

**CVG4184 / 6305: Rock Mechanics
Winter 2020**

**Chapter 2: Rock Exploration
and In-situ Testing**

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Introduction

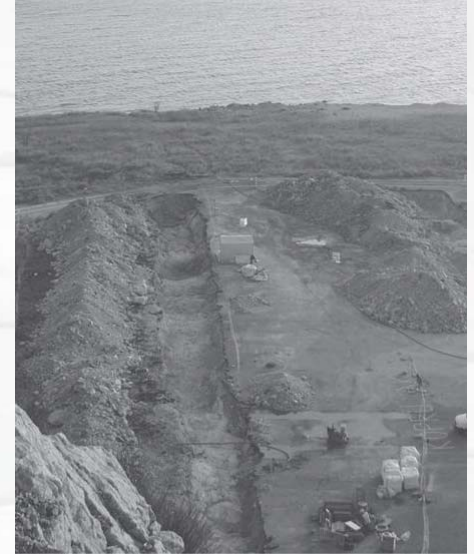
- **Rock mass** consists of intact rock blocks, separated by various discontinuities.
- Rock fragments and rock cores used in **laboratory tests** are generally all **intact rocks**.
- The engineering performance of a rock mass under external loadings is very often **governed by the strength and orientation of the discontinuities** rather than the properties of the intact rock.
- Other factors that influence rock behavior are the presence of **water** and the **in-situ stresses** within the rock mass.

Site Investigation

- **Objective:** to acquire the data needed to create a geotechnical model of the ground that will be affected by the construction of the project.
 - the **sizes and shapes** of the different bodies of geological materials in the ground;
 - the **geotechnical properties** of those materials that are relevant to the project;
 - the **distribution, orientation and engineering characteristics of the structural discontinuities** in the mass;
 - the location and behaviour of **groundwater**.

Site Investigation

- The methods used for **exploration and investigation of rock** include:
 - Exploration (test) pits
 - Rock core drilling
 - Non-core (destructive) drilling
 - Geologic mapping
 - Geophysical methods

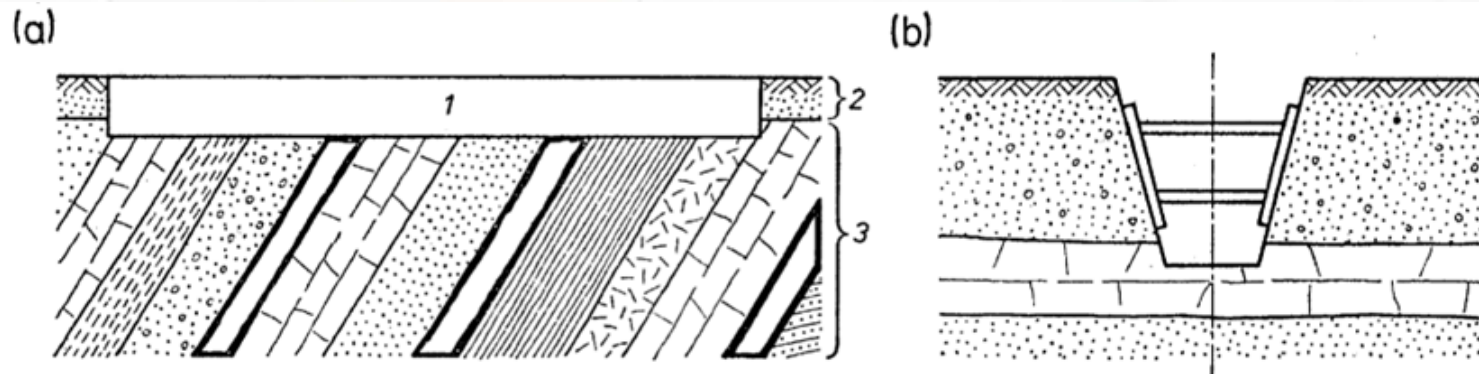


Rock Exploration

- **Exploration pits:** where there is little or no relevant, existing exposure; the extent of discontinuities and large-scale structural features can be investigated, mapped and recorded in better detail.
- **Non-core (destructive) drilling:** when an intact rock sample is not required and for identification of top of rock or cavity.
- **Geophysical methods** such as seismic refraction and ground penetrating radar (GPR) may be used to obtain the depth to rock, location of fractures, etc.
- **Geologic mapping** of rock exposures or outcrops provides a means for assessing the **composition and discontinuities** of rock strata on a large scale.

Rock Exploration

- Exploration pits:
 - Utilized for direct, detailed examination of the geological structure of rock masses;
 - Trenches are excavated perpendicularly to the strikes of the rock layers, where the soil cover thickness is not in excess of 3-4 m and rock layers are steeply inclined.

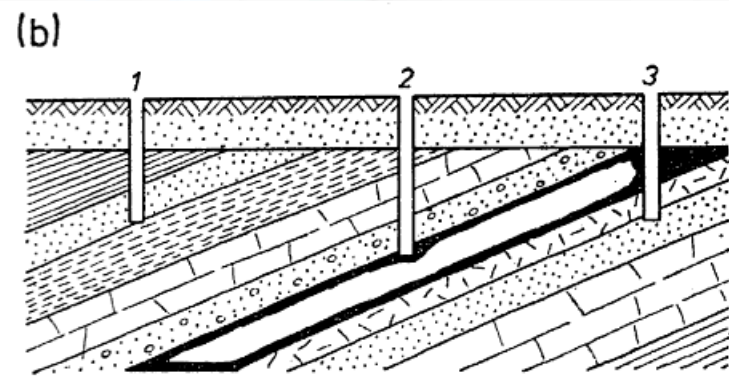
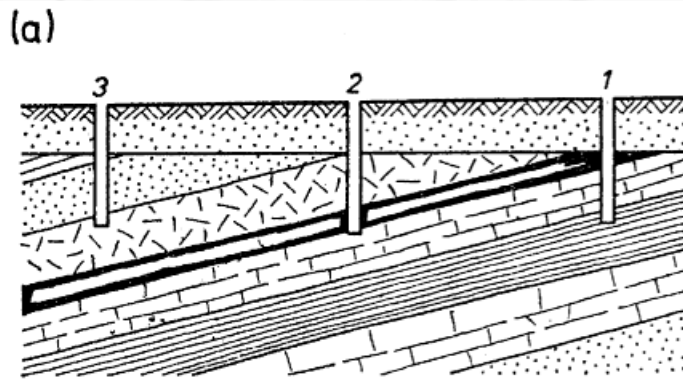


Open excavation—a trench (after Czekajowski, 1972): (a) vertical longitudinal section (1—trench, 2—soil cover, 3—bedrock); (b) vertical cross-section (on a scale differing from that in (a)).

Rock Exploration

- Exploration pits:

- Shallow shafts are used where the soil cover thickness does not exceed 3-4 m and the inclination angle of the layers is small.
- Shafts are placed along reference lines and are so spaced that the lower part of each extends to that bedrock layer which is cut by the upper part of the preceding shallow shaft.



Open excavation—shallow shafts, vertical cross-sections (after Czekajowski, 1972).
1, 2, 3—numbers indicating the order of making the shafts.

