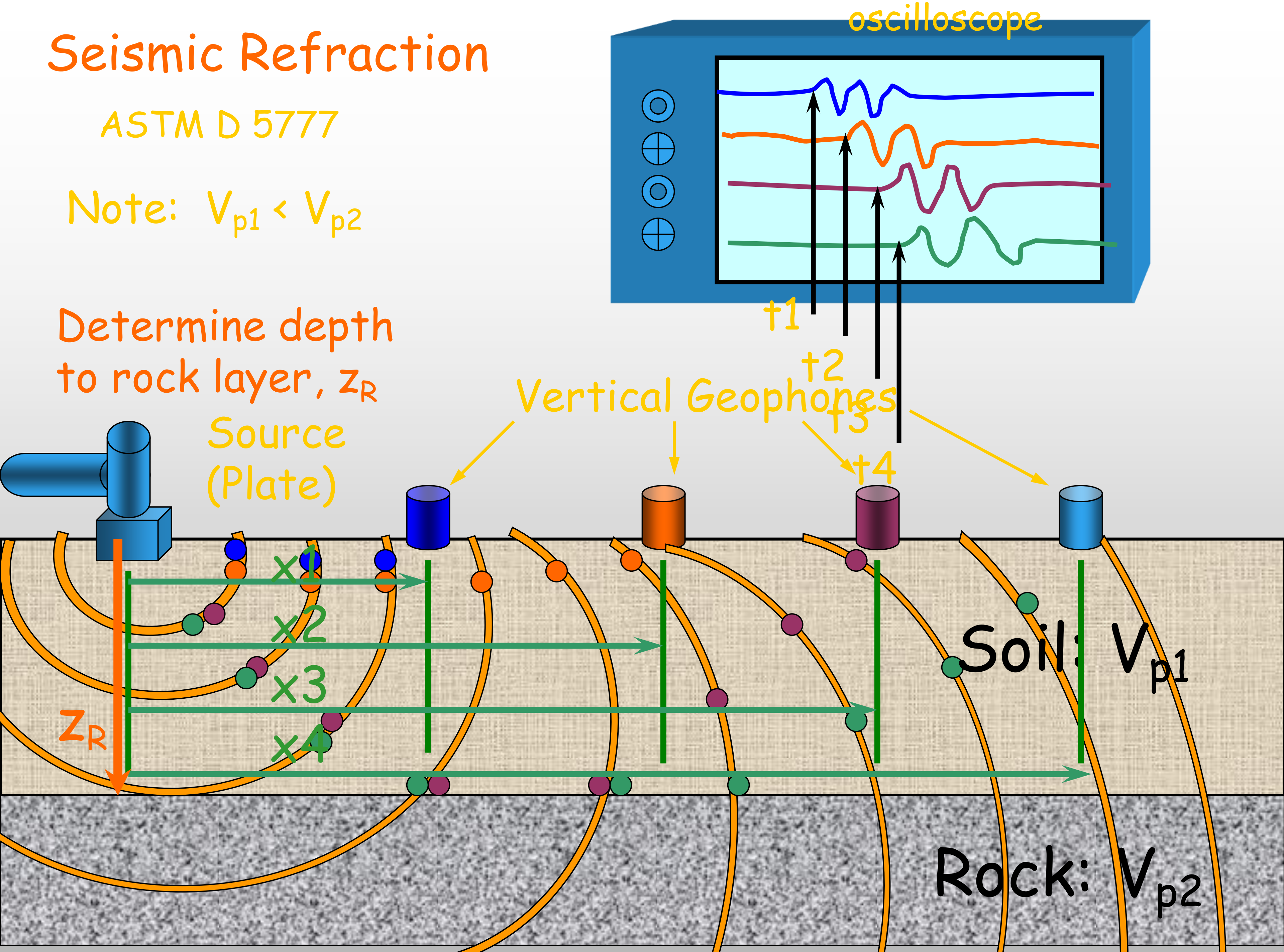
  - REFRACTION
  - REFLECTION
  - CROSS-HOLE
  - DOWN-HOLE

Seismic Refraction

ASTM D 5777

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

Determine depth to rock layer, z_R



REFRACTION AND REFLECTION

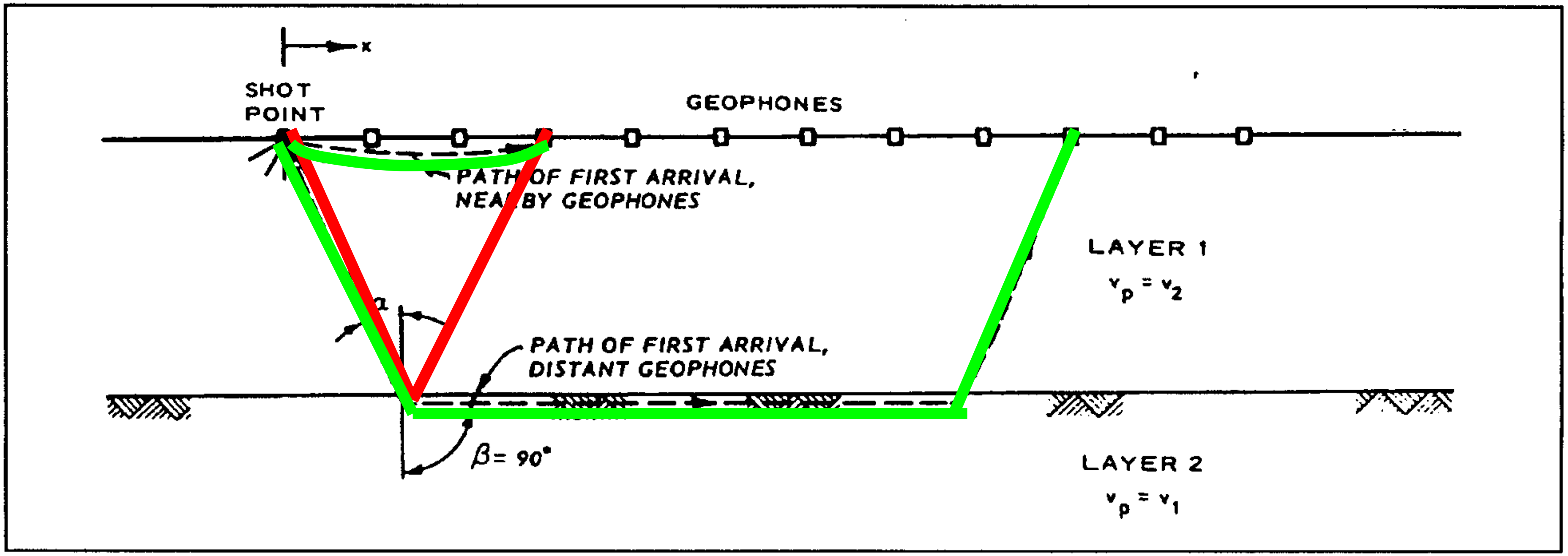
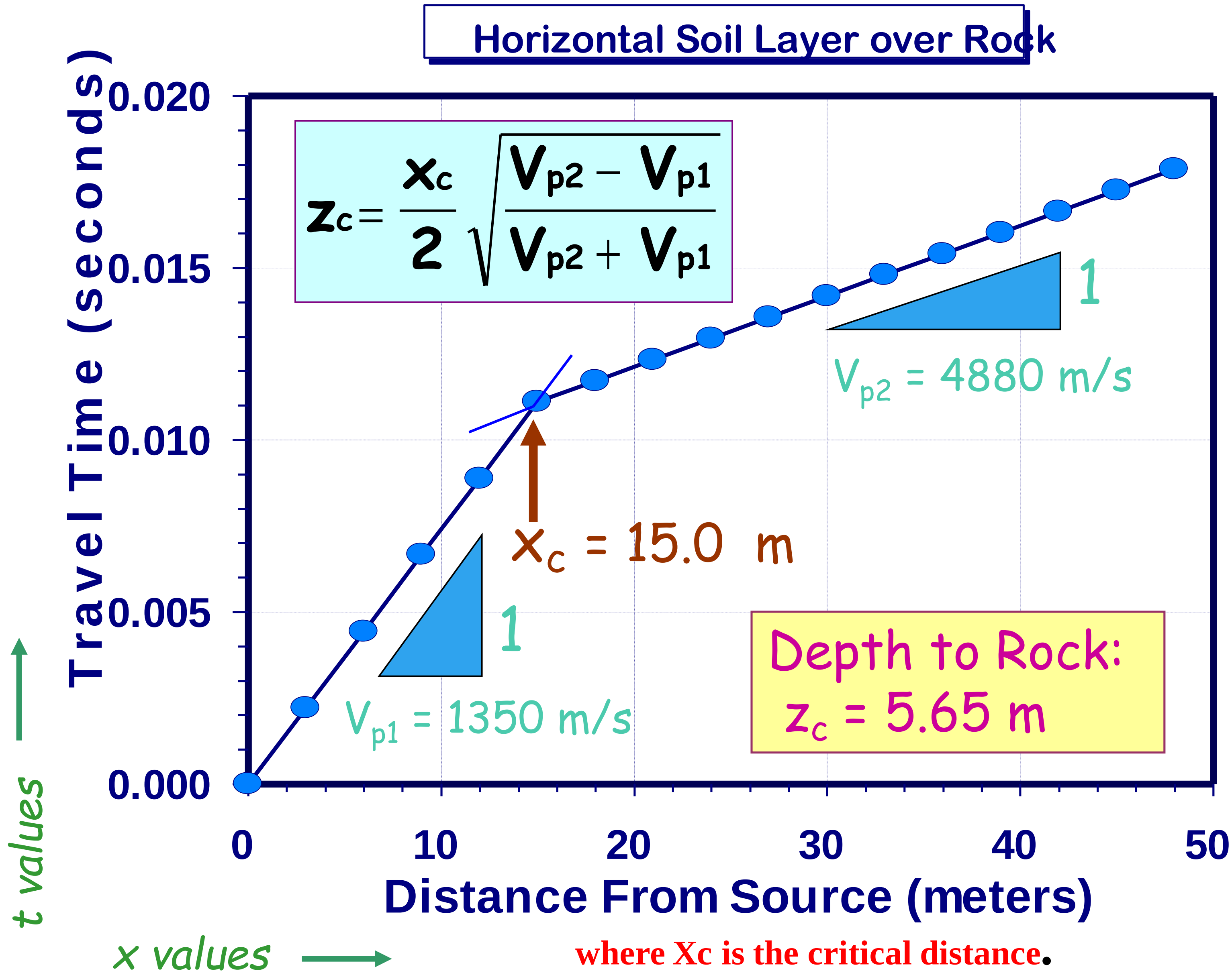


