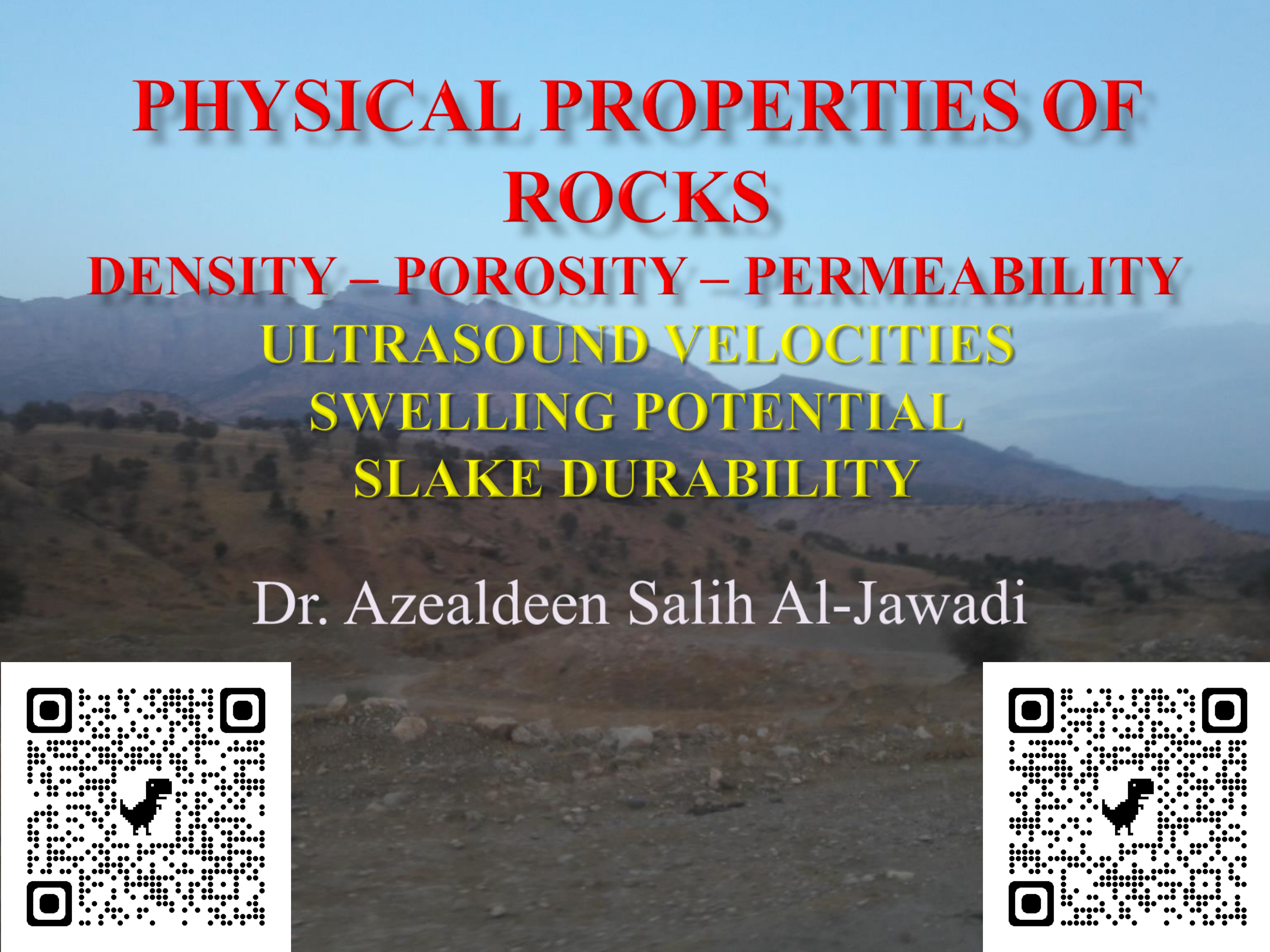


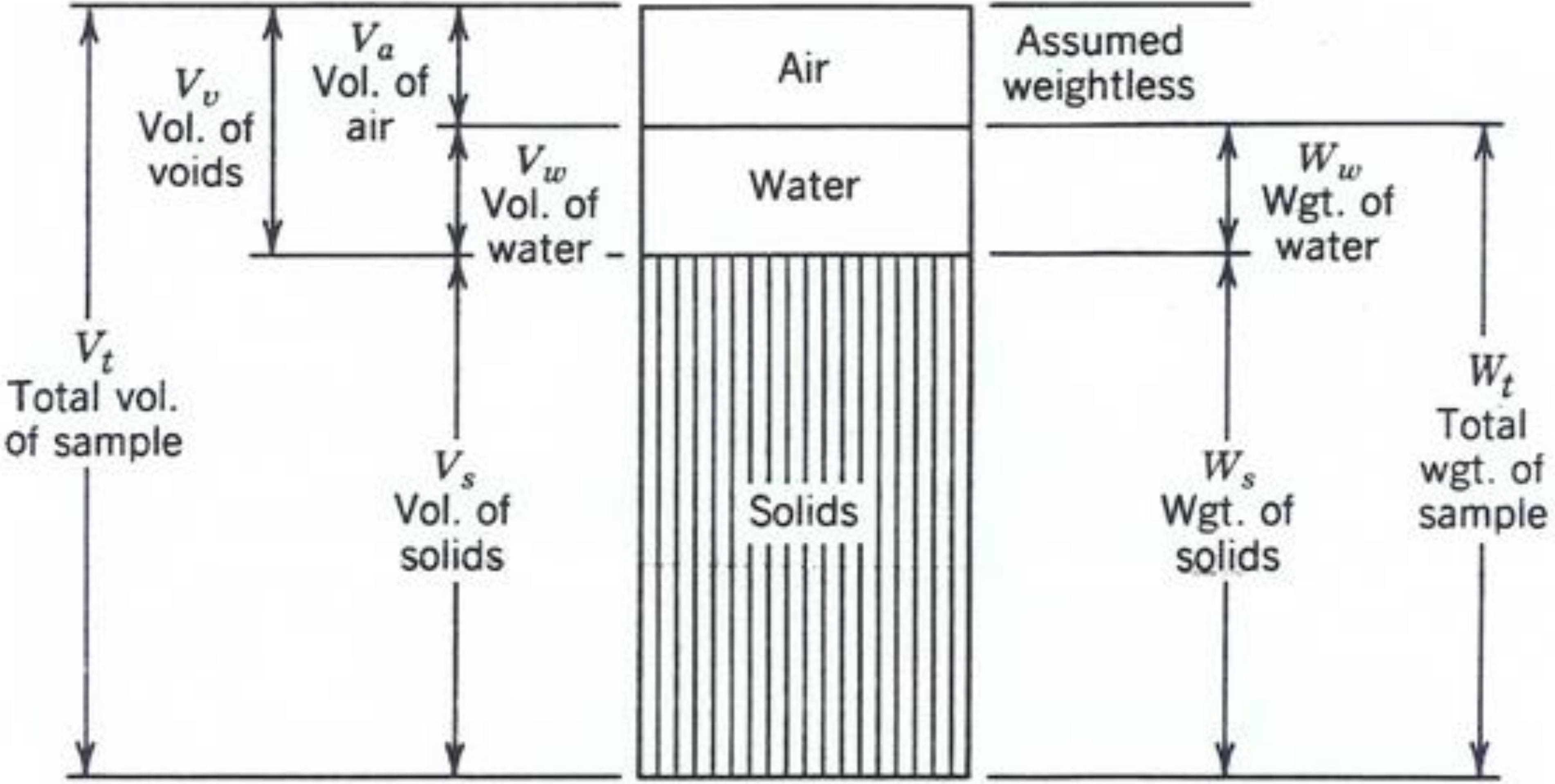
PHYSICAL PROPERTIES OF ROCKS

DENSITY – POROSITY – PERMEABILITY

ULTRASOUND VELOCITIES
SWELLING POTENTIAL
SLAKE DURABILITY

Dr. Azealdeen Salih Al-Jawadi

Volume – Weight Relations



Specific gravity of solids= density of dry rock/density of water at 20°C

$$G_s=\rho_s/\rho_w$$

Specific gravity of solids= density of dry rock/density of water at 20°C

$$G_s=\rho_s/\rho_w$$

Degree of saturation, S_r, is equal to the division of volume of water to the volume of voids.

