UNIVERSITY OF Baguio

Fundamental Properties of Materials

Prepared by: Engr. Jasmin G. Madayag

Learning Outcome

At the end of this lesson, students should be able to:

1. Understand the different fundamental properties of materials and how materials react when used in the construction.
2. Identify standard tests on how to determine these properties.

Properties of Materials

A building material's property is an intensive, often quantitative, property of the material.

Quantitative properties may be used as a metric by which the benefits of one material versus another can be assessed, thereby helping in materials selection.

Properties of Materials

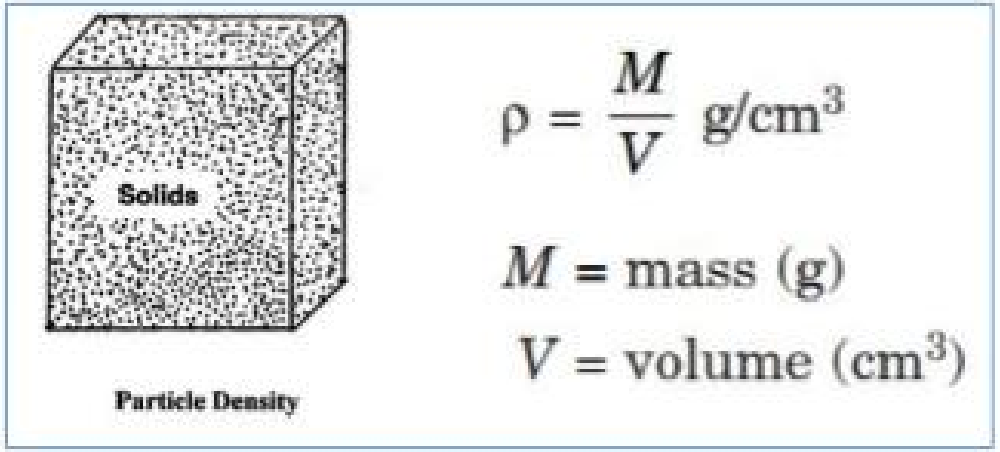
The fundamental properties of building materials include:

I. Parameters of state / structural characteristics
II. Physical (non-mechanical) properties
III. Mechanical properties

I. Structural Characteristics

1. Density and Unit Weight

Practical density *is the mass of a unit volume of homogeneous material. The mass is normally measured with a scale or balance; the volume may be measured directly (from the geometry of the object) or by the displacement of a fluid.*



I. Structural Characteristics

- **Bulk Density**

is defined as the mass of many particles of the material divided by the total volume they occupy. The total volume includes particle volume, interparticle void volume, and internal pore volume.
The bulk volume of a material—inclusive of the void fraction—is often obtained by a simple measurement (e.g. with a calibrated measuring cup) or geometrically from known dimensions.

I. Structural Characteristics

Examples of the density of some building materials:

Building materials	Practical Density [kg/m3]	Bulk Density [kg/m3]
Brick	2500 – 2800	1600 - 1800
Granite	2600 – 2900	2500 - 2700
Cement	2900 – 3100	
Wood	1500 – 1600	Pine wood: 500 - 600
Steel	7800 – 7900	7850
Concrete	2400	

I. Structural Characteristics

- **Density Index (r0)**

The density index indicates the degree to which the volume of a material is filled with solid matter.

$$\rho_o = \frac{bulk\ density}{practical\ density} = \frac{\rho_b}{\rho}$$

I. Structural Characteristics

- **Specific Gravity (Gs)**

Specific Gravity of solid particles of a material is the ratio of weight/mass of a given volume of solids to the weight/mass of an equal volume of water at 4°C