Figure 3-1. Schematic of seismic refraction survey

Refracted Wave

Reflected Wave

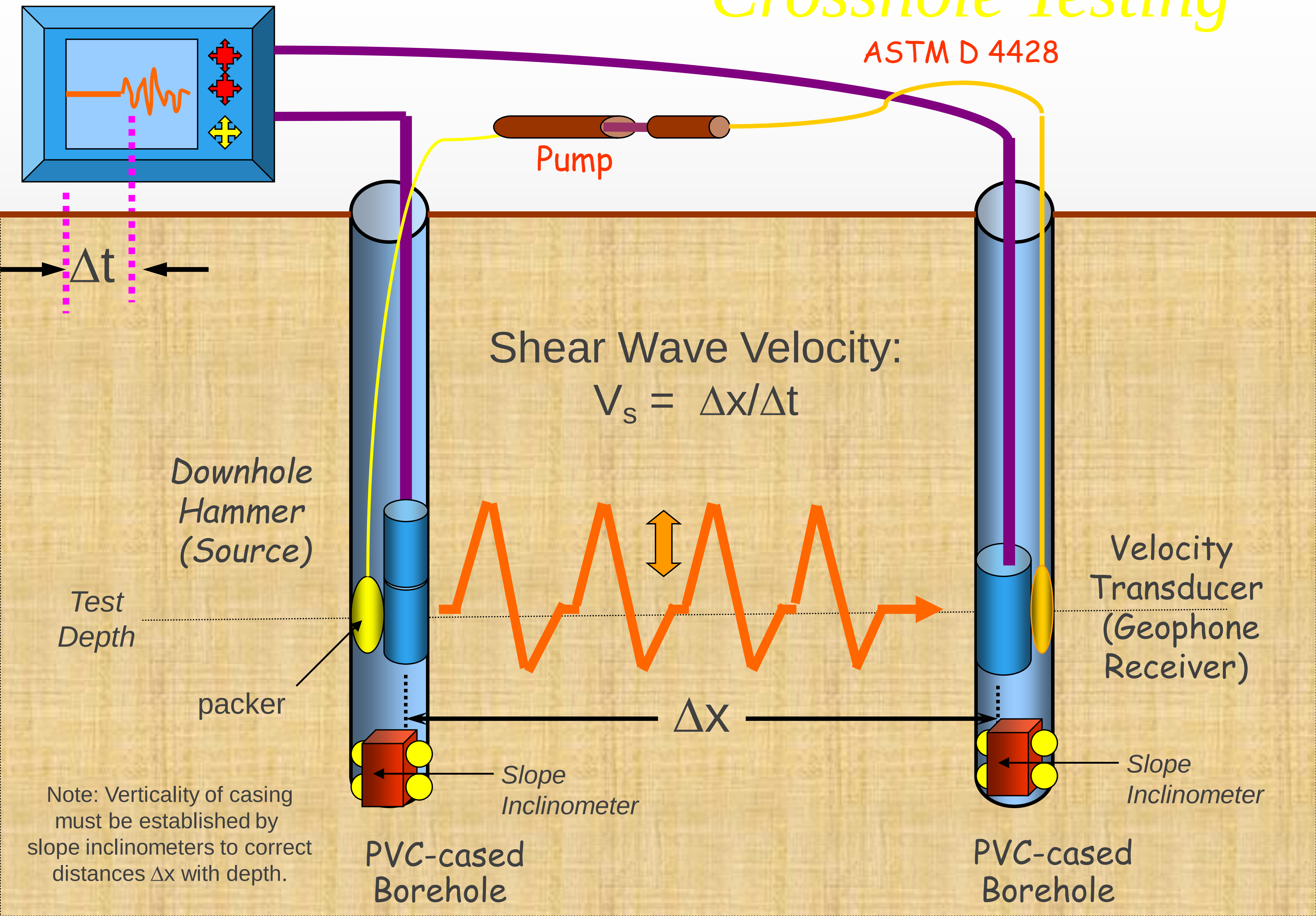
SEISMIC REFRACTION

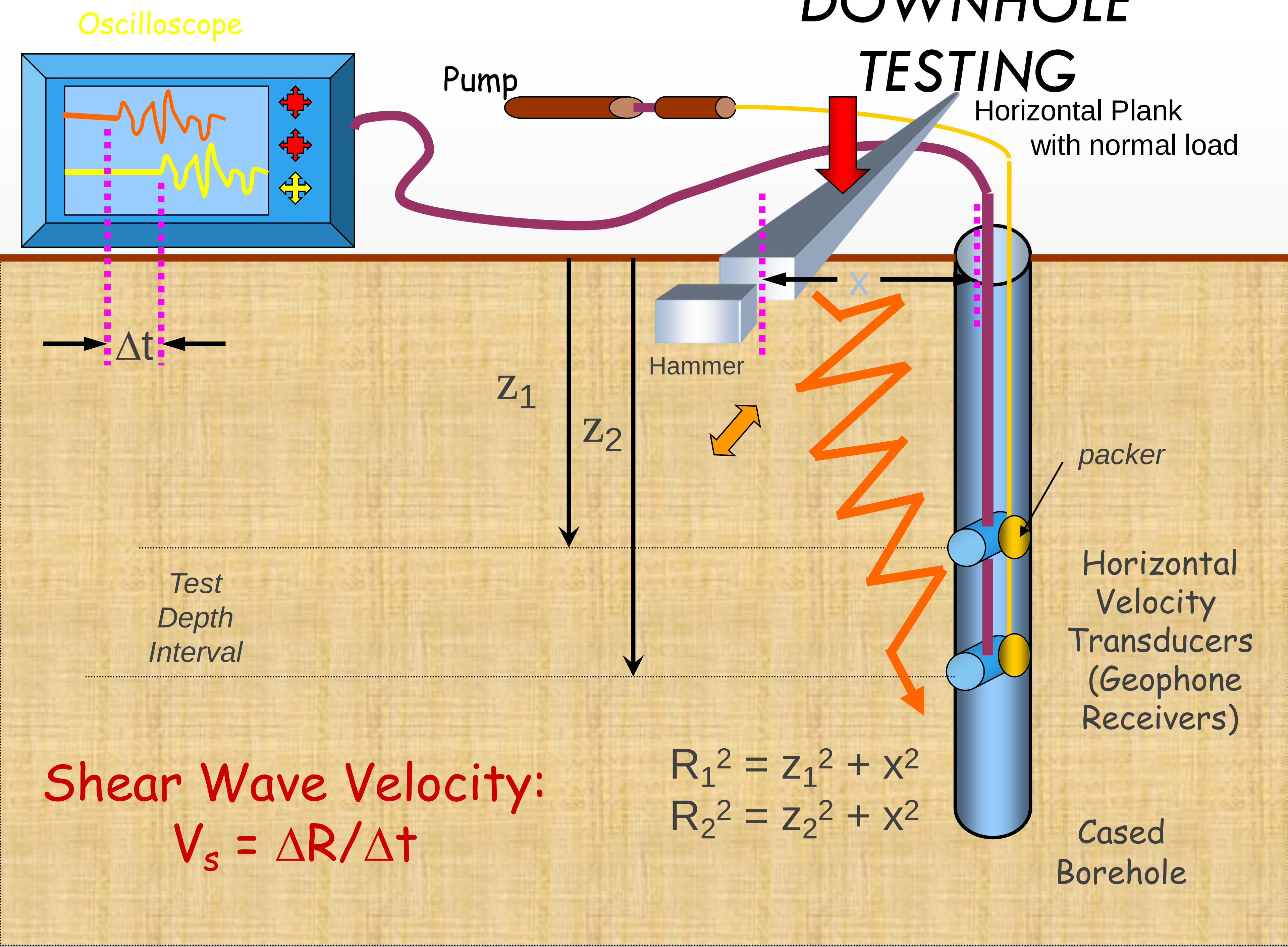


where Xc is the critical distance.