$$S_r = V_w/V_v$$

The water content of rock specimen can be calculated directly by dividing mass of pore water to mass of sample.

$$\text{Water content} = W_w/W_s$$

Bulk unit weight ρ=weight of dry rock/ total volume (kN/m^3)

$$\rho= W_d/V_t$$

Relative density = density of rock/density of water at 20°C

$$\eta = \rho / \rho_w$$

Density = mass of rock/volume (kg/m^3)

$$\rho = M_t / V_t$$

Unit weight of solids =weight of dry rock/true volume (kN/m^3)

$$\gamma s = W_d / V_s$$

Saturation and Buoyancy technique

Applicable only to:

- Non-friable coherent rocks that can be machined
- Rocks that do not swell or disintegrate when they are oven-dried or when immersed in water

At least three specimens selected

Minimum size should be of mass 50g

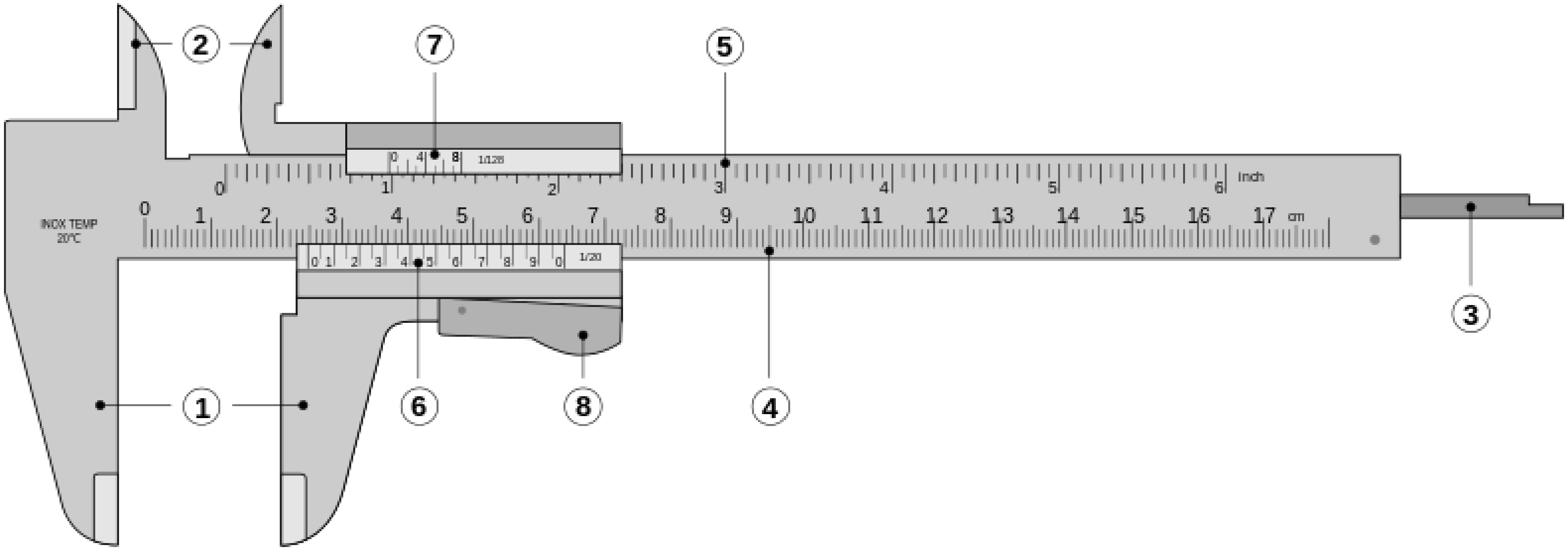
Minimum dimension should be ten times greater than maximum grain size whichever is greater

Apparatus required:

Oven, Desiccator, Vernier, Vacuum saturation equipment, Sample container, Balance, Immersion bath and Wire basket.

A digitally controlled oven suitable for heat storage, heat treatment and drying processes at temperatures up to 300 °C for timed periods up to 999 hours.

Laboratory Glass Desiccator



Legend:
1.**Outside jaws**: used to measure external length
2.**Inside jaws**: used to measure internal length
3.**Depth probe**: used to measure depth
4.**Main scale** (cm)
5.**Main scale** (inch)
6.**Vernier** (cm)
7.**Vernier** (inch)
8.**Retainer**: used to block/release movable part

Vacuum saturation equipment

Laboratory sample container

Laboratory Balance

Immersion bath and Wire basket

Procedure:

- The sample is washed in water to remove dust and then is saturated in water for 1 hour with a vacuum pressure of 0.8 kPa
- Determine the mass of wire basket submerged into immersion bath, M_1
- Transfer the mass of sample into wire basket into immersion bath and determine the mass. M_2
- Determine the mass of container which should be in clean and dry with lid, M_3
- Remove the sample from immersion bath and surface dry it with moist cloth. Place the sample into the container with lid and determine their mass, M_4
- Take out the lid and place the sample with container into the oven at 105°C for 24 hours
- Place the sample in desiccators and allow it cool for 30 minutes
- Determine the mass of dry sample with container provided with lid, M_5

Calculations:

Saturated-Submerged mass, $M_{sub} = M_2 - M_1$ (kg)

Saturated-Surface dry mass, $M_{sat} = M_4 - M_3$ (kg)

Dry mass, $M_s = M_5 - M_3$ (kg)

$$\text{Bulk volume, } V = \frac{M_{sat} - M_{sub}}{\rho_w} \ (\text{m}^3)$$

$$\text{Pore volume, } V_v = \frac{M_{sat} - M_s}{\rho_w} \ (\text{m}^3)$$

$$\text{Porosity, } n = \frac{V_v}{V} \times 100(\%) \qquad \text{Dry density, } \rho_d = \frac{M_s}{V} (\text{kg/m}^3)$$

Voids index, $V_i = \dfrac{M_{sat}}{M_s} \times 100(\%)$

Voids ratio, $e = \dfrac{V_v}{V_s} \times 100(\%)$

Grain density, $G_s = \dfrac{M_s}{V_s}$

Relative density, $G_m = \dfrac{\rho_d}{\rho_w}$

$e = \dfrac{n}{1-n}$ and $n = \dfrac{e}{1+e}$?

DENSITY

Density: mass of rock per unit volume.

Unit weight: weight per unit volume.

Highly porous rocks   Poor arrangement of grains

Less densities

Bulk unit weight   Solid unit weight

Bulk (total) volume   Volume excluding the pores, fissures

Bulk unit weight depends on:

- Type of rock,
- Porosity and
- Geological processes.

Bulk unit weight of a rock may vary from region to region, some times in one location to another within the same geological formation.