Rock Exploration

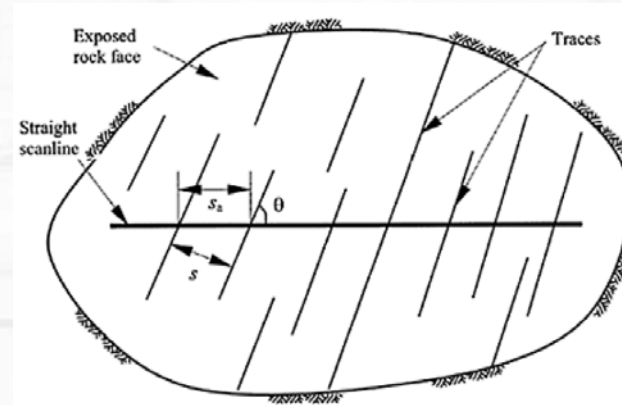
- Discontinuity sampling on exposed rock faces:
 - From sampling on exposed rock faces, either above or below ground, information about the **orientation, spacing, roughness and curvature** of discontinuities can be obtained.
 - Intersections between discontinuities and the rock face produce linear traces which provide **2D sample of the discontinuity network**.
 - The **size and shape of discontinuities** can only be **inferred** based on assumptions.

Rock Exploration

- Discontinuity sampling on exposed rock faces:
 - Straight scanline sampling: to determine spacing, length and orientation of discontinuities.

$$s = s_a \sin \theta$$

$$N = \frac{N_a}{\sin \theta}$$



Where:

- s = true spacing between discontinuities of the same set;
- s_a = measured (apparent) spacing between discontinuities of the same set on the rock face;
- θ = angle between the scanline and the discontinuity traces;
- N = adjusted number of discontinuities;
- N_a is the measured (apparent) number of discontinuities.

Rock drilling and sampling

- **Rock drilling** procedures are used when formations are encountered that are too hard to be sampled by soil sampling methods (ASTM D 2113).
- A penetration of 25 mm (1 in) or less by a 51 mm (2 in) diameter split-barrel sampler following 50 blows using standard penetration energy indicates that soil sampling methods are not applicable and rock drilling or coring is required.
- **Rock drilling** should be performed to a depth that assures that refusal was not encountered on a boulder.

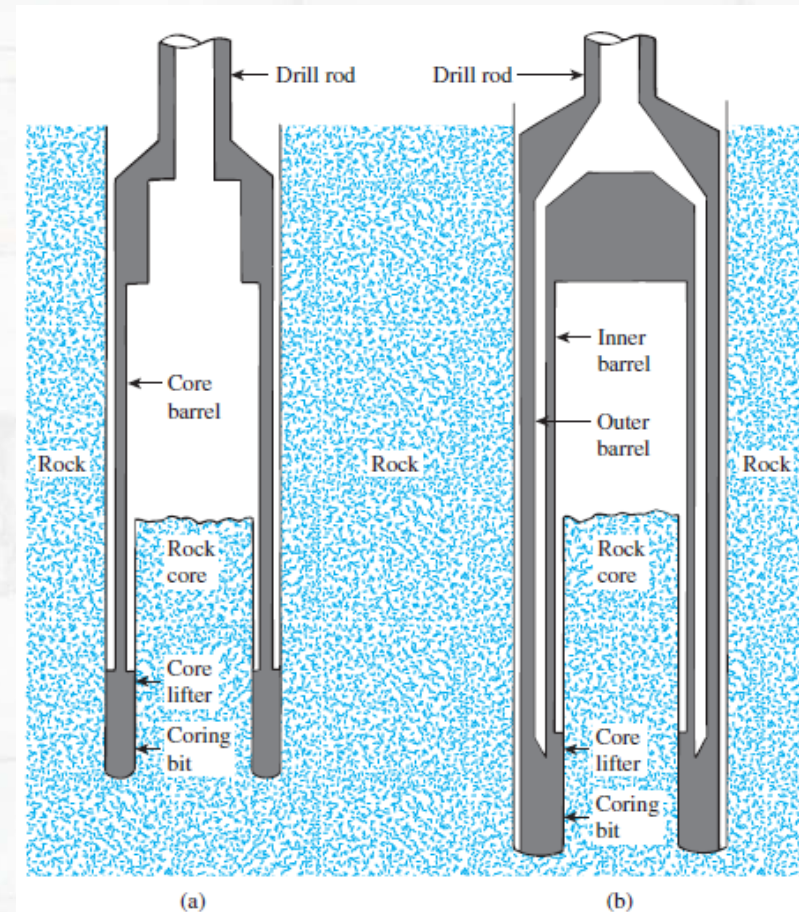
Rock drilling and sampling

- Two ways of drilling into the rock overburden:
 - **Rotary drilling:** a sharp rotating drill bit is advanced into the ground, exerting a downward pressure as well.
 - **Percussion drilling:** the drill bit is repeatedly hammered into the rock.
- **Rock core drilling** is used to obtain **intact samples of rock** for testing purposes and for assessing rock quality and structure.



Rock drilling and sampling

- A **core barrel** is attached to a drilling rod.
 - **single-tube** core barrel (a): disturbed samples; used in homogeneous hard intact rock mass.
 - **double-tube** core barrel (b): most common; minimizes disturbance.
- A **coring bit** (diamond, carbide saw tooth) is attached to the bottom of the barrel.



<https://www.youtube.com/watch?v=U5TpDxA-KIU>

Rock drilling and sampling

- Common **core sizes** and their standard designations

Core size designations and nominal diameters

Symbol	Nominal core diameter		Nominal hole diameter	
	(mm)	(in.)	(mm)	(in.)
AQ	27.0	1 $\frac{1}{16}$	48.0	1 $\frac{57}{64}$
BQ	36.5	1 $\frac{7}{16}$	60.0	2 $\frac{23}{64}$
NQ	47.6	1 $\frac{7}{8}$	75.8	2 $\frac{63}{64}$
HQ	63.5	2 $\frac{1}{2}$	96.0	3 $\frac{25}{32}$
PQ	85.0	3 $\frac{11}{32}$	122.6	4 $\frac{53}{64}$
EX	22.2	$\frac{7}{8}$	36.5	1 $\frac{7}{16}$
AX	30.2	1 $\frac{3}{16}$	47.6	1 $\frac{7}{8}$
BX	41.3	1 $\frac{5}{8}$	58.7	2 $\frac{5}{16}$
NX	54.0	2 $\frac{1}{8}$	74.6	2 $\frac{15}{16}$

Rock drilling and sampling

- Selection of **core size**
 - in **most rocks** a diameter of not less than **70 mm** is adequate for good recovery, proper examination and testing.
 - In **massive, strong rocks**, a diameter of **55 mm** is usually adequate.
 - For **very weak and/or friable rocks** it may be necessary to obtain **100 mm** or even **150 mm diameter** core.

Rock drilling and sampling

- **Diamond bits** are applicable in all rock types, and permit higher rates of coring when compared to other bits.
- **Carbide insert bits** are cheaper than diamond bits and can be used in soft to medium-hard rock.
- **Sawtooth bits** are the cheapest, but lead to slower coring, and are typically only used in soft rock.



Rock drilling and sampling

- In fractured and weathered rock zones the core length should be **1.5 meters or less**.
- The core lengths should **not be greater than 3 m** under any conditions because of the potential to damage the long cores.
- Rock coring can be accomplished with either **conventional or wireline equipment**.
 - With **conventional drilling** equipment, the entire string of rods and core barrel are brought to the surface after each core run to retrieve the rock core.
 - **Wireline drilling** equipment allows the inner tube to be uncoupled from the outer tube and raised rapidly to the surface by means of a wire line hoist.