Crosshole Testing

ASTM D 4428





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

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

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

Material	V_P (m/s)	$p_{b,dry}$ (mg/m^3)	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		

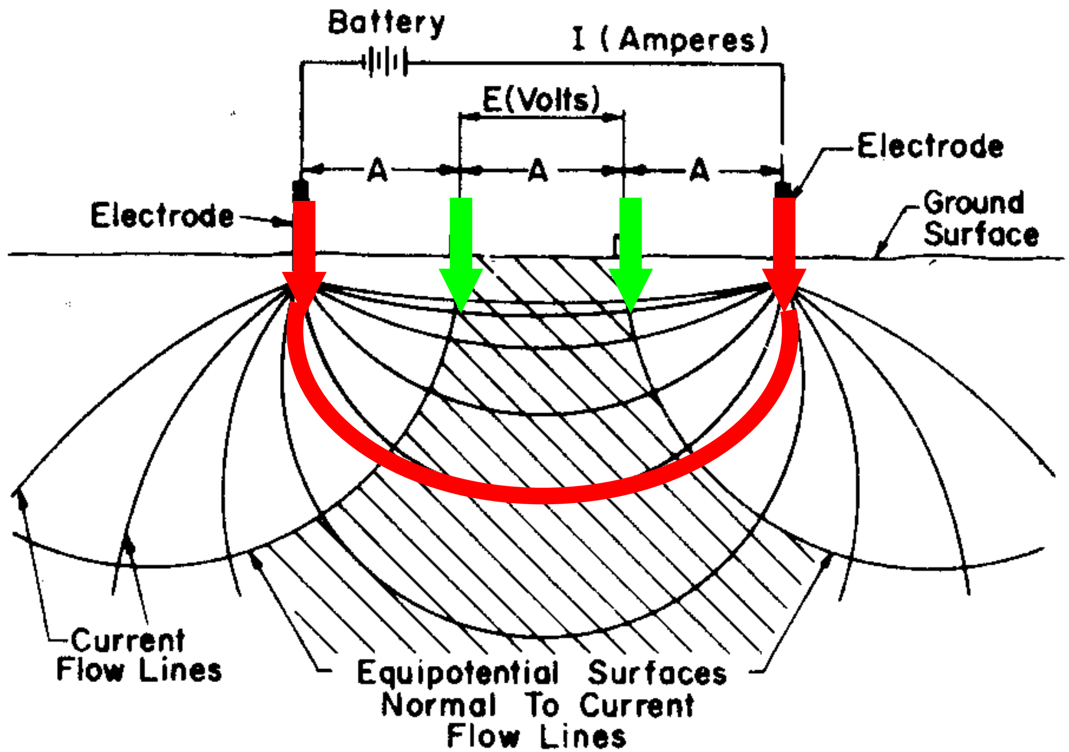
LIMITATION

- **IN CASE OF SATURATED MEDIA ?**
- **WAVES WILL PASS THROUGH WATER (1500 M/S) AND NOT THROUGH THE SOIL STRUCTURE**

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.

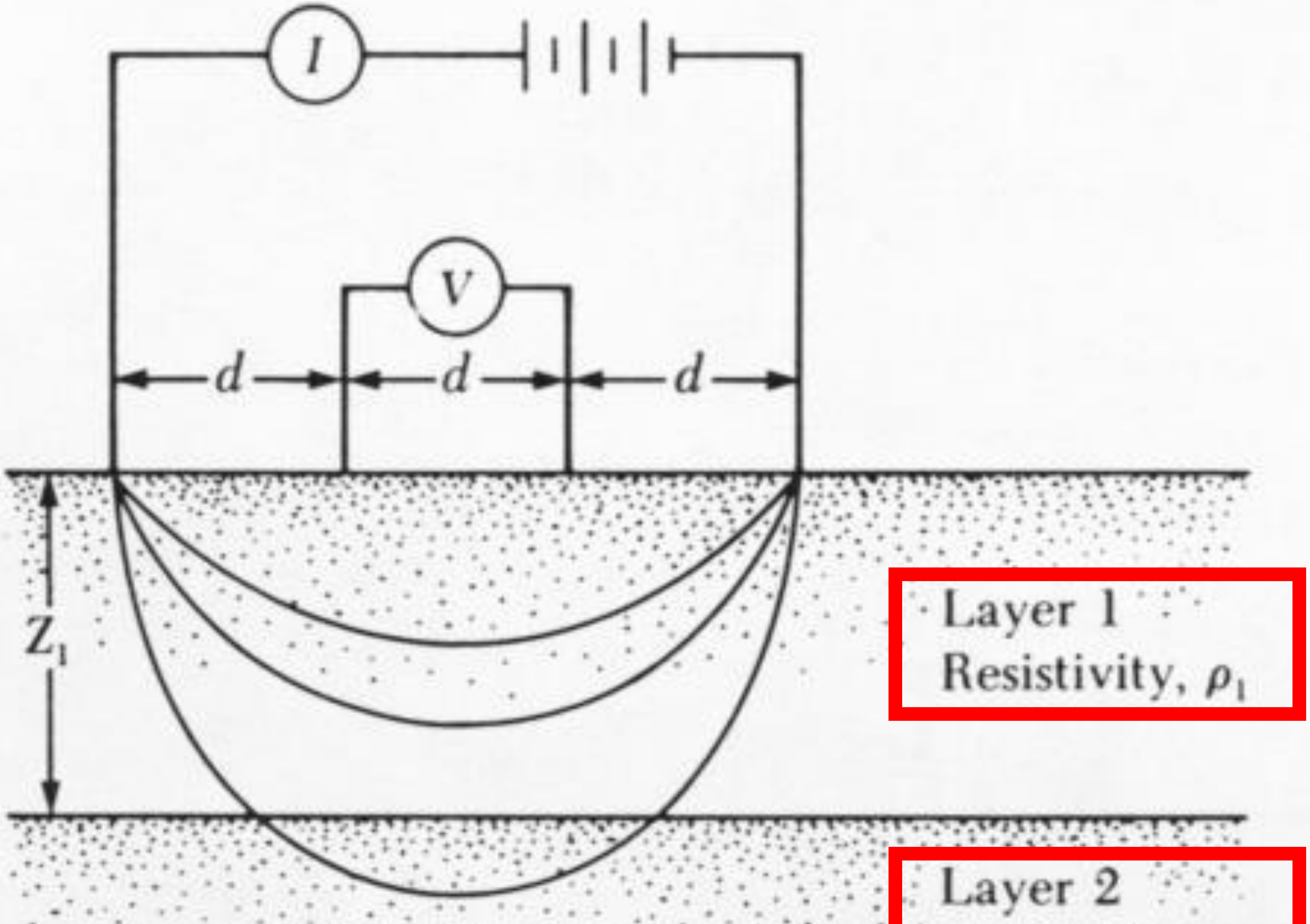
THEORY OF MEASUREMENTS



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



(a)

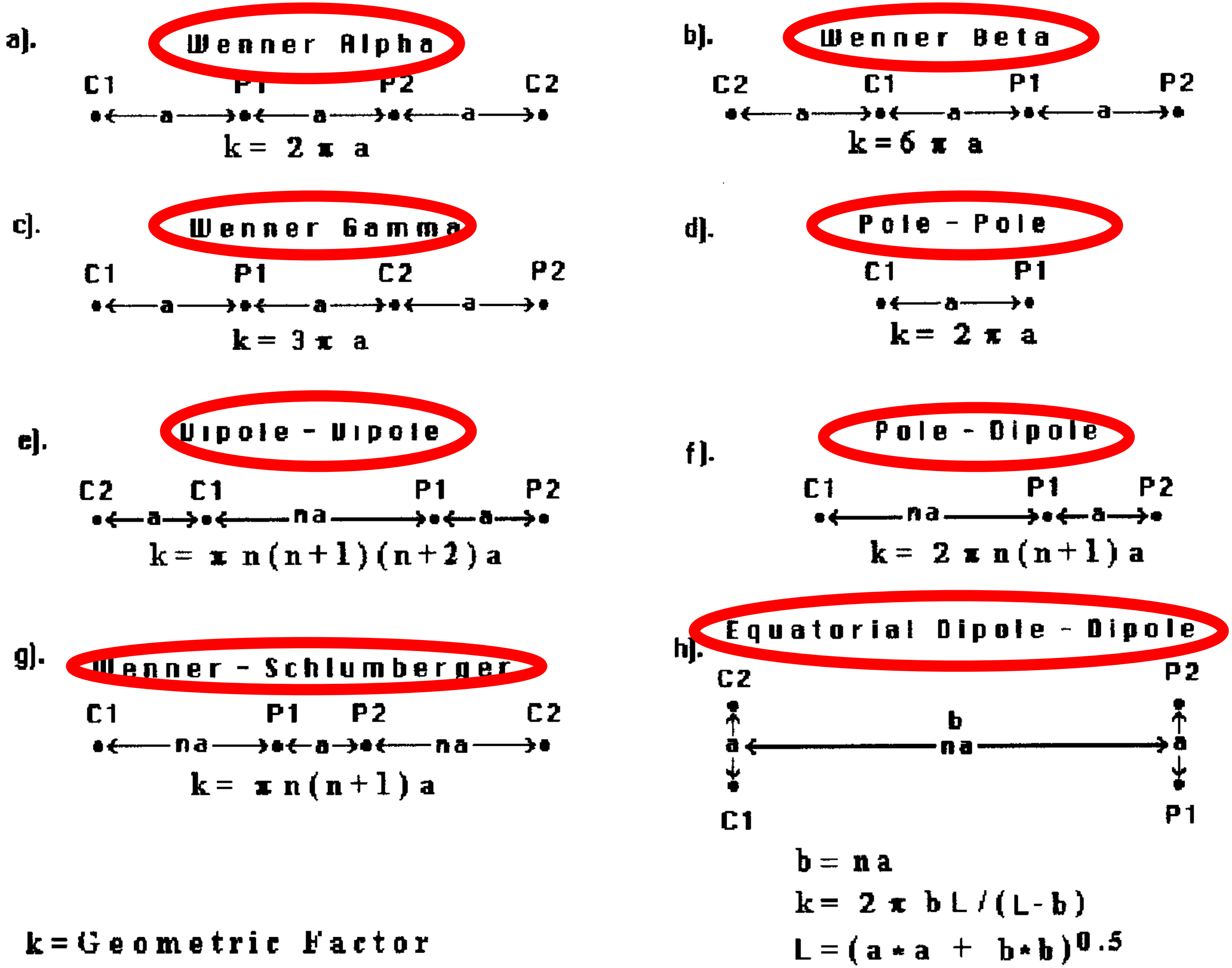


Figure 2. Common arrays used in resistivity surveys and their geometric factors.