POROSITY

Porosity can be estimated through:

- Volumetric measurements of core samples,
- Geophysical logs,
- Petrographic Image Analysis (PIA)

Voids (Pores)

Interred connected

Separated

If the rocks are inter connected and pressure gradient exists Rock can conduct fluids or gases

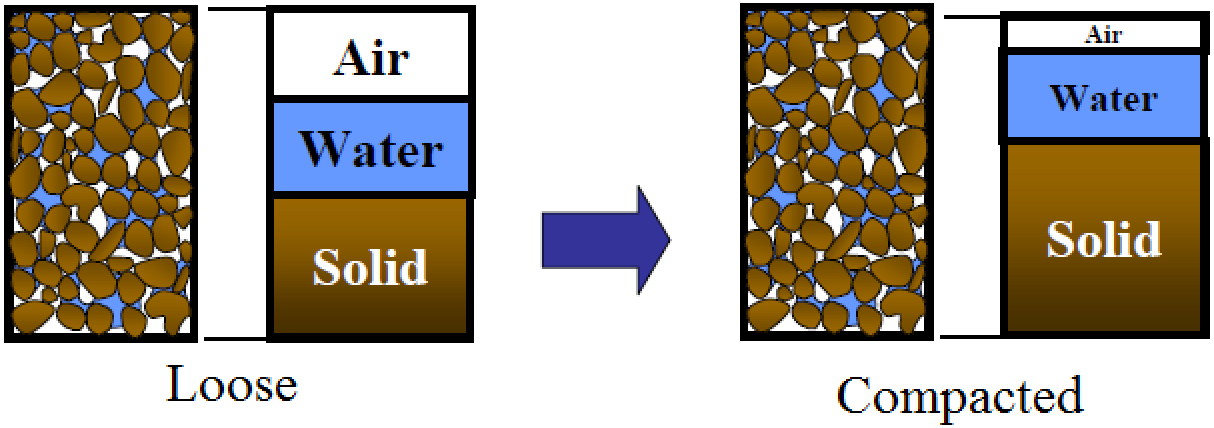
Porosity represents the storage capacity of the geologic material

Primary porosity of a sediment or rock consists of the spaces between the grains that make up that material.

Secondary porosity of rock consists of and increased through fractures or solution of the rock itself.

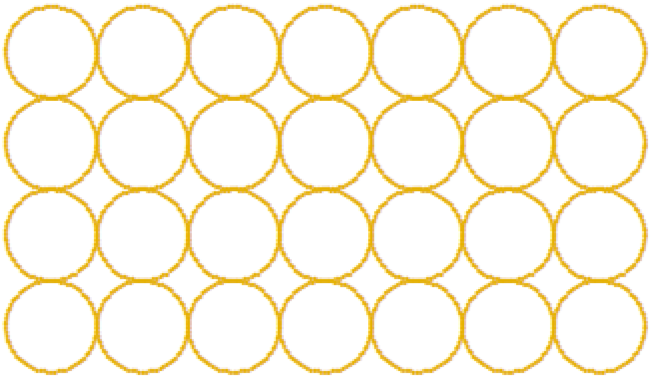
Primary porosity

Compaction Effect

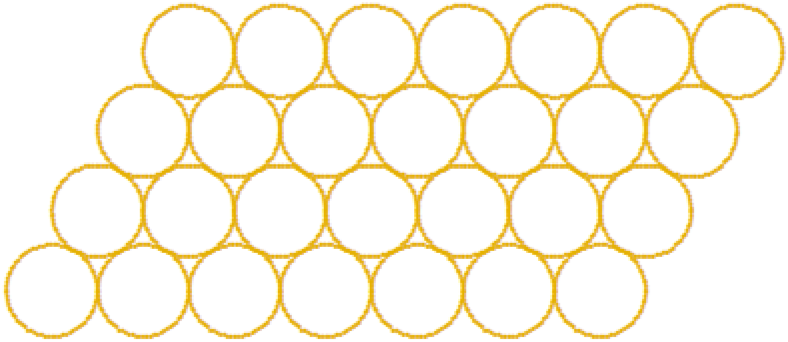


Box of marbles

Cubic array



Densest array

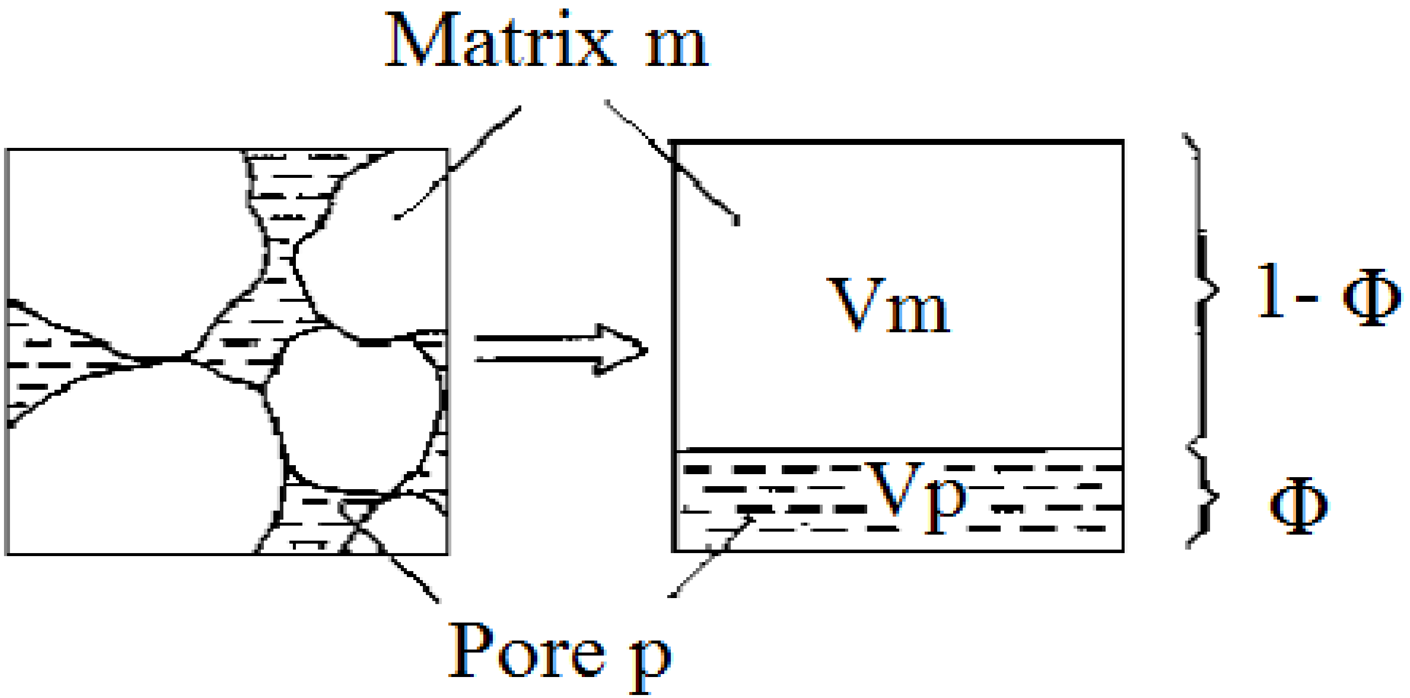


Primary porosity can range from less than one percent in crystalline rocks like granite to over 55% in some soils.

igneous or metamorphic	sedimentary rocks
very low porosity (0-2%)	(up to 40%)

Factors affect porosity

grain size distribution
grain shape
grain arrangement
degree of cementation of grains
applied pressure