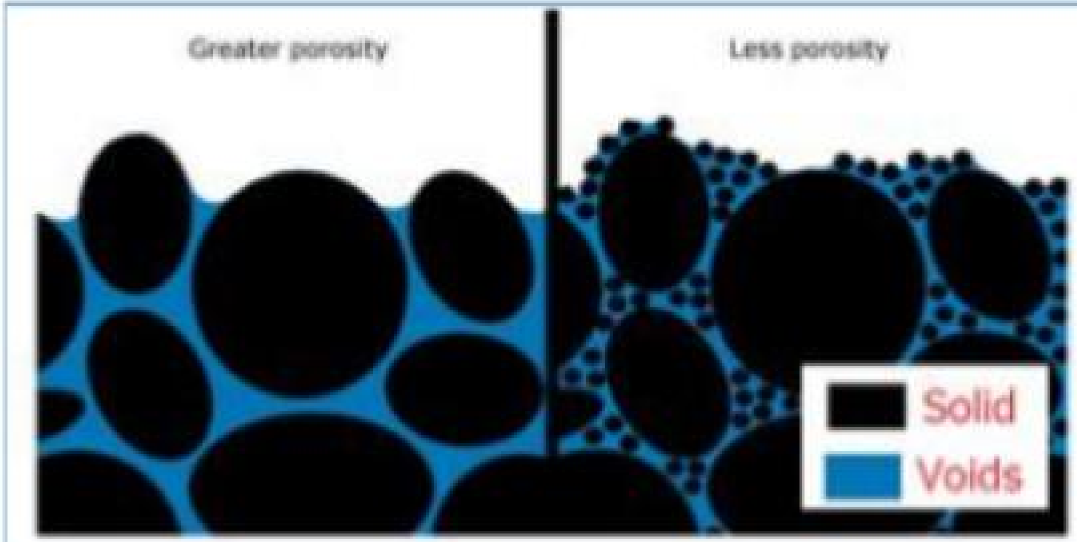
- **Specific weight**

It is the weight per unit volume of material (same as the Unit weight)

I. Structural Characteristics

2. POROSITY

Porosity or void fraction is a measure of the void (i.e., "empty") spaces in a material, and is a fraction of the volume of voids over the total volume.



$$n = \frac{V_v}{V}$$

Vv = volume of voids
V = total volume of the material

I. Structural Characteristics

TYPES OF POROSITY:

- ❑ **Effective porosity (also called open porosity)**
  the fraction of the total volume in which fluid flow is effectively taking place.

- ❑ **Ineffective porosity (also called closed porosity)**
  the fraction of the total volume in fluids or gases are present but in which fluid flow cannot effectively take place and includes the closed pores.

I. Structural Characteristics

3. VOID RATIO

Void Ratio is defined as the ratio of volume of voids (Vv) to the volume of solids (Vs). There are two methods for measuring voids:

Methods in determining the Void Ratio:

1. The Direct Method

consists in determining the volume of liquid, generally water, which is required to fill the voids in a given quantity of material

2. The Indirect Method

the solid volume of a known quantity of aggregate is obtained by pouring the material into a calibrated tank partially filled with water; the difference between the apparent volume of material and the volume of water displaced equals the voids.

II. Physical Characteristics

1. *HYDRO-PHYSICAL PROPERTIES*

Hygroscopicity

is the capacity of a product (e.g. cargo, packaging material) to react to the moisture content of the air by absorbing or releasing water vapor.

Water absorption (Ww)

The amount of water absorbed by a material when immersed in water for a period of time. Materials with coefficient of softening less than 0.8 should not be recommended in the situations permanently exposed to the action of moisture

II. Physical Characteristics

1. *HYDRO-PHYSICAL PROPERTIES*

Water permeability

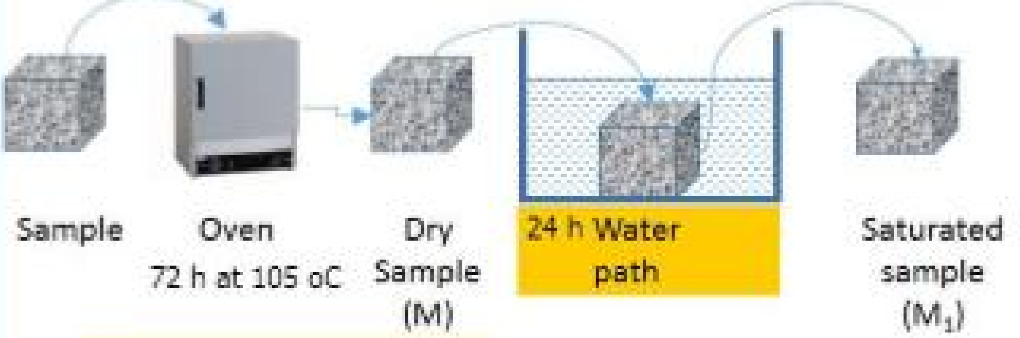
The rate of water vapor flow in cubic meter per day through a cross section of 1 square meter under a unit hydraulic gradient, at the prevailing temperature.