DIFFERENT MODELS

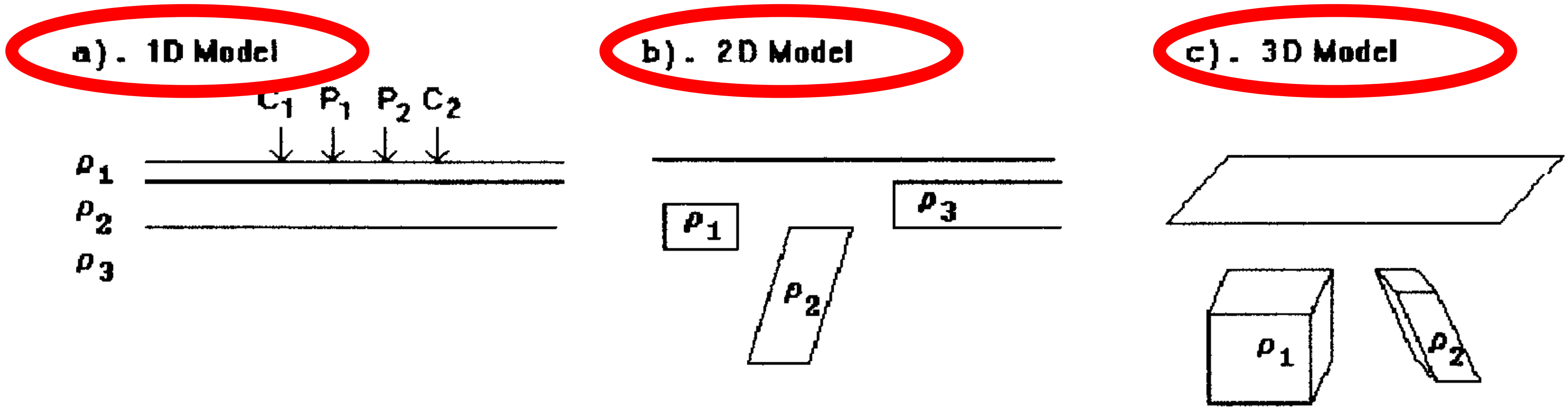
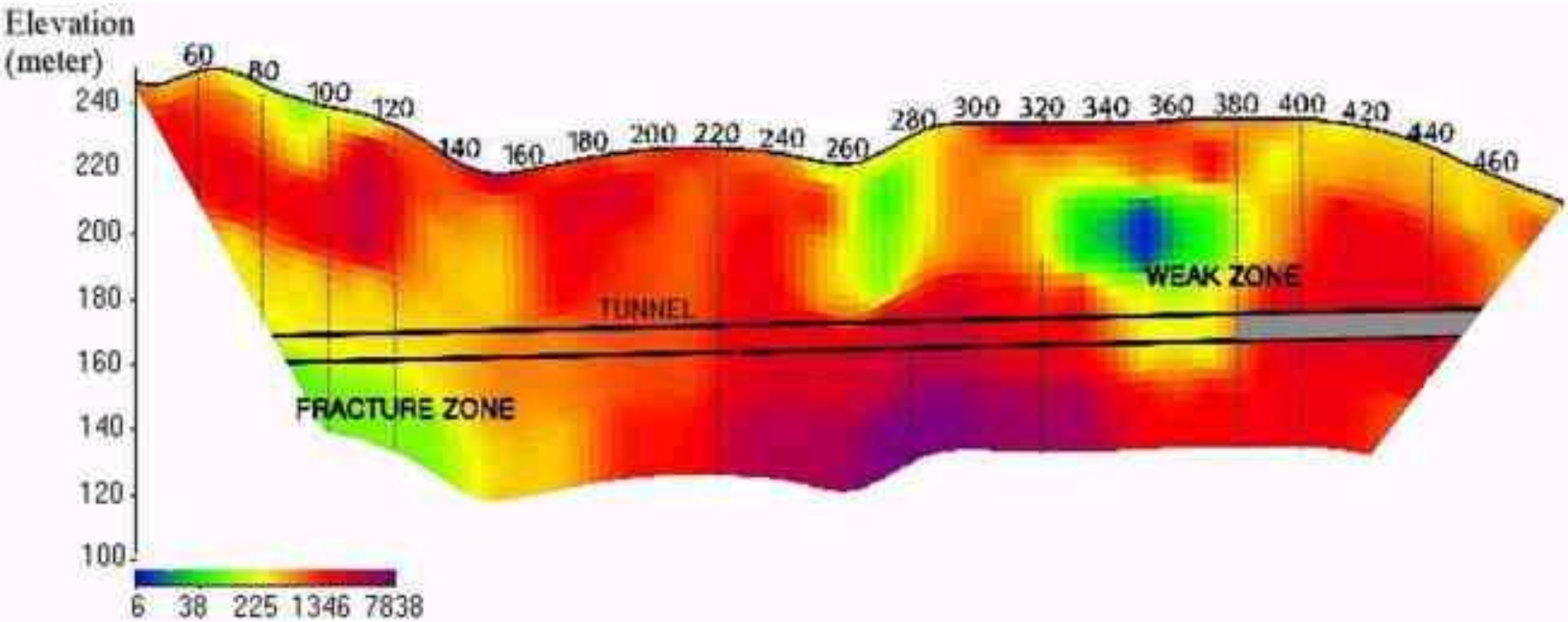
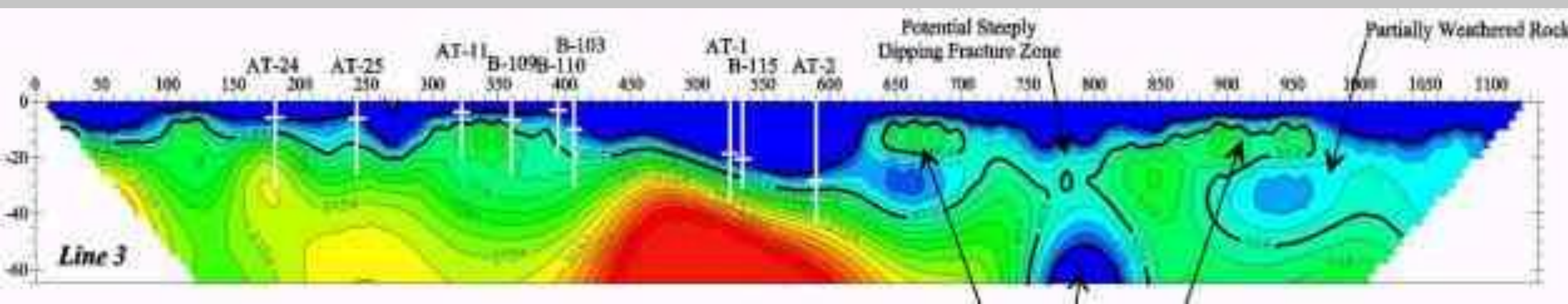


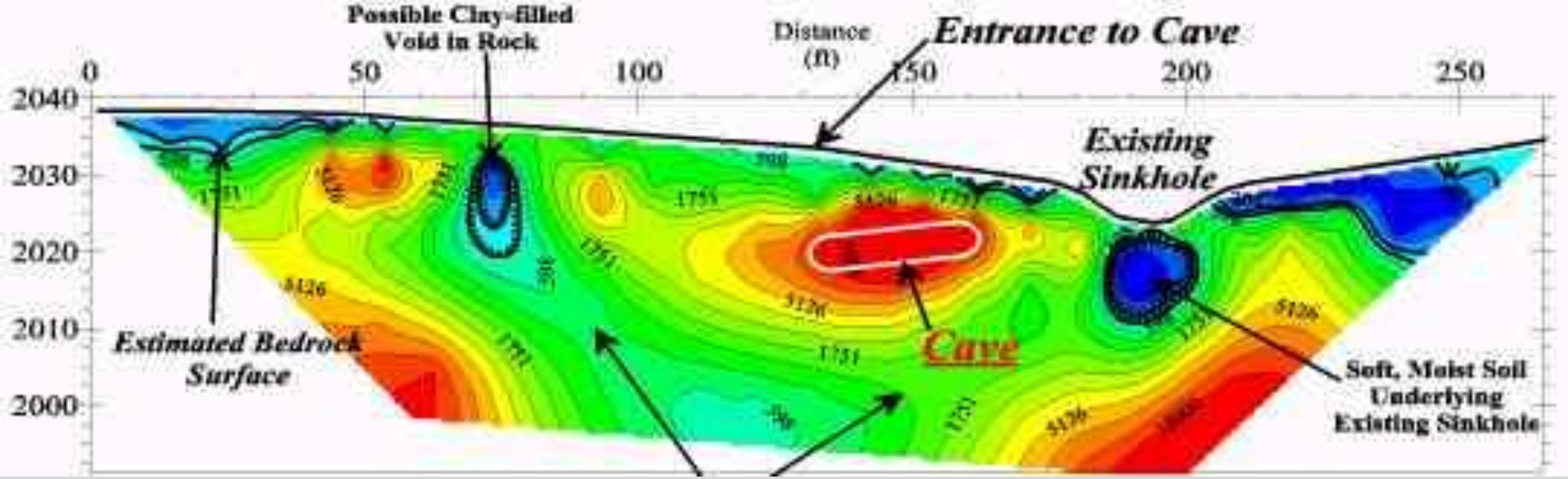
Figure 3. The three different models used in the interpretation of resistivity measurements.