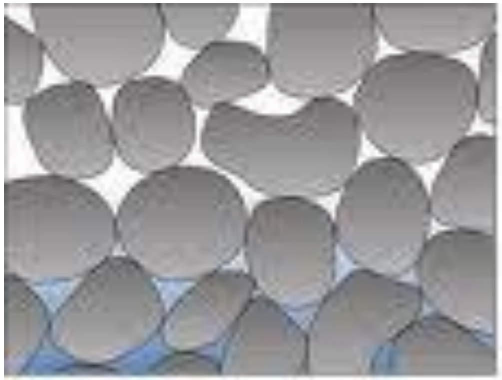


High porosity	Highly porous marine sediments
	Unconsolidated sediments
	Sandstones
	Carbonate rocks
Low porosity	Fractured igneous rocks, other dense rock types

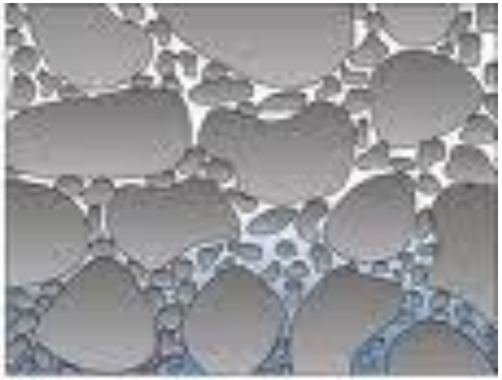
Secondary porosity

Grade	Term	Total Porosity%	Dry Density (gm/cm^3)
I	Fresh Rock	3.48	2.63
II	Slightly Weathered	3.57	2.59
III	Moderately Weathered	4.65	2.46
IV	Highly Weathered	5.42	2.38
V	Completely Weathered	9.08	2.30
VI	Residual Soil	15.5	2.00

Secondary Porosity increases with increase of density of discontinuities.



Well sorted



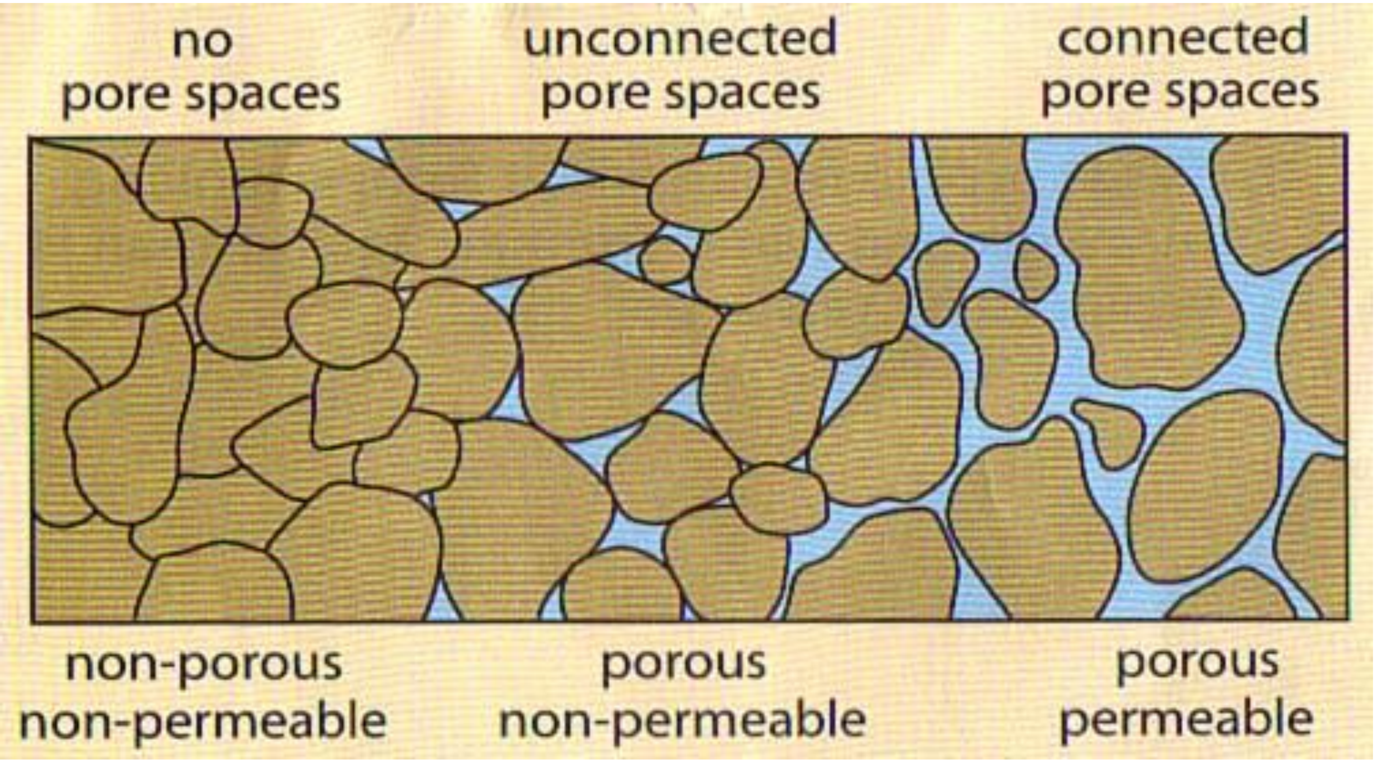
Poorly sorted

Fractured

Dissolved

PERMEABILITY

Permeability: a measure of the ability of a material (such as rocks) to transmit fluids. Dense rocks like granite, basalt, schist and crystalline limestone possess very low permeabilities as lab specimens, but field tests can show significant permeability due to open joints and fractures.



permeability can be expressed by the coefficient of conductivity k [m.s^{-1}], which means a discharge velocity of water flow in a rock under the action of a unit hydraulic gradient, usually expressed in meters per second

$$k = \frac{A.\,h.\,t}{Q.\,l} \qquad [m.s^{-1}] \qquad (1)$$

where

Q is the volume of water leaking through the specimen during time t

l is the height of the tested specimen

A is the cross-section of the specimen

h is the difference in the water pressure levels

t is the period of measurement.