<https://www.youtube.com/watch?v=SyLnsdeuLy4>

Rock drilling and sampling

- **Observations during drilling**
 - **Drilling Rate/Time:** The drilling rate should be monitored and recorded on the boring log in the units of minutes per 0.3 m (1 ft).
 - **Core Photographs:** cores in the split core barrel should be photographed immediately upon removal from the borehole.
 - **Rock Classification:** the rock type and its inherent discontinuities, joints, seams, and other facets should be documented.
 - **Core Recovery and Core Recovery (CR) Ratio**
 - **Rock Quality Designation (RQD)**

- The Rock Core Log:

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Rock drilling and sampling

Project:	Key to Rock Core Log Sheet 1 of 2
Project Location:	
Project Number:	

Depth, meters	Elevation, meters	ROCK CORE								MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES	
		Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology							
0															
1	2	3	4	5	6	7	8	9	10	11		13	14	15	16
2		1	1	100		80									Slow drilling
4					0			1	M	12	a b c d e f g h 1: 75, J, VN, Fe, Su, Pl, S, VC M: Mechanical Breakage				

- 1** **Depth:** Distance (in meters) from the collar of the borehole.
- 2** **Elevation:** Elevation (in meters) from the collar of the borehole.
- 3** **Run No.:** Number of the individual coring interval, starting at the top of bedrock.
- 4** **Box No.:** Number of the core box which contains core from the corresponding run.
- 5** **Recovery:** Amount (in percent) of core recovered from the coring interval; calculated as the length of core recovered divided by the length of the run.
- 6** **Frac. Freq.:** (Fracture Frequency) The number of naturally occurring fractures in each foot of core; does not include mechanical breaks, which are considered to be induced by drilling.
- 7** **R Q D:** (Rock Quality Designation) Amount (in percent) of intact core (pieces of sound core greater than 100 mm in length) in each coring interval; calculated as the sum of the lengths of intact core divided by the length of the core run.
- 8** **Fracture Drawing:** Sketch of the naturally occurring fractures and mechanical breaks, showing the angle of the fractures relative to the cross-sectional axis of the core. "NR" indicates no recovery.
- 9** **Fracture Number:** Location of each naturally occurring fracture (numbered) and mechanical break (labeled "M"). Naturally occurring fractures are described in Column 11 (keyed by number) using descriptive terms defined on the following page (Items a - h).
- 10** **Lithology:** A graphic log presentation using symbols to represent differing rock types.
- 11** **Description:** Lithologic description in this order: rock type, color, texture, grain size, foliation, weathering, strength, and other features; descriptive terms are defined on the following page. A detailed descriptive log of overburden materials is not necessarily provided.
- 12** **Discontinuity Description:** Abbreviated description of fracture corresponding to number of naturally occurring fracture in Column 9 using terms defined on the following page (Items a - h).
- 13** **Packer Tests:** A vertical line depicts the interval over which a packer test is performed.
- 14** **Laboratory Tests:** A vertical line depicts the interval over which core has been removed for laboratory testing. Laboratory tests performed are indicated in Column 16.
- 15** **Drill Rate:** Rate (in meters per hour) of penetration of drilling. "N/O" indicates rate not observed.
- 16** **Field Notes:** Comments on drilling, including water loss, reasons for core loss, and use of drilling mud; also, laboratory tests performed on core.

Template: M4SK Pre ID: KEY

Sheet 1 of 2

Project:	Key to Rock Core Log Sheet 2 of 2
Project Location:	
Project Number:	

Depth, meters	Elevation, meters	ROCK CORE							MATERIAL DESCRIPTION	Packer Tests	Laboratory Tests	Drill Rate, meters/hour	FIELD NOTES
		Run No.	Box No.	Recovery, %	Frac. Freq.	R Q D, %	Fracture Drawing/ Number	Lithology					

KEY TO DESCRIPTIVE TERMS USED ON CORE LOGS

DISCONTINUITY DESCRIPTORS

- a** Dip of fracture surface measured relative to horizontal
- b** **Discontinuity Type:**
- F - Fault
 - J - Joint
 - Sh - Shear
 - Fo - Foliation
 - V - Vein
 - B - Bedding
- c** **Discontinuity Width (millimeters):**
- W - Wide (12.5-50)
 - MW - Moderately Wide (2.5-12.5)
 - N - Narrow (1.25-2.5)
 - VN - Very Narrow (<1.25)
 - T - Tight (0)
- d** **Type of Infilling:**
- Cl - Clay
 - Cc - Calcite
 - Ch - Chlorite
 - Fe - Iron Oxide
 - Gy - Gypsum/Talc
 - H - Healed
 - No - None
 - Py - Pyrite
 - Qz - Quartz
 - Sd - Sand
- e** **Amount of Infilling:**
- Su - Surface Stain
 - Sp - Spotty
 - Pa - Partially Filled
 - Fi - Filled
 - No - None
- f** **Surface Shape of Joint:**
- Wa - Wavy
 - Pl - Planar
 - St - Stepped
 - Ir - Irregular
- g** **Roughness of Surface:**
- Slk - Slickensided [surface has smooth, glassy finish with visual evidence of striations]
 - S - Smooth [surface appears smooth and feels so to the touch]
 - SR - Slightly Rough [asperities on the discontinuity surfaces are distinguishable and can be felt]
 - R - Rough [some ridges and side-angle steps are evident; asperities are clearly visible, and discontinuity surface feels very abrasive]
 - VR - Very Rough [near-vertical steps and ridges occur on the discontinuity surface]
- h** **Discontinuity Spacing (meters):**
- EW - Extremely Wide (>20)
 - W - Wide (7-20)
 - M - Moderate (2.5-7)
 - C - Close (0.7-2.5)
 - VC - Very Close (<0.7)

ROCK WEATHERING / ALTERATION

Description	Recognition
Residual Soil	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is not apparent; material can be easily broken by hand
Completely Weathered/Altered	Original minerals of rock have been almost entirely decomposed to secondary minerals, although original fabric may be intact; material can be granulated by hand
Highly Weathered/Altered	More than half of the rock is decomposed; rock is weakened so that a minimum 50-mm-diameter sample can be broken readily by hand across rock fabric
Moderately Weathered/Altered	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 50-mm-diameter sample cannot be broken readily by hand across rock fabric
Slightly Weathered/Altered	Rock is slightly discolored, but not noticeably lower in strength than fresh rock
Fresh	Rock shows no discoloration, loss of strength, or other effect of weathering/alteration

ROCK STRENGTH

Description	Recognition	Approximate Uniaxial Compressive Strength (kPa)	
Extremely Weak Rock	Can be indented by thumbnail	250	- 1,000
Very Weak Rock	Can be pried by pocket knife	1,000	- 5,000
Weak Rock	Can be pried with difficulty by pocket knife	5,000	- 25,000
Medium Strong Rock	Can be indented 5 mm with sharp end of pick	25,000	- 50,000
Strong Rock	Requires one hammer blow to fracture	50,000	- 100,000
Very Strong Rock	Requires many hammer blows to fracture	100,000	- 250,000
Extremely Strong Rock	Can only be chipped with hammer blows	> 250,000	

Template: M4SK Pre ID: KEY

Sheet 2 of 2

Rock core logging

- Cores are placed in **well-labelled core boxes** and are stored so that their condition **as recovered** from the borehole is maintained.
- Features in the cores resulting from **drilling**, have to be identified.
- If **samples are extracted for testing** then something should be put in their place (ideally a block of wood cut to length and labelled) and noted.
- Core boxes should have a **logging record** pinned to the inside of the lid.