2-D MODELS

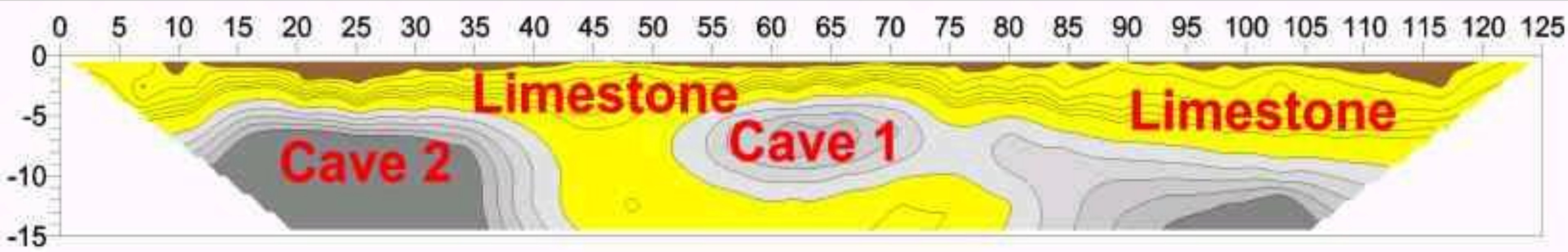

Elevation
(meter)
240
220
200
180
160
140
120
100
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
400
420
440
460
TUNNEL
WEAK ZONE
FRACTURE ZONE
6
38
225
1346
7838


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

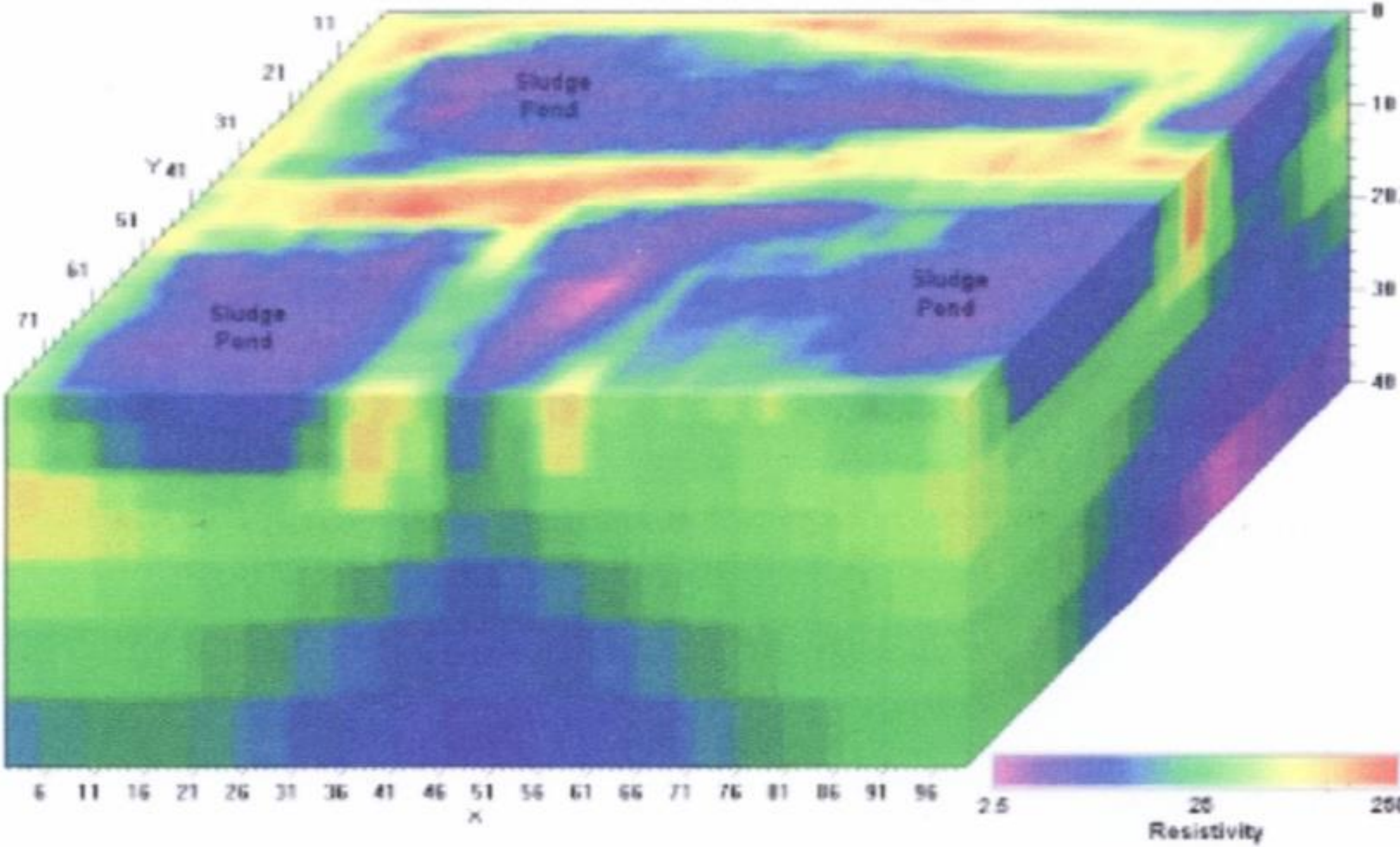


Possible Clay-filled Void in Rock
Distance (ft)
Entrance to Cave
0
50
100
150
200
250
2040
2030
2020
2010
2000
Existing Sinkhole
Estimated Bedrock Surface
Cave
Soft, Moist Soil Underlying Existing Sinkhole



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
-5
-10
-15
Limestone
Limestone
Cave 2
Cave 1

3-D MODEL


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

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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

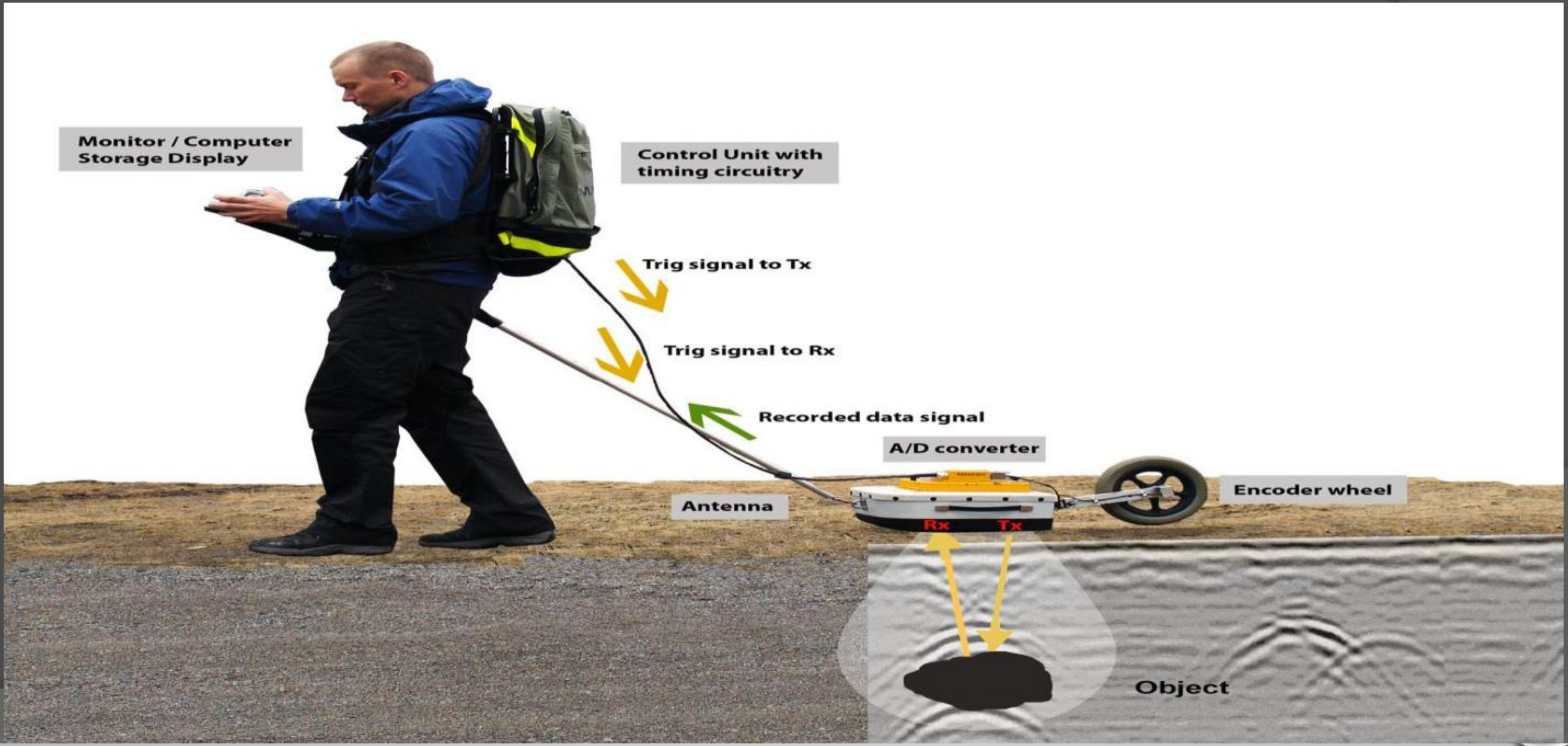
Table 1. Resistivities of some common rocks, minerals and chemicals.