ULTRASOUND VELOCITIES

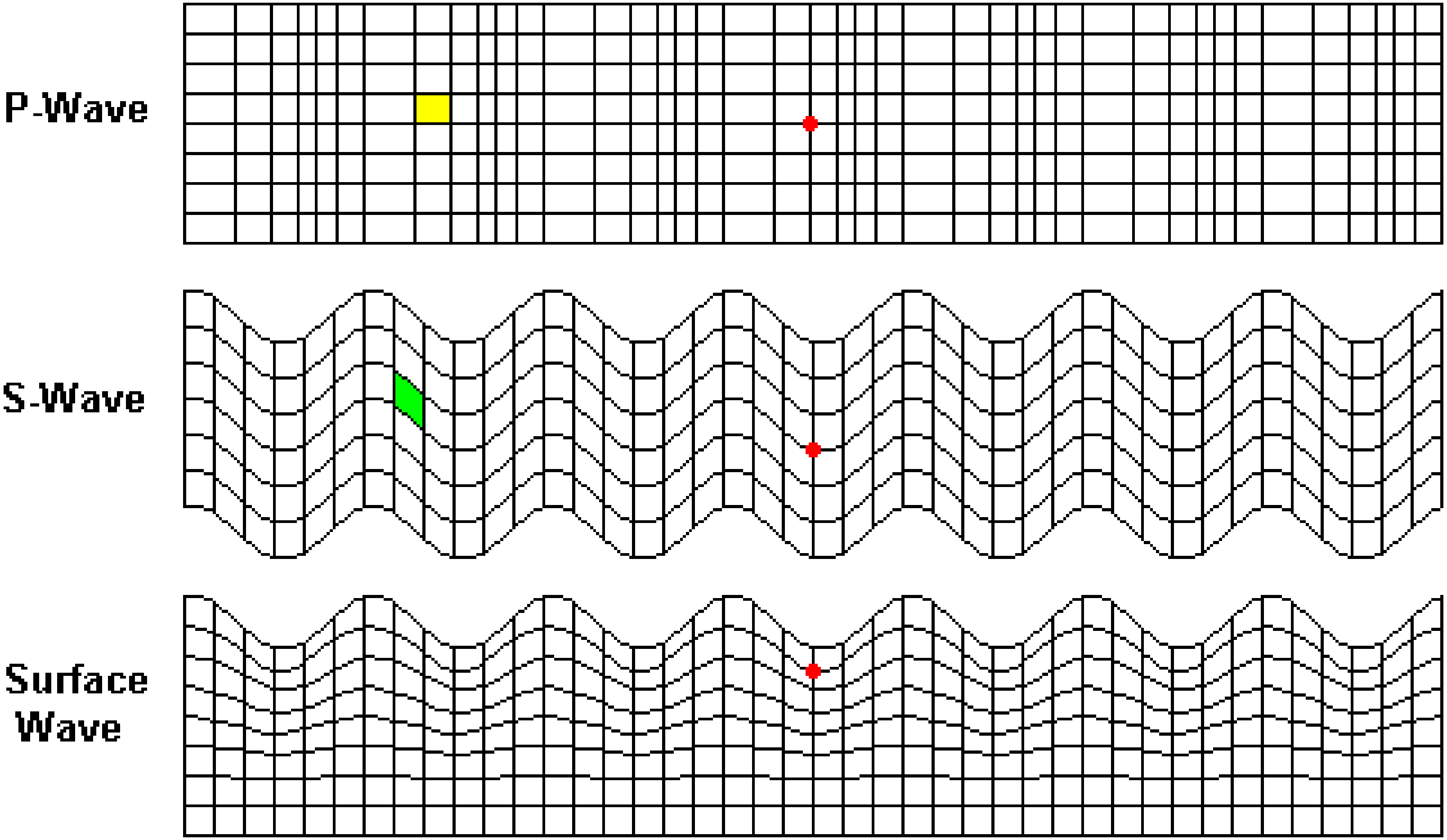
Sound is traveling in the earth by two types of waves:

- Body waves travel through the interior of the earth.
- Surface waves propagate at the interface between the earth and the atmosphere.

Body waves are of two types:

- Primary waves (P-waves, compression waves, or pressure waves). They can propagate in the solid or liquid material.
- Secondary waves (S-waves, or shear waves). They only propagate in solid material. By studying the trajectories of S-waves, scientists could prove that the earth had a liquid outer core.

The propagation velocity of the waves depends on the density and elasticity of the medium. Velocity tends to increase with depth and ranges from approximately 2 to 8 km/s in the Earth's crust, up to 13 km/s in the deep mantle.


P-Wave
S-Wave
Surface Wave

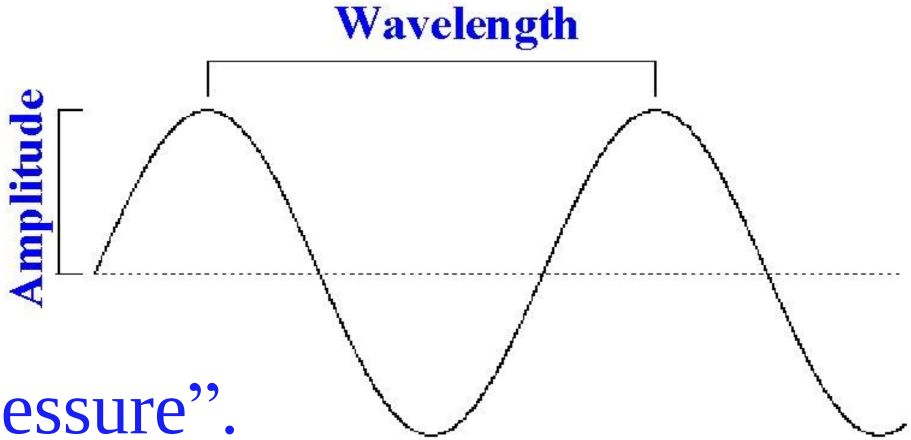
Body Waves: P-wave

Wavelength, λ

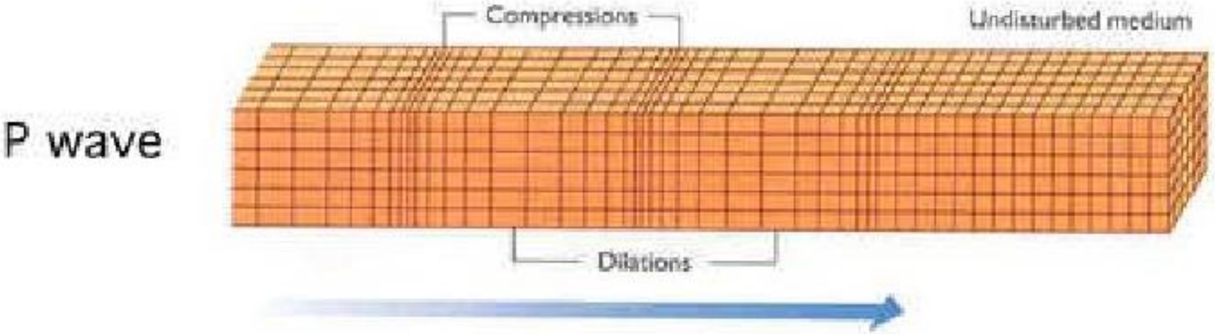
Frequency, f

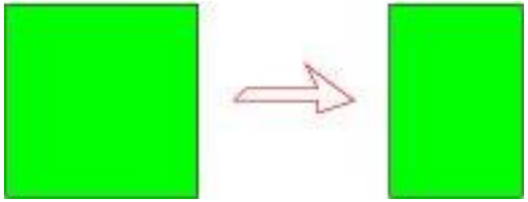
Period, $T=1/f$

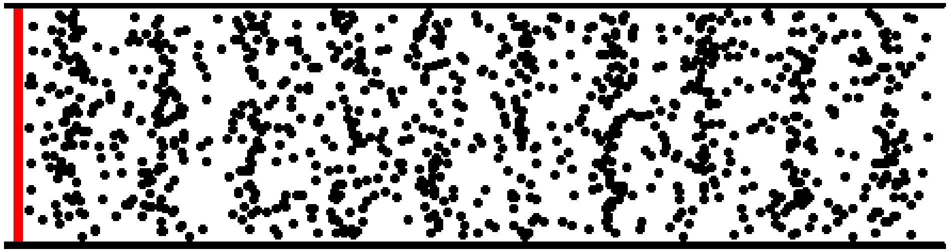
Velocity, $V=\lambda/T = \lambda f$



- P stands for “Primary” or “Pressure”.
- Particles undergo coaxial volume change.
- Similar to sound waves traveling through air.