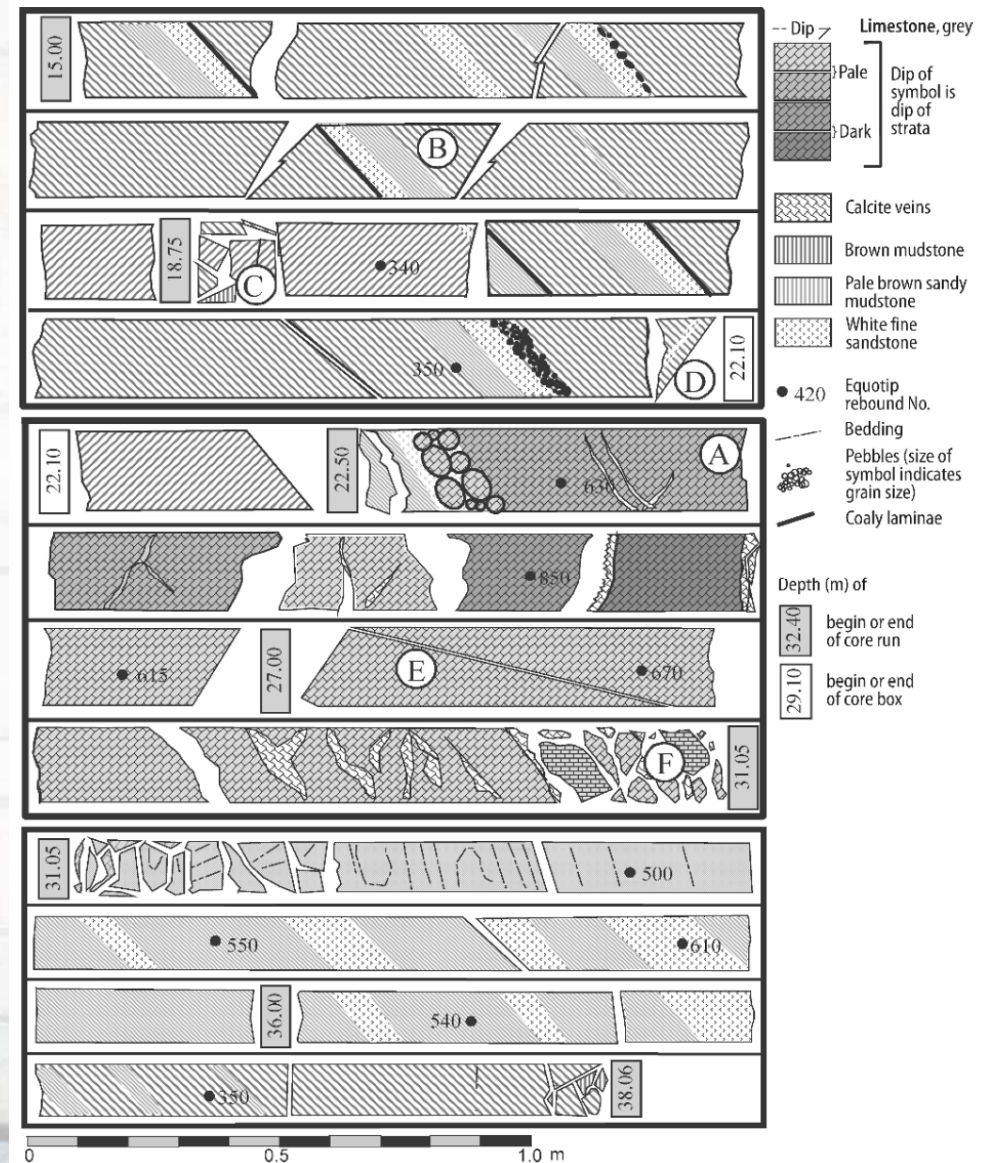
Rock core logging

- Core logging provides information about the total **core recovery**, discontinuity **frequency**, rock quality designation (RQD) and other discontinuity information such as **orientation, spacing and aperture**.
- **Discontinuity frequency** is defined as the number of natural discontinuities intersecting a unit length of recovered core and should be counted for each meter of core.
- **Discontinuity spacing** may also be estimated by matching the individual core pieces and measuring the length along the core axis between adjacent natural discontinuities of one set.

Rock drilling and sampling

Example of core logging

Three core boxes are illustrated containing cores obtained by rotary core drilling from 15.00 to 38.06 m depth. The upper two boxes contain 160 mm diameter core, the lowest 120 mm diameter core. The driller has marked the beginning and end of each core run, which are measured from the drill rods, and has also estimated the depth of the end or beginning of the core in each core box.



Rock drilling and sampling

- Intact rock quality

- Core recovery ratio (CR)

$$CR(\%) = \frac{\text{Length of rock core recovered}}{\text{Total length of the core run}} \times 100$$

- Rock quality designation (RQD)

$$RQD(\%) = \frac{\sum \text{Length of core pieces equal to or longer than 100 mm}}{\text{Total length of the core run}} \times 100$$

<i>RQD (%)</i>	<i>Rock quality</i>	<i>Allowable bearing pressure (MPa)</i>
0–25	Very poor	1–3
25–50	Poor	3–6.5
50–75	Fair	6.5–12
75–90	Good	12–20
90–100	Excellent	20–30

Source: Peck, R.B. et al., *Foundation Engineering*

Rock drilling and sampling

Example 1

In a 1500-mm rock core run, the following rock pieces were recovered from a borehole: 53 mm, 108 mm, 125 mm, 75 mm, 148 mm, 320 mm, 68 mm, 145 mm, 35 mm and 134 mm. Find the *RQD* and the *CR*.