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	$6.998x10^{16}$	$1.429x10^{-17}$

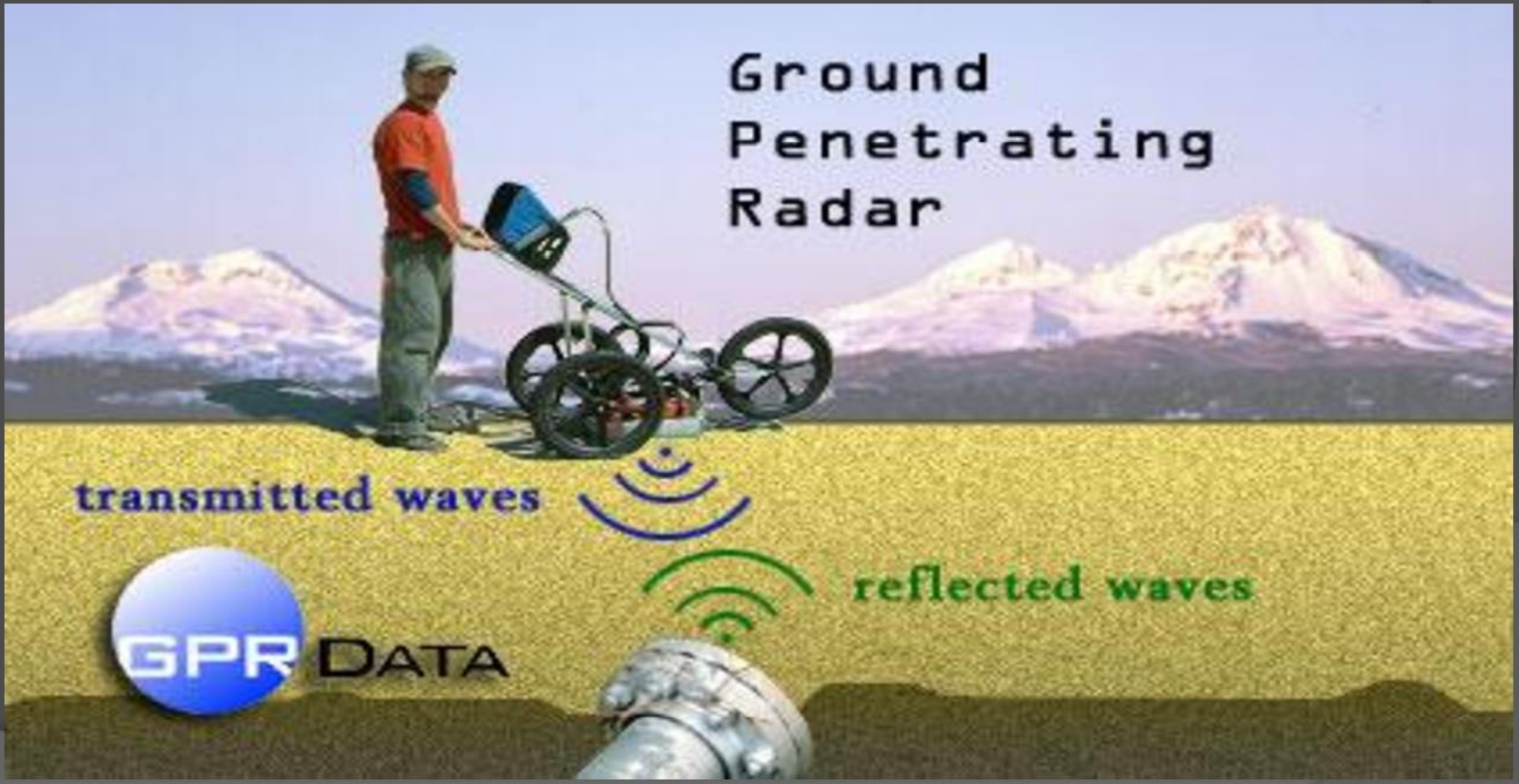
Ground Penetrating Radar (GPR)

- A GPR works on the principle of measuring a contrast in 'Dielectric Constant' of different materials
- The equipment consists of an Antenna which sends a signal into the ground and a receiver which receives back the reflected signal
- The signals could be reflected from different interfaces; for e.g. soil horizons, the groundwater surface, soil/rock interfaces, man-made objects, or any other interface possessing a contrast in dielectric properties.

Ground Penetrating Radar (GPR)

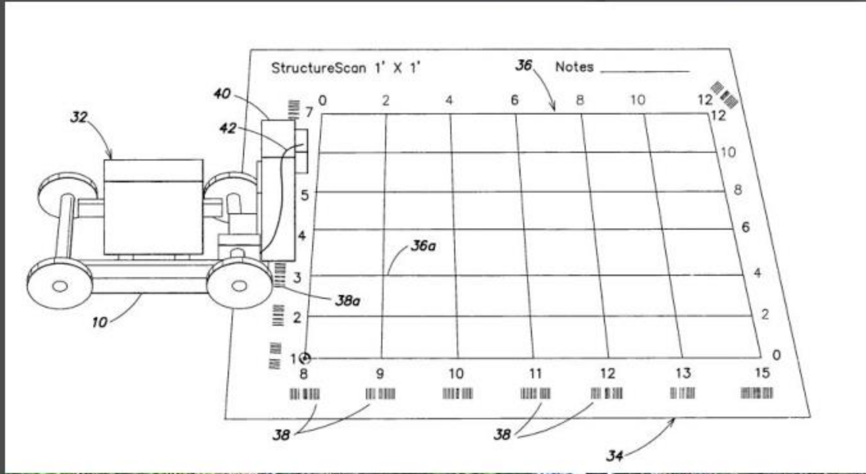


Ground Penetrating Radar (GPR)



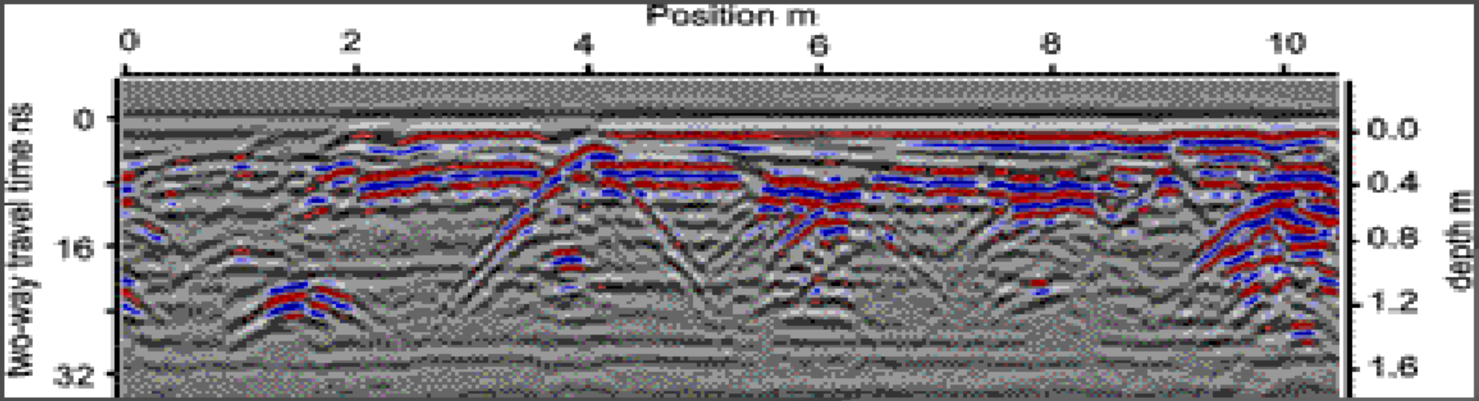
Ground Penetrating Radar (GPR)

- GPR surveys conducted on gridded areas
- Transmitter send Short impulses of high-freq EM wave
- Receiver antenna recives back the reflected waves to ascertain relative changes in dielectric properties of subsurface materials
- Depth of exploration is soil dependent (up to 30 m in dry sands; only 3 m in wet saturated clay)