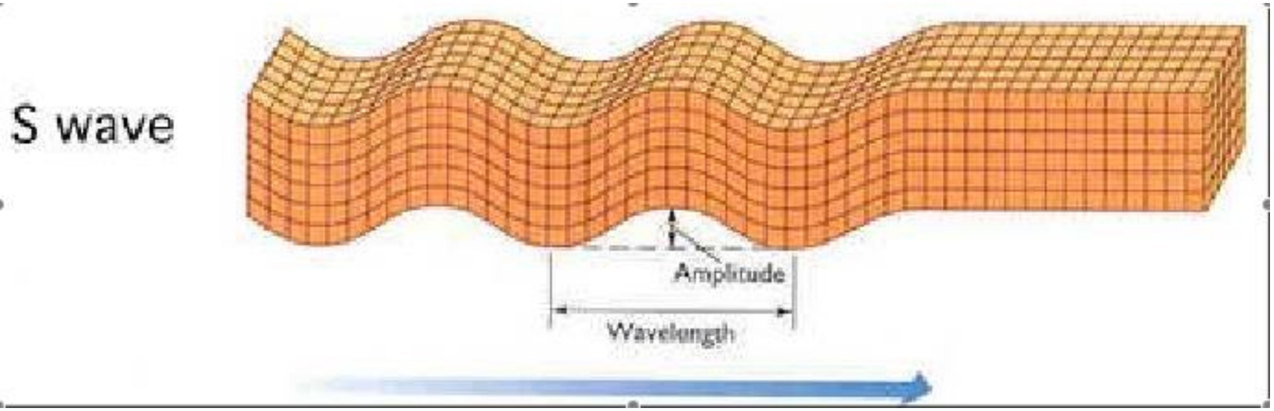


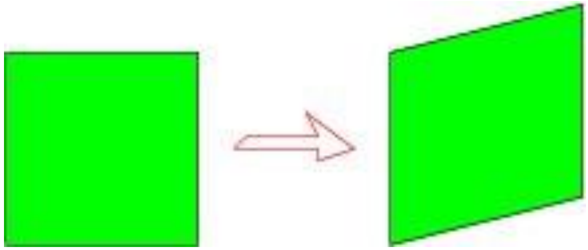


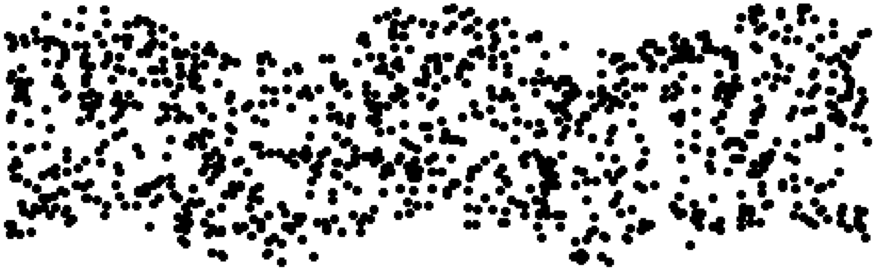


Body Waves: S-wave

- S stands for “Secondary” or “Shear”.
- Particles undergo non-coaxial with no volume change.



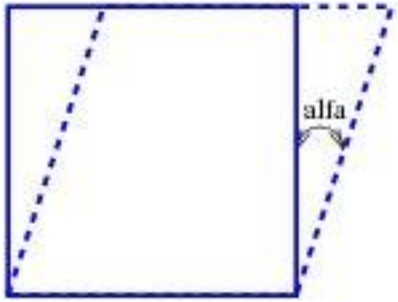




Hook’s law

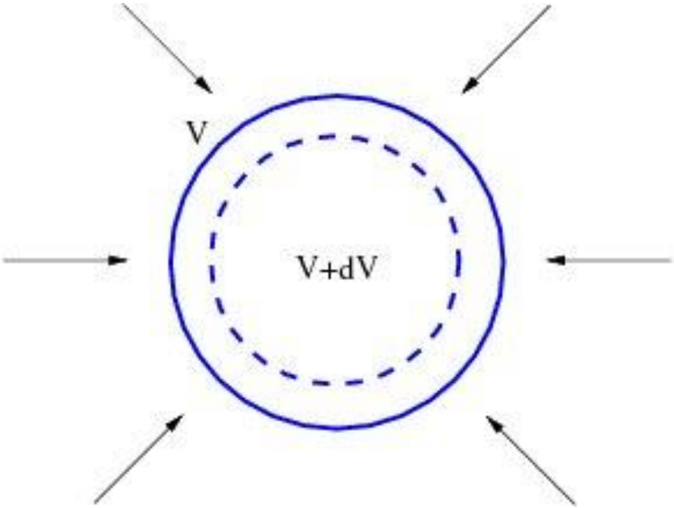
$$\text{stress} = \text{elastic modulus} \times \text{strain}$$

Shear modulus (or rigidity):



$$\mu = \frac{\text{shear stress}}{\text{shear strain}}$$

Bulk modulus:



$$K = \frac{\text{pressure}}{\text{volume change}}$$

P-velocity: $$V_P = \sqrt{\frac{K + \frac{4}{3}\mu}{\rho}}$$

Bulk modulus, K
Shear modulus, μ
Density, ρ

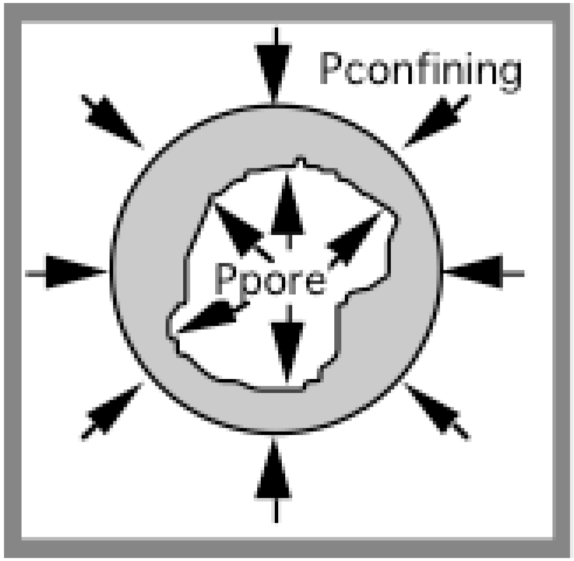
S-Velocity: $$V_S = \sqrt{\frac{\mu}{\rho}}$$

- $V_P > V_S$ (since both bulk and shear modulus are positive).
- For liquids and gases μ=0, therefore $V_S=0$, and V_P is reduced.
- P and S velocities are reduced if the rock is fractured or porous.

$$V = \sqrt{\frac{\text{elastic constant}}{\text{density}}}$$

Parameters That Influence Seismic Velocity

- Velocities almost always increase with effective pressure for reservoir rocks.
- To first order, only the difference between confining pressure and pore pressure matters, not the absolute levels of each "effective pressure law".
- High confining pressure (depth) and cementation, tend to decrease the soft porosity and therefore decrease these effects.



- The pressure dependence results from the closing of cracks, flaws, and grain boundaries, which elastically stiffens the rock mineral frame.
- The only way to know the pressure dependence of velocities for a particular rock is to measure it.
- Make ultrasonic measurements on dry cores; fluid-related dispersion will mask pressure effects.
- The amount of velocity change with pressure is a measure of the number of cracks; the pressure range needed to reach the high-pressure asymptote is a measure of crack shape.
- Velocities tend to be sensitive to the pore fluid content. Usually, the P-wave velocity is most sensitive and the S-wave velocity is less sensitive.
- Saturation dependence tends to be larger for soft (low velocity) rocks.
- High pore pressure tends to increase the soft porosity and therefore increases these effects.