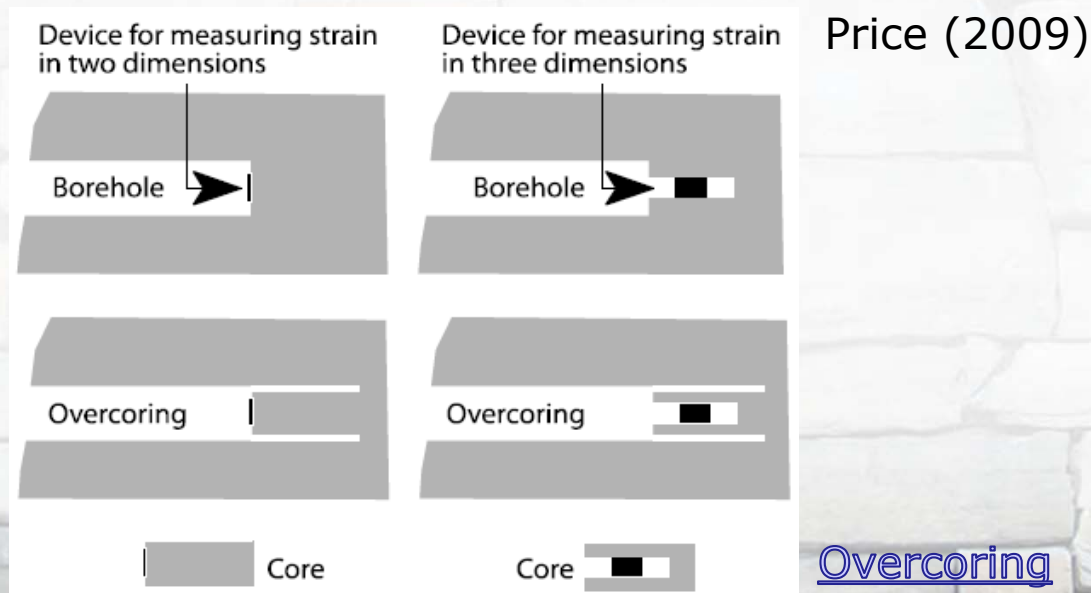
In-situ Testing in Rock

- **In-situ testing** is a major part of investigation programs for major structures founded on rock because of the difficulty in sampling and testing large samples representative of the rock mass.
- The **primary objective of in-situ testing** is to evaluate rock mass deformation modulus and shear strength.
- **Common methods** of in-situ deformation modulus and shear strength testing:
 - overcoring;
 - borehole dilatometer;
 - borehole jack;
 - plate load test;
 - in-situ direct shear test.

In-situ Testing in Rock

- Overcoring

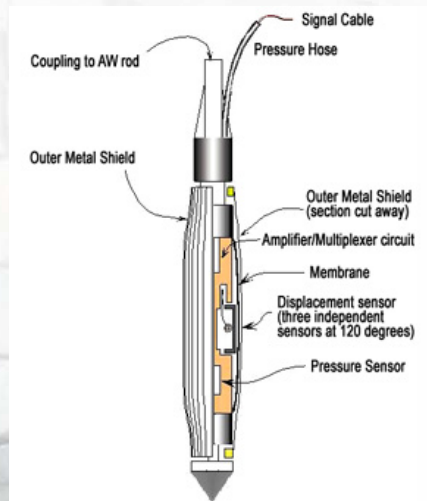
- involves fixing a **strain measuring device** in a borehole and over-coring the device which then **records strains opposite to the in-situ stresses**.
- the readings taken from the strain device allow **calculation of the direction and magnitude of the principal stresses and strains**.



In-situ Testing in Rock

- **Borehole Dilatometer:**

- the dilatometer is lowered to the test elevation and the flexible rubber membrane is expanded exerting a uniform pressure on the sidewalls of the borehole.
- as the pressure is raised, the volumetric expansion of the borehole is measured by electronic transducers that measure radial displacement of the inside of the sleeve.



In-situ Testing in Rock

- **Borehole Dilatometer:**

- Modulus of elasticity of intact rock:

$$E = \frac{\Delta p (1 + \nu)}{\Delta d / d}$$

- Modulus of elasticity of fractured rock:

$$E = \frac{\Delta p}{\Delta d} \left(1 + \nu + \log \frac{b}{r} \right)$$

Where:

E = modulus of elasticity (MPa)

Δp = applied pressure increment (MPa)

d = borehole diameter (m)

r = borehole radius (m)

b = radius of broken rock (m)

ν = Poisson's ratio

In-situ Testing in Rock

- Borehole Dilatometer Test
- Advantages:
 - Test is carried out in **undisturbed** rock mass and at **in-situ moisture** conditions;
 - The cost is relatively low and the test is fast.
 - Mainly applied is **soft rocks** where deformations are high and contact pressures at the dilatometer/rock interface are low ($<15\text{-}20\text{ MPa}$).
- Limitations:
 - Poisson's ratio of rock must be assumed;
 - test only affects small area of the rock mass but several tests over the depth of influence can be performed.

In-situ Testing in Rock

- **Borehole Jack:**

- The jack exerts a unidirectional pressure against the borehole wall by means of semi-cylindrical steel loading plates.
- The applied pressure is measured with a pressure gauge, and the deformation of the rock is measured by two linear variable differential transformers (LVDT).



In-situ Testing in Rock

- Borehole Jack

➤ Modulus of elasticity of fractured rock:

$$E = \frac{\Delta p K}{\Delta d / d}$$

Where:

E = modulus of elasticity (MPa);

Δp = applied pressure increment (MPa);

d = borehole diameter (m);

$K(\nu, \beta)$ = constant depending upon ν and E and the load applied through angle β ;

ν = Poisson's ratio;

β = angle of loaded arc of the jack.

In-situ Testing in Rock

- **Borehole Jack:**

- Applicable in rock that is **too stiff for a dilatometer**.
- Used to **measure rock mass deformability** in a drill hole.
- Measured elastic modulus value **must be corrected** to account for stiffness of steel platens.
- **Test can be performed in any desired direction** in order to evaluate anisotropy or assess the effect of any geological feature on the stability of a rock mass.

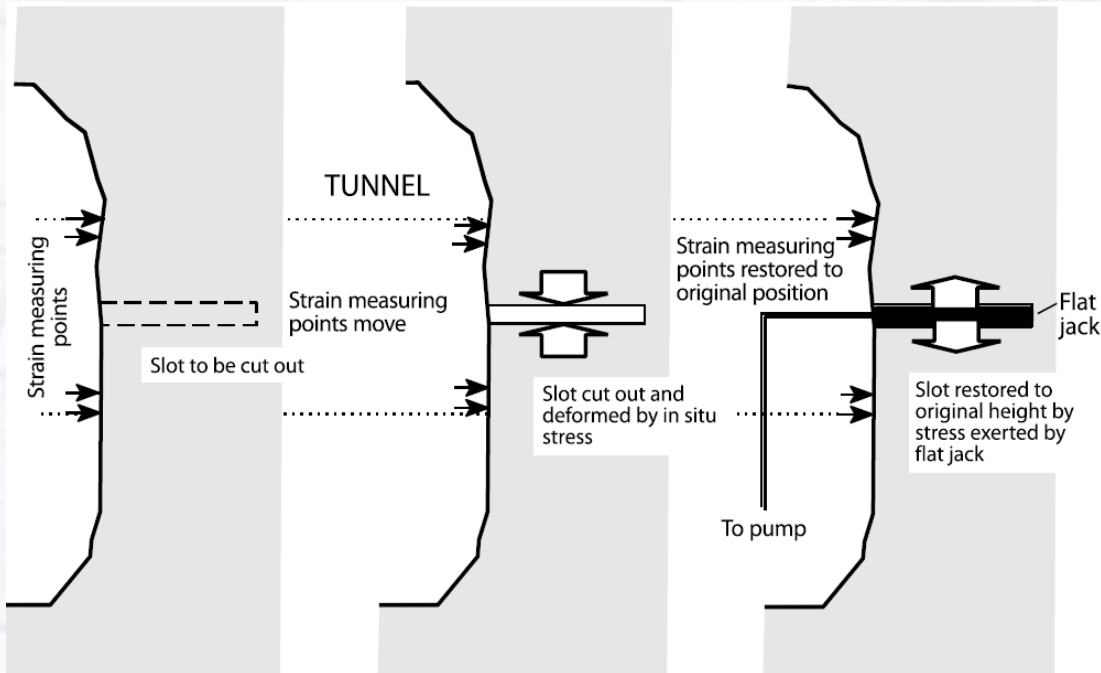
In-situ Testing in Rock

- Flat Jack:

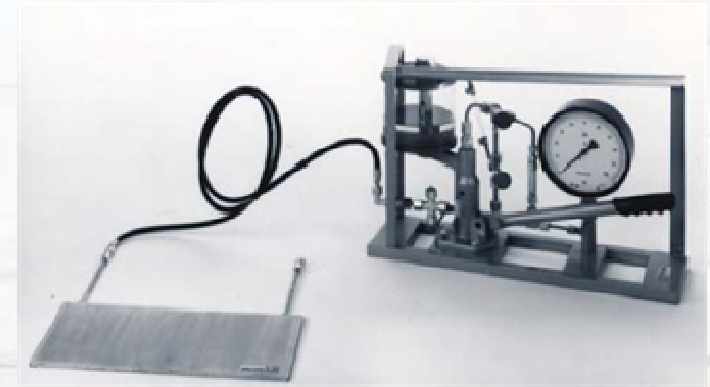
- The distances between measuring points on a rock surface are recorded.
- A slot (1 cm wide and 24 cm deep) is excavated between the points by saw cut or by overlapping drill holes.
- The previously existing stresses are relieved as the rock expands into the slot.
- A flat jack is cemented into the slot and pumped up until the points return to their original position.
- Jack pressure is then equal to in the in-situ stress normal to the slot.