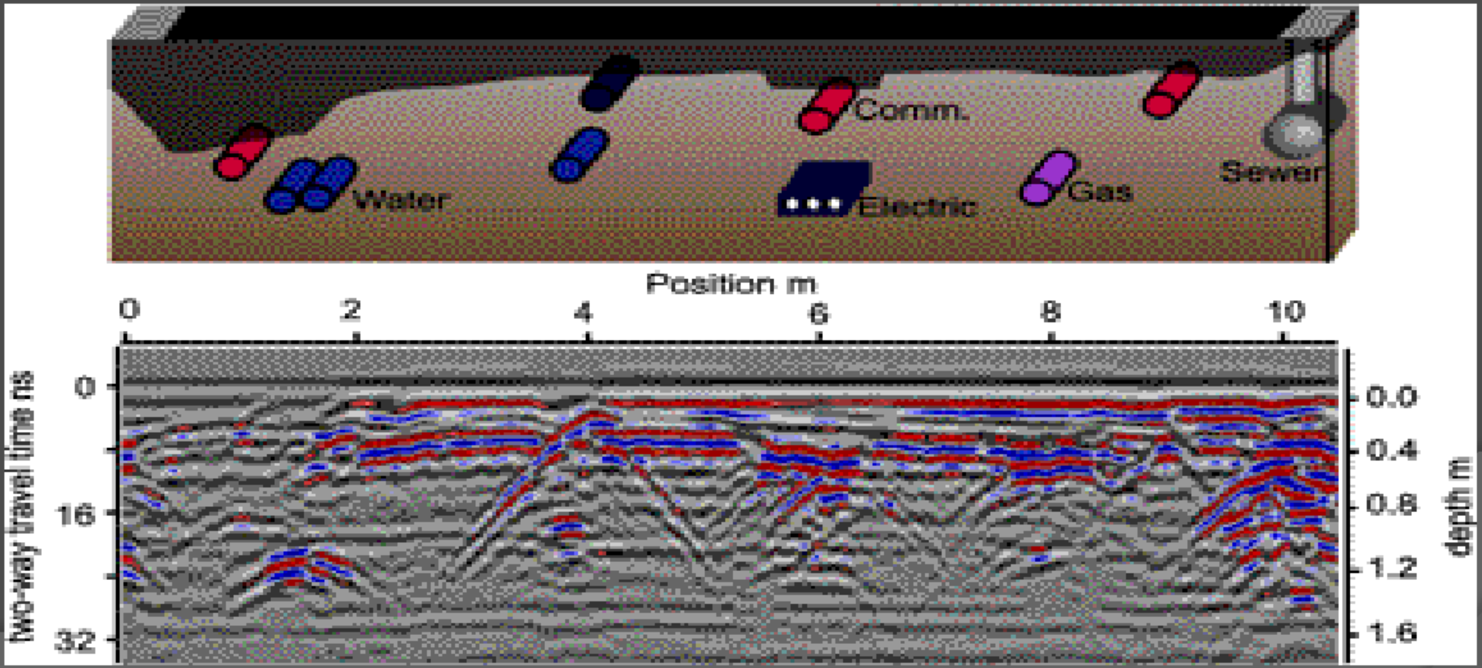
Ground Penetrating Radar (GPR)

- Results
  Locating Underground utilities



Ground Penetrating Radar (GPR)

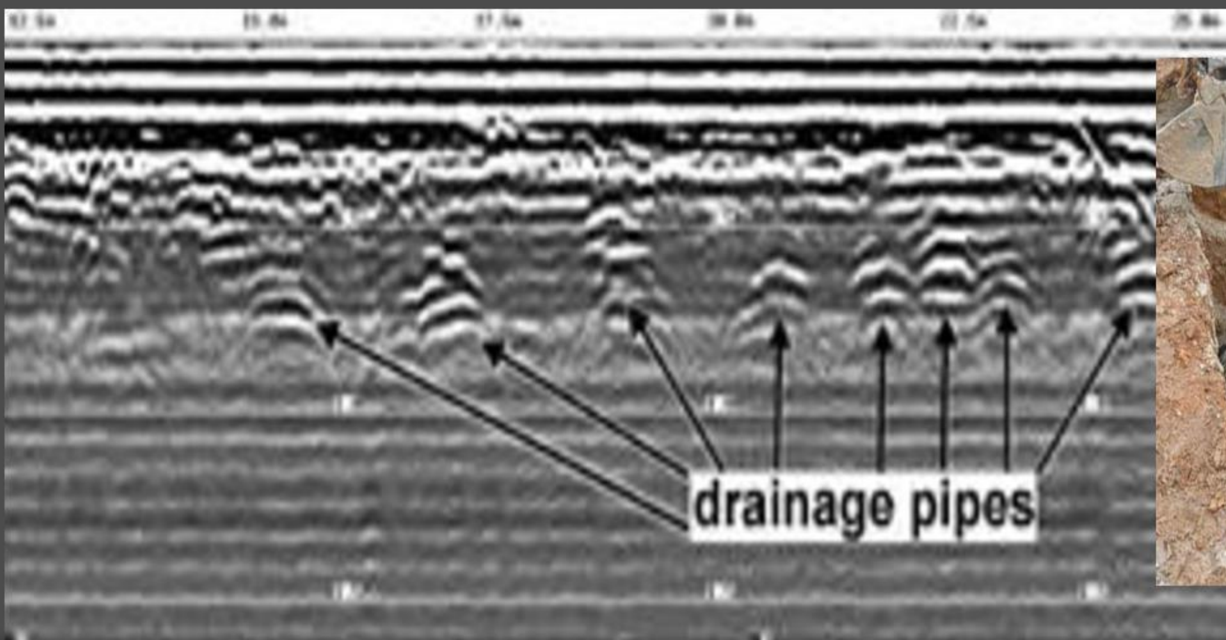
- Results
  Locating Underground utilities



Ground Penetrating Radar (GPR)

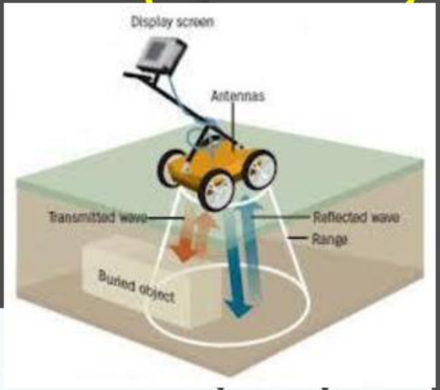
- Results

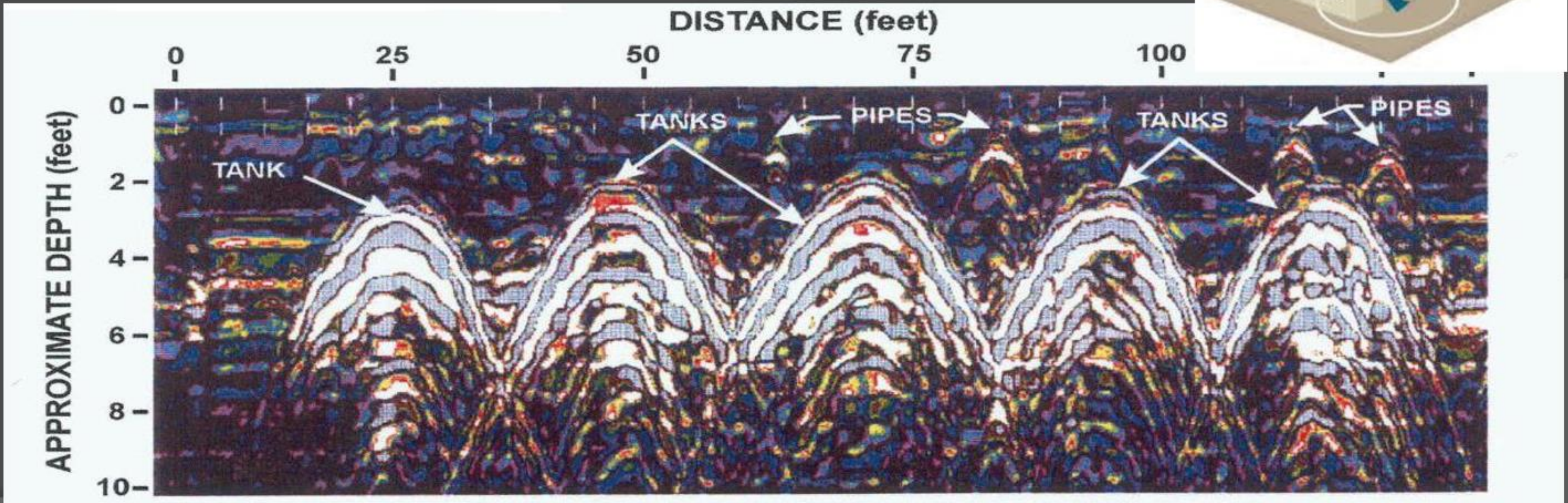
  Locating Underground utilities



Ground Penetrating Radar (GPR)