SWELLING POTENTIAL

Chemical weathering transformation anhydrite → gypsum

increases in volumes 30 - 58%

swelling pressures 70 MPa

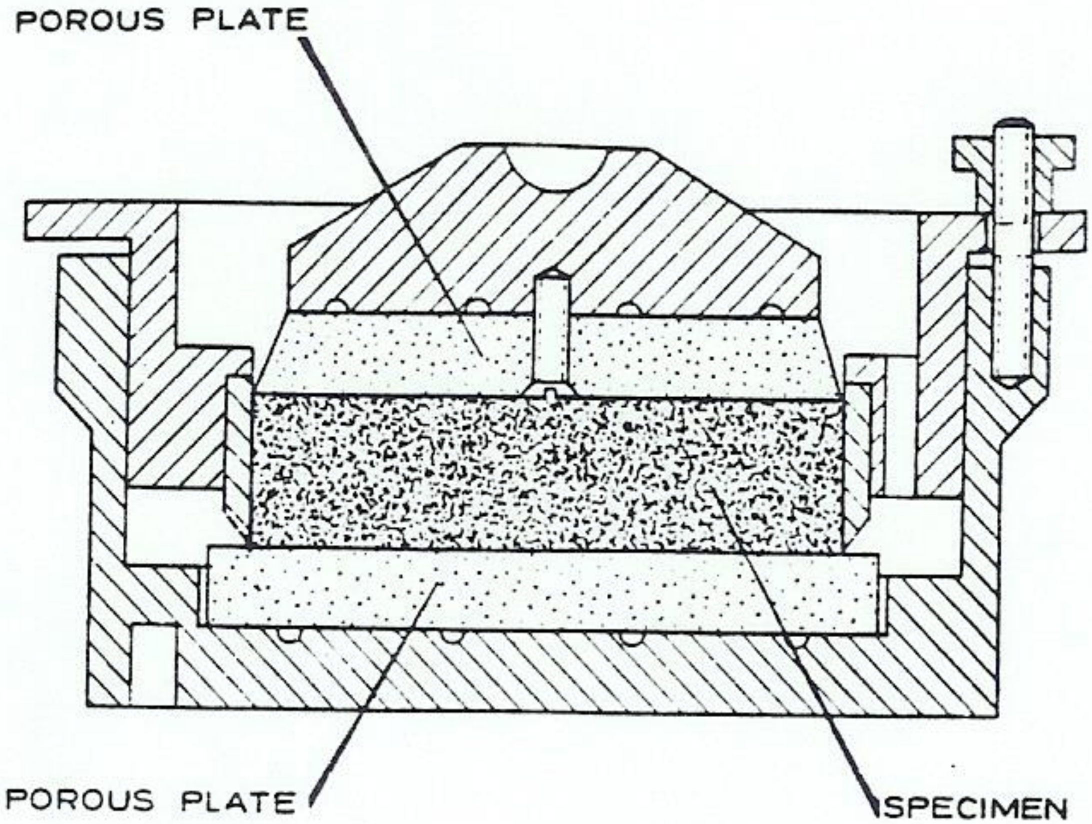
ANHYDRITE	GYPSUM
$CaSO_4 + 2H_2O$	$CaSO_4 2H_2O$
($46\ cm_3$) ($36\ cm_3$)	($74\ cm_3$)

Black shale (Pyrite oxidation) → secondary sulfates (Gypsum)

Swelling → clay-bearing rocks (montmorillonite)

Expansive soils and rocks do at least $ 1 billion a year in damage to U.S. homes more than the combined residential damage from floods, hurricanes, earthquakes, and tornadoes.

The term swelling rock implies not only the tendency of a material to increase in volume when water is available but also to decrease in volume and shrink if water is removed.



Confined Swelling Test Assembly

Which factors dose rock depend on with high swelling potential?

(1) The difference between the field moisture content at the time of construction and the final equilibrium, moisture content associated with the completed structure

(2) The degree of compaction with more compaction favor swelling as moisture becomes available,

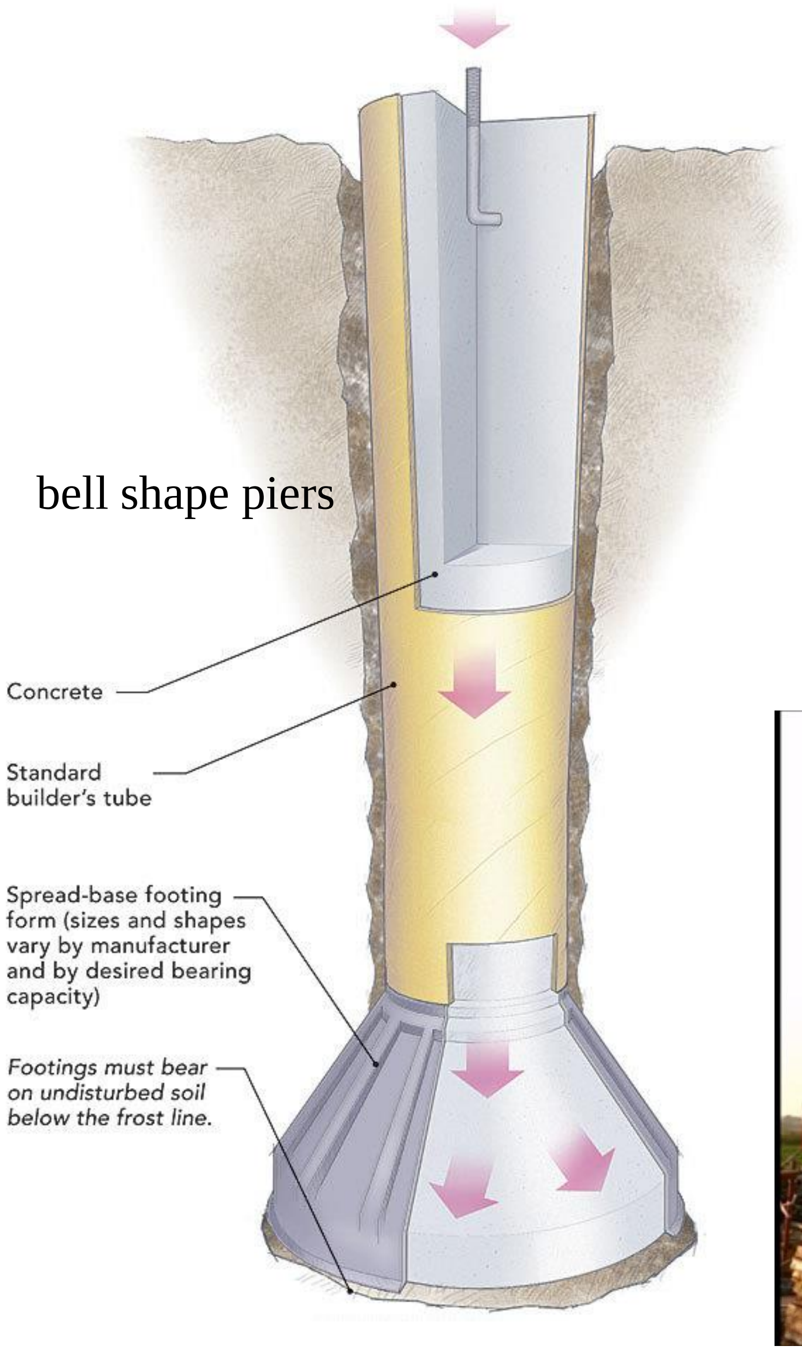
(3) The final stress to which the material will be subjected after construction is complete.