In-situ Testing in Rock

- Flat Jack:



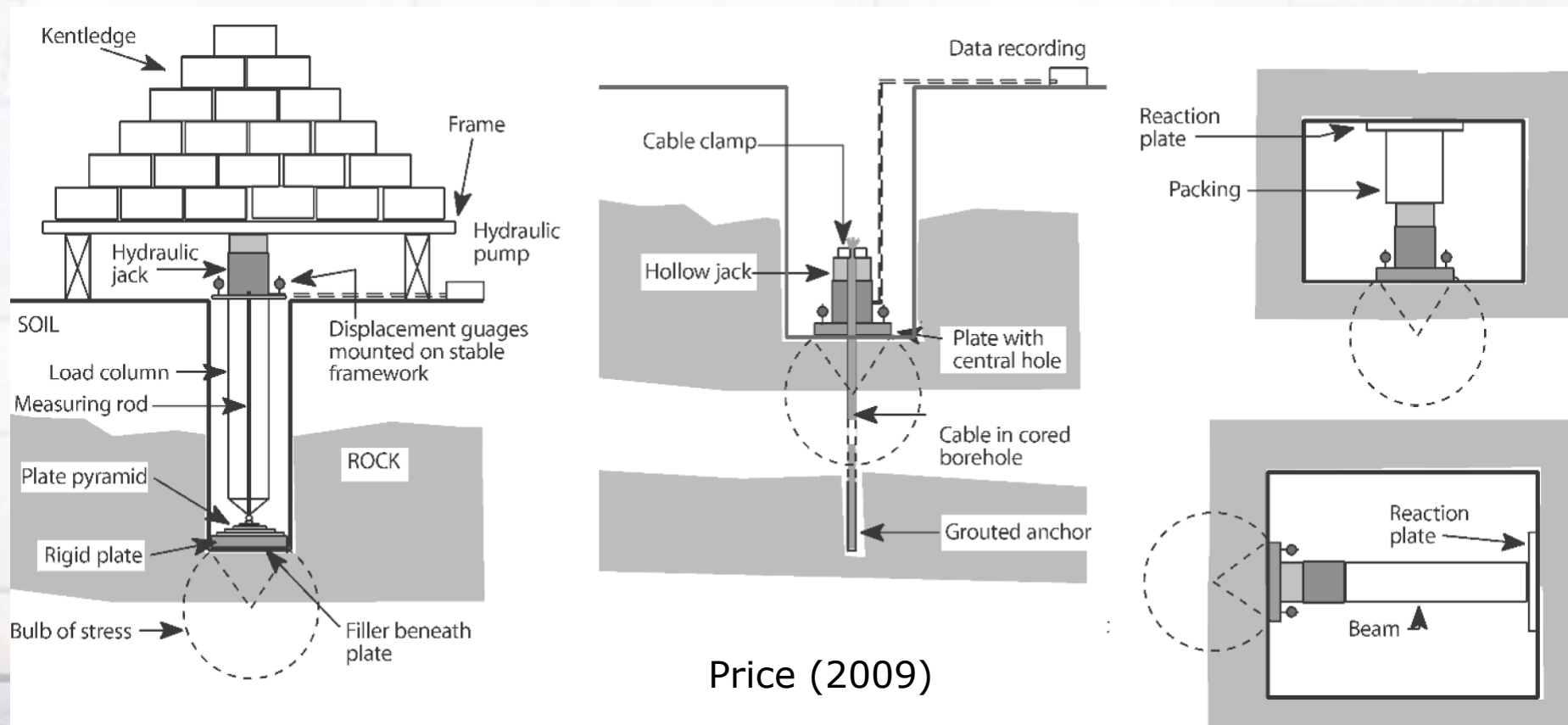
Price (2009)



In-situ Testing in Rock

- **Plate load test:**

- Load is applied to a steel plate using a system of hydraulic jacks and a reaction frame anchored to the foundation rock.



In-situ Testing in Rock

- Plate load test:

- Modulus of elasticity of fractured rock can be determined from:

$$S = \frac{\pi \Delta p}{4} B \frac{(1 - \nu^2)}{E}$$

Where:

E = modulus of elasticity;

Δp = applied pressure increment;

B = plate diameter;

ν = Poisson's ratio ($\nu = 0.10$ for hard rock, $\nu = 0.25$ for soft rock);

S = average settlement of the plate.

In-situ Testing in Rock

- Plate load test:

- Used to measure modulus of elasticity of the rock mass.
- Loaded area is limited so may not be effectively testing rock mass if joints are widely spaced.
- Modulus values need to be corrected for plate geometry, effect of rock breakage, rock anisotropy, and steel plate stiffness.
- If cable anchorage is used, test can be performed in any desired direction in order to evaluate stress anisotropy.

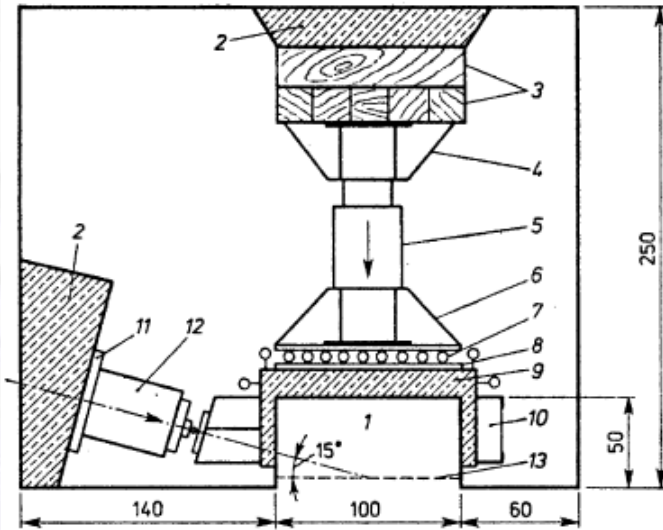
In-situ Testing in Rock

- In-situ Direct Shear Test:

- when the **scale** of laboratory tests is **too small** to give **reliable values of shear strength**.
- to determine the **shear strength (peak and residual) of discontinuities or discontinuity infilling** in rock mass.
- At least **three or four specimens** should be tested at **different normal stresses** on the same test horizon.
- Testing is typically performed in an adit where reaction for the shear load is provided by an adit wall.
- Normal load applied via a jack system that uses the adit roof for reaction.