- Results
  Locating Burried Objects

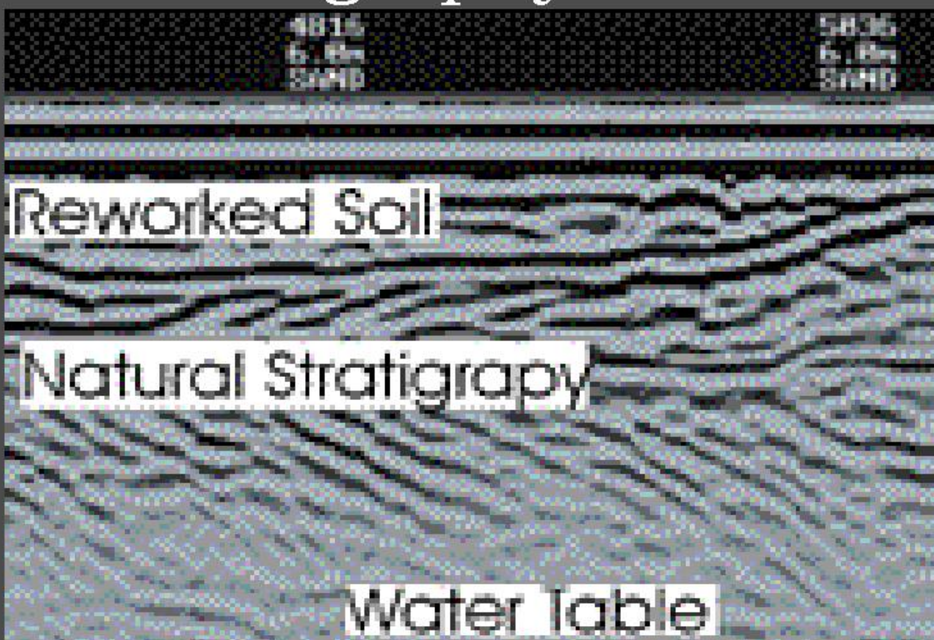


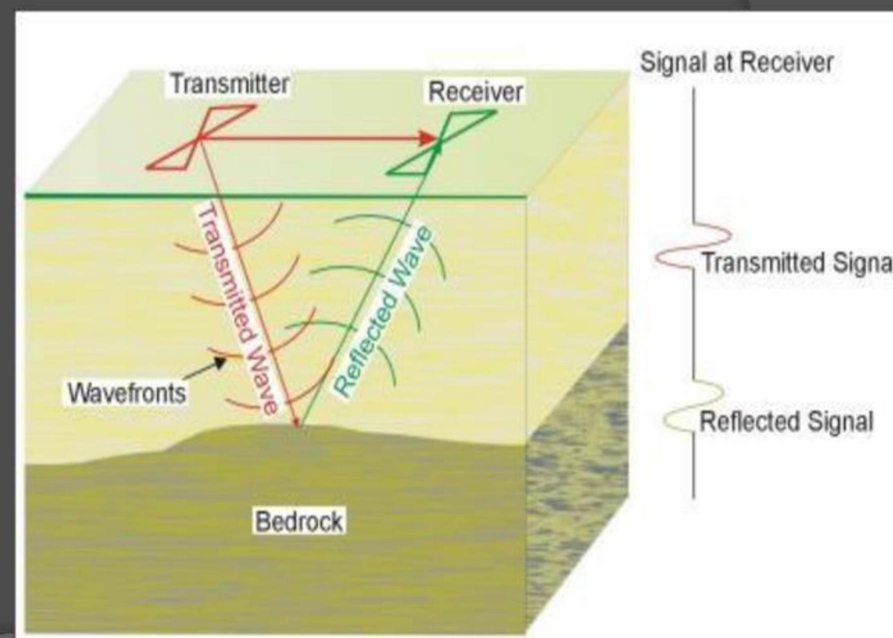


GPR Survey to Locate Underground Storage Tanks

Ground Penetrating Radar (GPR)

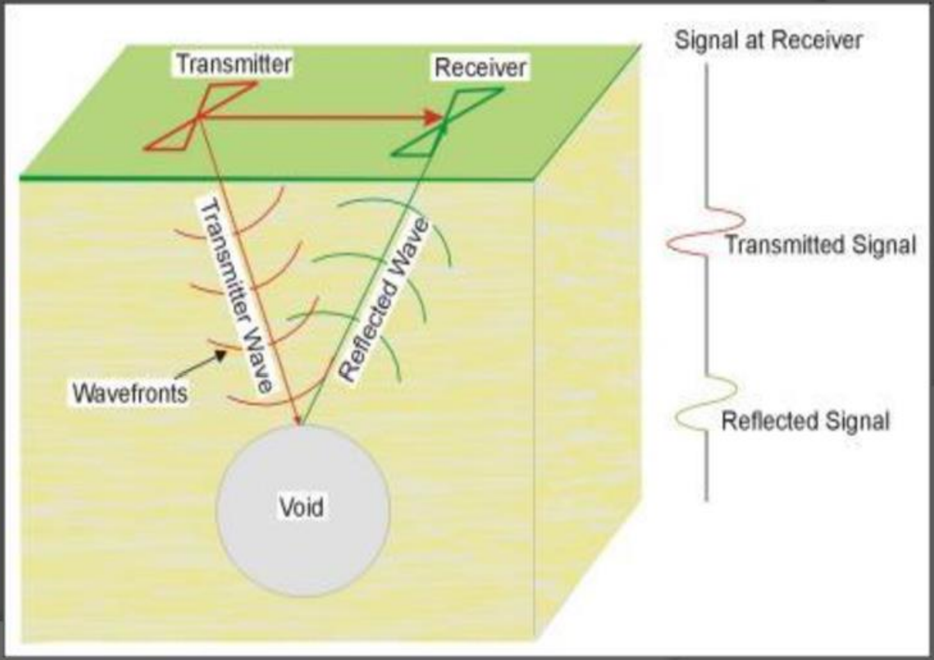
- Results
  Stratigraphy





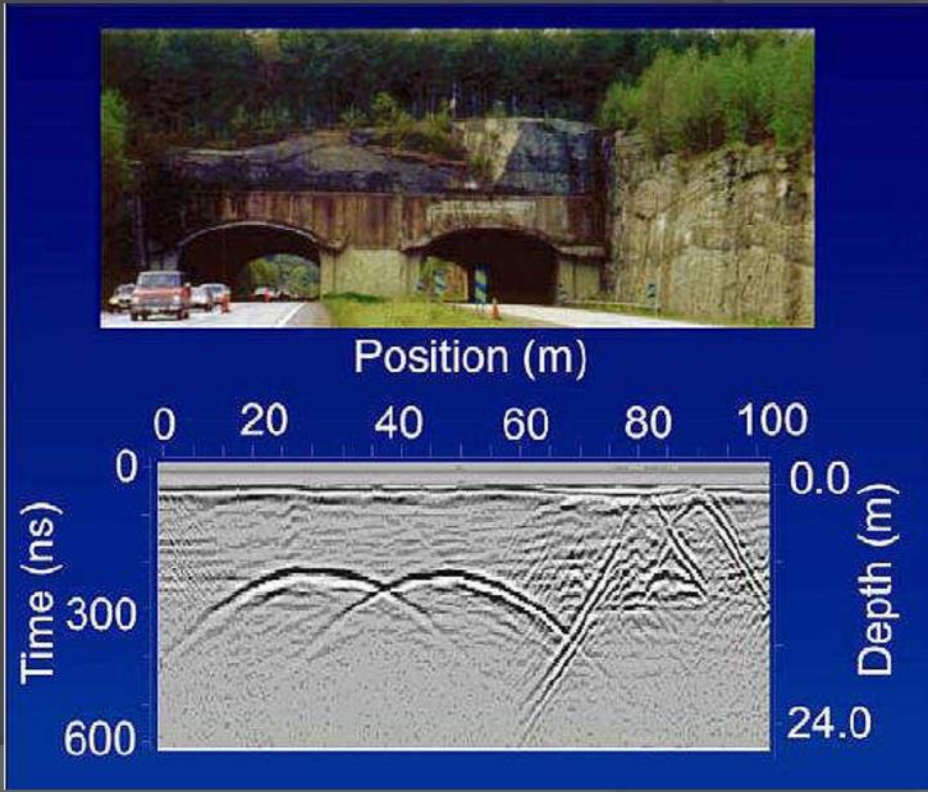
Ground Penetrating Radar (GPR)

- Results
  Stratigraphy



Ground Penetrating Radar (GPR)

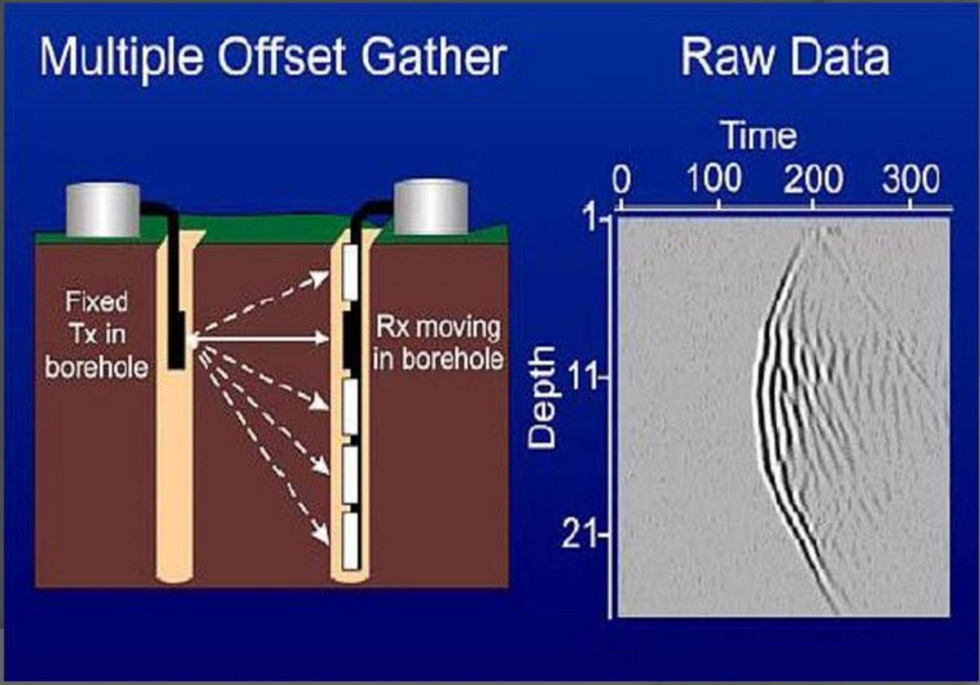
- Results
  Infrastructure Imaging



Ground Penetrating Radar (GPR)

- Results
  Infrastructure Imaging

- Transillumination measurement between two boreholes
- Variations in travel time and signal amplitude indicate structure changes between the transmitter and receiver



Ground Penetrating Radar (GPR)

- Results
  Horizontal Profiling

THANK YOU…