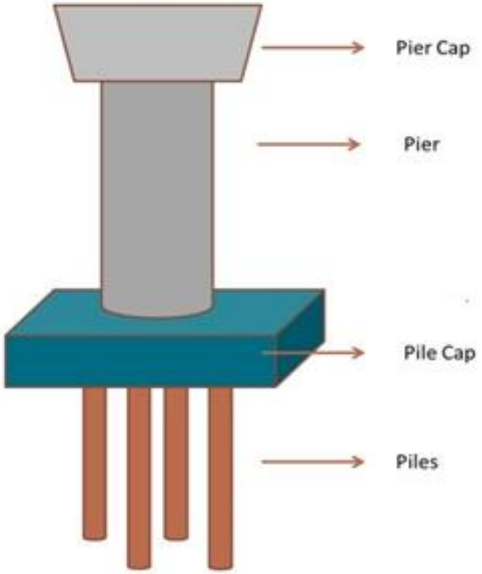
What are the remedial actions to reduce the swelling potential of a rock?

(1) Treating the rock (removal or control its water content or chemical treatment) and

(2) Design engineering structures to account for possible swelling or shrinking (bell shape piers, caissons, piles).

bell shape piers





piles

caissons

Explain the recommended design procedure with the proposed approaches?

Passive approach (flexible) design:

- Allowing rock to swell freely and is removed on a regular basis such that the structure is always useable.
- Leave a void between the rock surface and an internal rigid structure.
- Shape the excavated opening in such a way that the stress redistribution minimizes the effect of swelling pressures.

Active approach:

- Counter-stresses (thick-walled curved liners, bolting, prestressing).
- Limiting the access of water by drainage, sealing of exposed rock surfaces and grouting.

Intermediate solution between passive and active

How you can avoid or reduce the effect of swelling of soils and rocks on foundations?

Isolating the structure from the swelling materials,

designing a structure that will remain undamaged in spite of swelling (rare approach), and

Elimination of the swelling altogether.

Swelling damage

SLAKE DURABILITY

Exfoliation, hydration, slaking, solution, oxidation and abrasion all lower rock quality. Measured by Franklin and Chandra’s (1972) :slake durability test.

Approximately 500 g of broken rock lumps (~ 50 g each) are placed inside a rotating drum which is rotated at 20 revolutions per minute in a water bath for 10 minutes. The drum is internally divided by a sieve mesh (2mm openings)

After the 10 minutes rotation, the percentage of rock (dry weight basis) retained in the drum yields the slake durability index (SDI).

A six step ranking of the index is applied (very high- to very low) as shown in table. ●

Used to evaluate shales and weak rocks that may degrade in service environment.

Apparatus and Test

two or four drums 100 mm long and 140 mm in diameter, containing about 500g of rocks (10 lumps) in each drum.

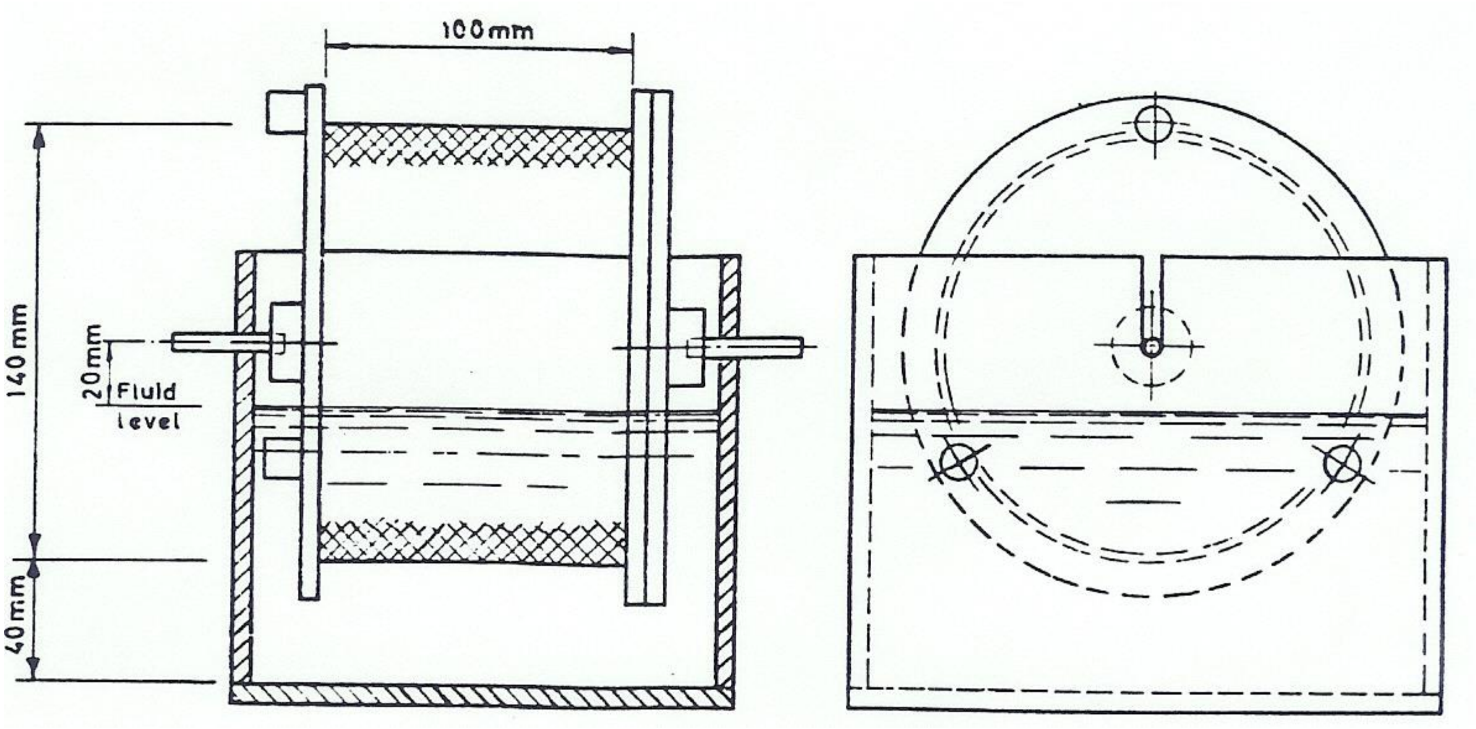
Sieve mesh forms the walls of the drums with openings of 2 mm.

The drums rotate at a speed of 20 rpm for a period of 10 minutes in a water bath.

The rocks in the drums are subject to different cycles of wetting in the bath and drying in the oven.

$$Weatherability \propto \frac{1}{Durability}$$

slake durability apparatus



Calculations

Let D be the mass of the empty dry drum. The initial dry mass of rock plus drum is defined as A. After one cycle of wetting and drying, the new dry mass of the drum and the rock is B. The slake durability index Id_1 is the percent of rock retained and is equal to

$$I_{d1} = \frac{(B-D)}{(A-D)} \times 100(\%)$$

The test is repeated a second time and C is the final dry mass of the drum and remaining rock. The slake durability index Id_2 is then equal to

$$I_{d2} = \frac{(C-D)}{(A-D)} \times 100(\%)$$

Slake Durability Classification

I_{d2}

Classification	Slake durability (%)
Very low	0-25
Low	25-50
Medium	50-75
High	75-90
Very high	90-95
Extremely high	95-100

It is also recommended that the value of I_{d1} be used whenever the values of I_{d2} range between 0 and 10%.

Note:

- From a practical point of view, slaking of clay-bearing rocks requires the protection of all outcrops. Shotcrete or any other forms of protective layers are usually adequate.
- More cycles of drying and wetting may be necessary especially for rocks with higher durability.
- Rocks giving low slake durability results should be subjected to soils classification tests such as Atterberg limits.
- The liquid limit test in soil mechanics can be used to predict the maximum amount of slaking that can be expected for argillaceous rocks.

Thank you