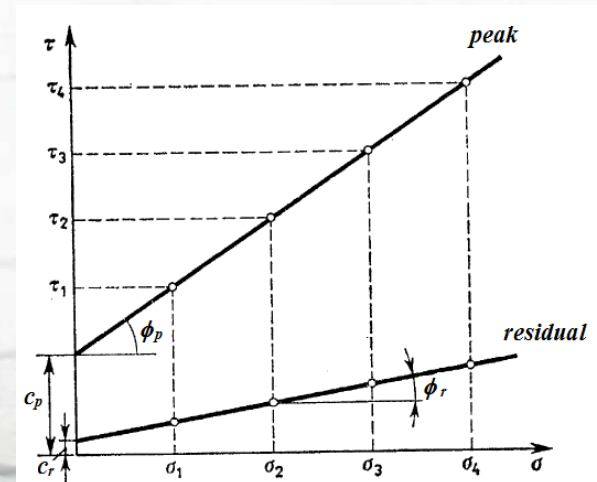
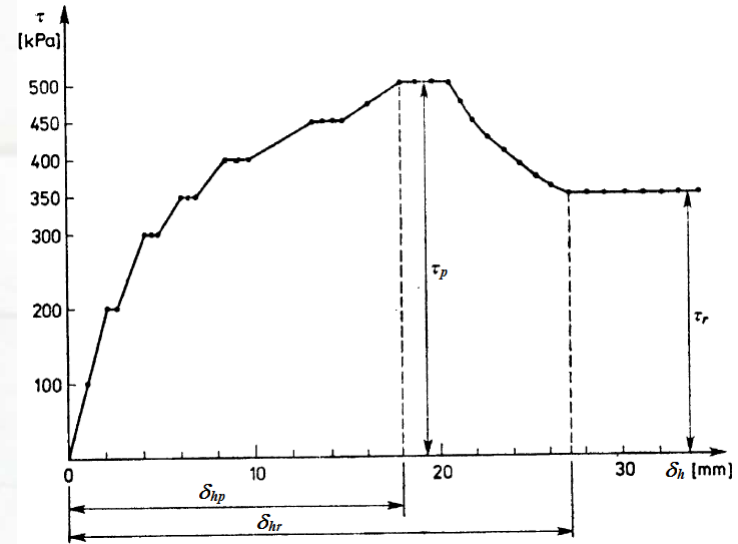
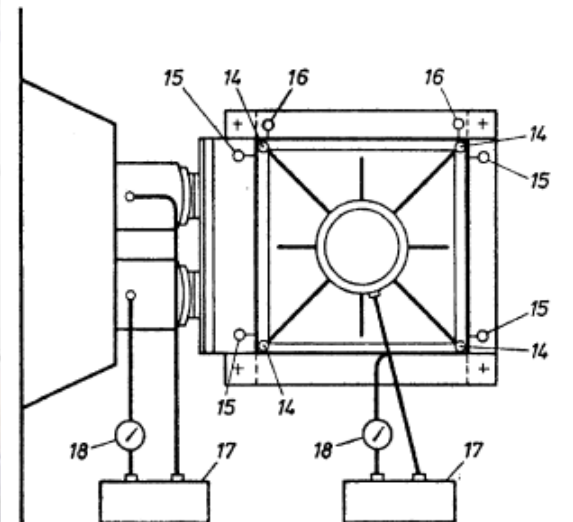
In-situ Testing in Rock

• In-situ Direct Shear Test:



Schematic arrangement of a block under shear and the test apparatus (Polska Norma Branżowa BN-77/8950, 1977).

1—rock block, 2—reaction blocks, 3—timber blocking (oak), 4—upper steel grillage, 5—normal loading hydraulic jack, 6—lower steel grillage, 7—roll assembly to reduce friction, 8—steel plate, 9—concrete encapsulation, of the rock block, 10—steel band, 11—steel plate, 12—hydraulic jack for applying shearing force, 13—forced shear surface, 14—normal displacement gauge, 15—shear displacement gauge, 16—lateral displacement gauge 17—hydraulic pump, 18—manometer.



In-situ Testing in Rock

- In-situ Direct Shear Test:

- Expensive but appropriate for cases in which the shear strength of an **undisturbed, potentially sensitive, infilling** is required for design analyses.
- Testing can be conducted on a rock surface using cables anchored into the rock adjacent to the test site to supply the reaction for loading in the direction normal to the shear load.
- The **peak and residual strength parameters** (cohesion and friction angle) can be determined from τ vs σ plots.

Geophysical Exploration

- Geophysical testing is often used as part of the **initial site exploration phase** of a project.
- Consist of making **indirect measurements** on the ground surface, or in boreholes, to obtain generalized subsurface information (e.g., profile of the top of bedrock, depth to groundwater, limits of types of rock strata, presence of voids).
- Data from geophysical testing should **always be correlated** with information from direct methods of exploration (e.g., boreholes).

Geophysical Exploration

- Advantages:

- tests are non-invasive;
- can cover a relatively large area, with few tests;
- tests assess the characteristics of soil and rock at very small strains, allowing measurement of truly elastic parameters;
- relatively inexpensive compared to core borings or test pits.

- Disadvantages:

- best suited for cases where there is a large difference in stiffness between adjacent subsurface units;
- specialized equipment and expertise are required.

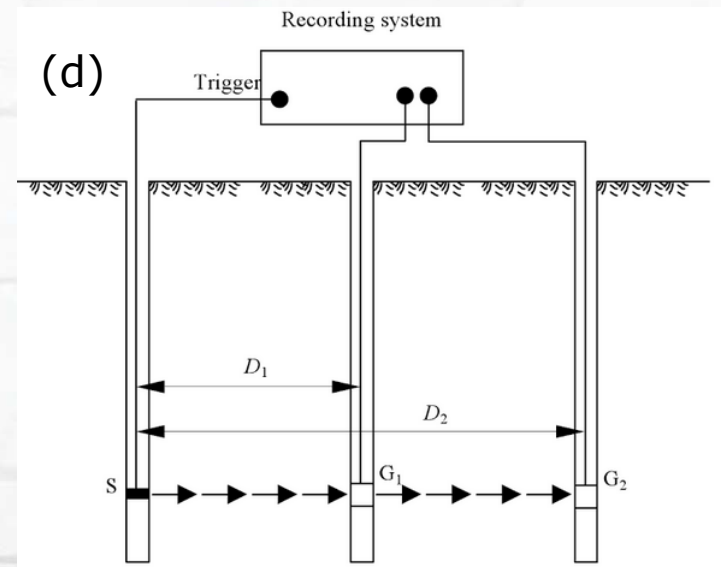
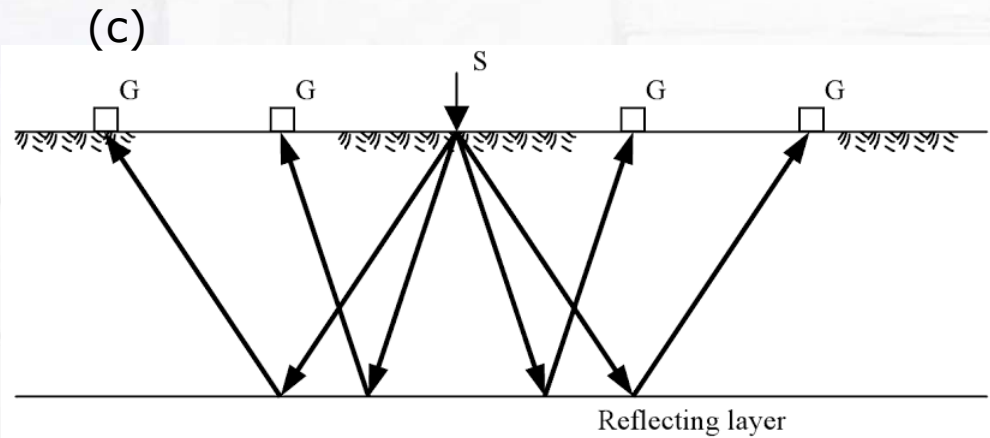
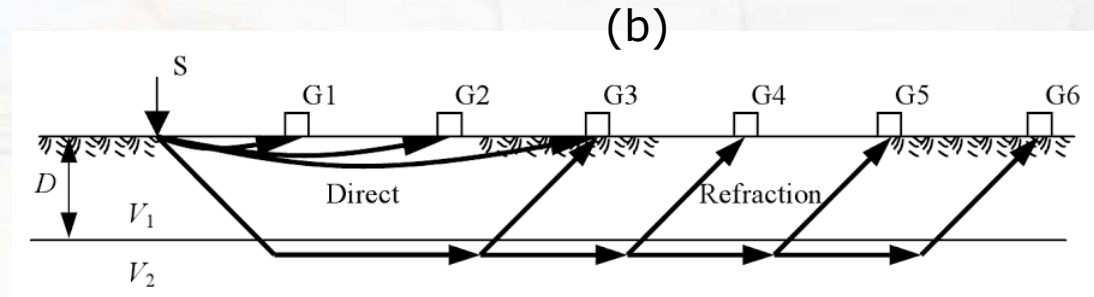
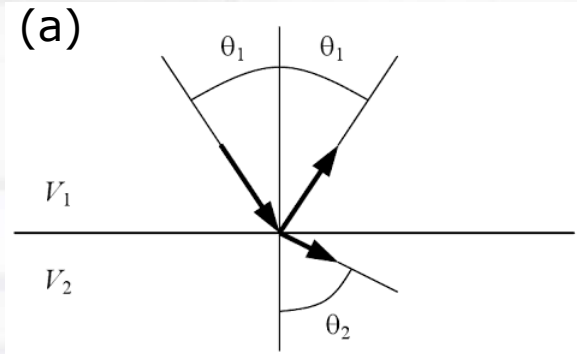
Geophysical Exploration

- **Seismic methods:**

- the **most commonly conducted** geophysical surveys for engineering investigations;
- measure the relative arrival times, and thus the **velocity of seismic waves** traveling between an energy source and a number of geophones.
- the **energy source** may be a hammer blow or detonation of a light explosive charge.
- measured **shear wave velocity** is directly related to **small-strain material stiffness**, which in turn, is often correlated to strength and soil/rock type.
- used for assessing the **vertical stiffness profile** and the **interface** between soil and rock.

Geophysical Exploration

- Seismic methods:



(a) Seismic reflection and refraction; (b) The seismic refraction method; (c) The seismic reflection method; (d) Cross hole method. After Zhang (2004).

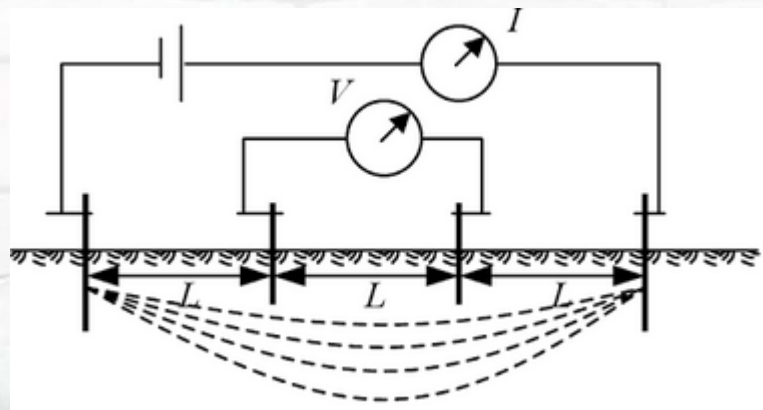
Geophysical Exploration

- **Electrical methods:**

- Used to locate voids, sinkholes, buried objects, contamination plumes, depth to GWT.

- **Electrical Resistivity method:**

- DC current is applied to the ground using electrodes.
- Voltages are measured at different points on the ground surface with other electrodes positioned along a line.



Geophysical Exploration

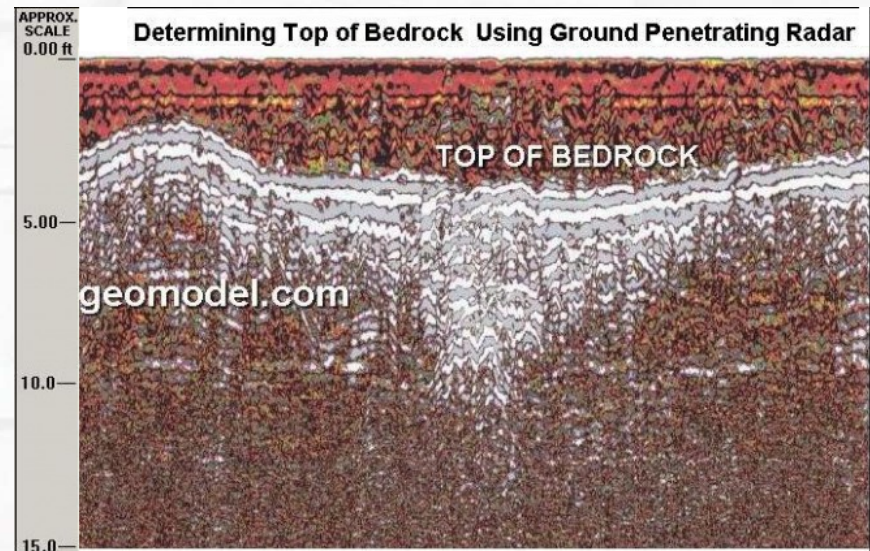
- **Ground Penetrating Radar:**

- high-frequency (80 to 1,000 MHz) electromagnetic (EM) waves are transmitted into the ground.
- transmitted EM waves are reflected from various interfaces within the ground and are detected by the radar receiver at the surface;
- reflecting interfaces may be soil horizons, GWT, soil/rock interfaces, man-made objects, etc.
- fracture infillings with dielectric properties different from their adjacent rock mass can be detected.

Geophysical Exploration

- **Ground Penetrating Radar:**

- not effective below the water table or in clay;
- the penetration depth of radar is limited to usually less than 10 meters.



Geophysical Exploration

- **Electromagnetics:**

- a **magnetic field** is generated by passing AC current through a wire loop or through a wire grounded at both ends.
- if any **conductive material** lies within the generated magnetic field electrical currents will be generated in it and these will, in turn, generate a **secondary magnetic field**.
- the **total magnetic field** consists of the primary field (generated by the source current) and the induced secondary field (generated by the conducting body).
- **resolution decreases** significantly with decreasing depth.

Geophysical Exploration

- **Electromagnetics:**

- the field equipment consists of a transmitting coil (transmitting the primary field) and a receiver coil (measuring the total field).