II. Physical Characteristics

1. ***HYDRO-PHYSICAL PROPERTIES***

Moisture Content

Water content or moisture content is the quantity of water contained in a material.



$$W_w = \frac{M_1 - M}{M} \times 100$$

$$W_v = \frac{M_1 - M}{V} \times 100$$

M_1 = mass of saturated material (g)

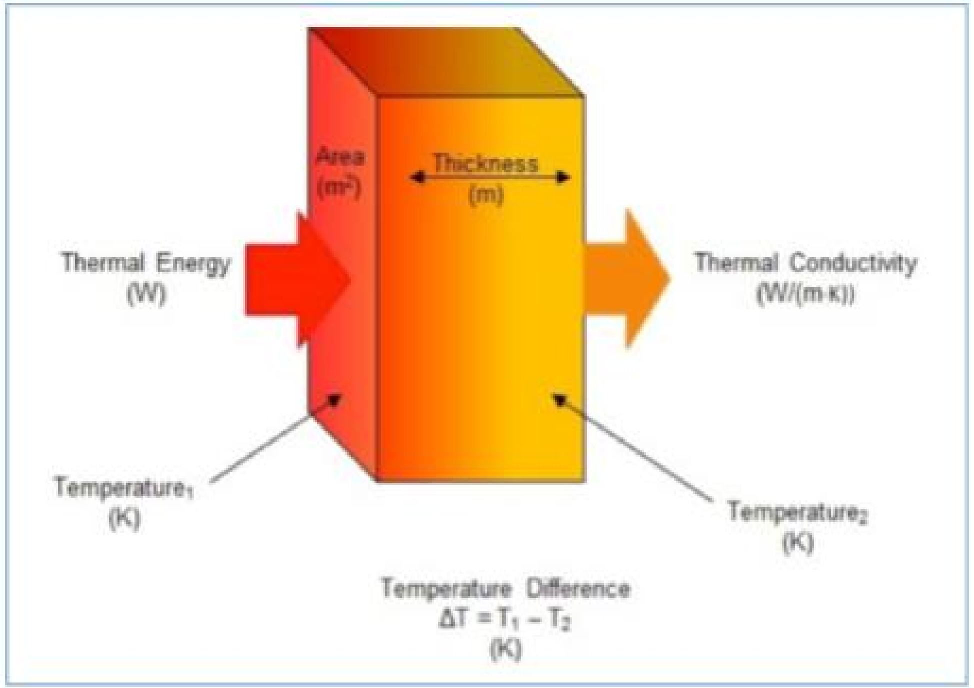
M = mass of dry material (g)

V = volume of material including the pores (mm^3)

II. Physical Characteristics

2. **THERMAL CONDUCTIVITY**

is the material ability to conduct heat. Each material has a characteristic rate at which heat will flow through it. The faster heat flows through a material, the more conductive it is.



$$k \ or \ \lambda = \frac{q * L}{A * \Delta T}$$

- k = the thermal conductivity of the material (W/mK).
- q = the resultant heat flow (Watts)
- A = the surface area through which the heat flows (m^2)
- ΔT = the temperature difference between the warm and cold sides of the material (K)
- L = the thickness / length of the material (m)

II. Physical Characteristics

2. THERMAL CONDUCTIVITY

Thermal diffusivity

The thermal diffusivity is a measure of the transient heat flow through a material. It measures the heat transfer from the hot material to the cold.

Specific heat

The specific heat is a measure of the amount of energy required to change the temperature of a given mass of material.

Melting point

The melting point is the temperature at which a material goes from the solid to the liquid state at one atmosphere.

II. Physical Characteristics

3. VISCOSITY

is a measure of the resistance of a fluid which is being deformed by either shear or tensile stress.

Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction.

Plastic viscosity of concrete is critical for the concrete industry because it affects placement and workability.

III. Mechanical Characteristics

The mechanical behavior of material is the response of the material to external loads.
Catastrophic failure of a structural member (resulting in the collapse of the structure) is an obvious material failure.

III. Mechanical Characteristics

1. Strength

In materials science, the strength of a material is its ability to withstand an applied load without failure or plastic deformation. When a solid body (assumed to be at rest) is acted upon by external forces (assumed to be in equilibrium), the body is deformed and internal forces are developed in the body that balance the external applied forces.

III. Mechanical Characteristics

TYPES OF LOADING:

Transverse Loading

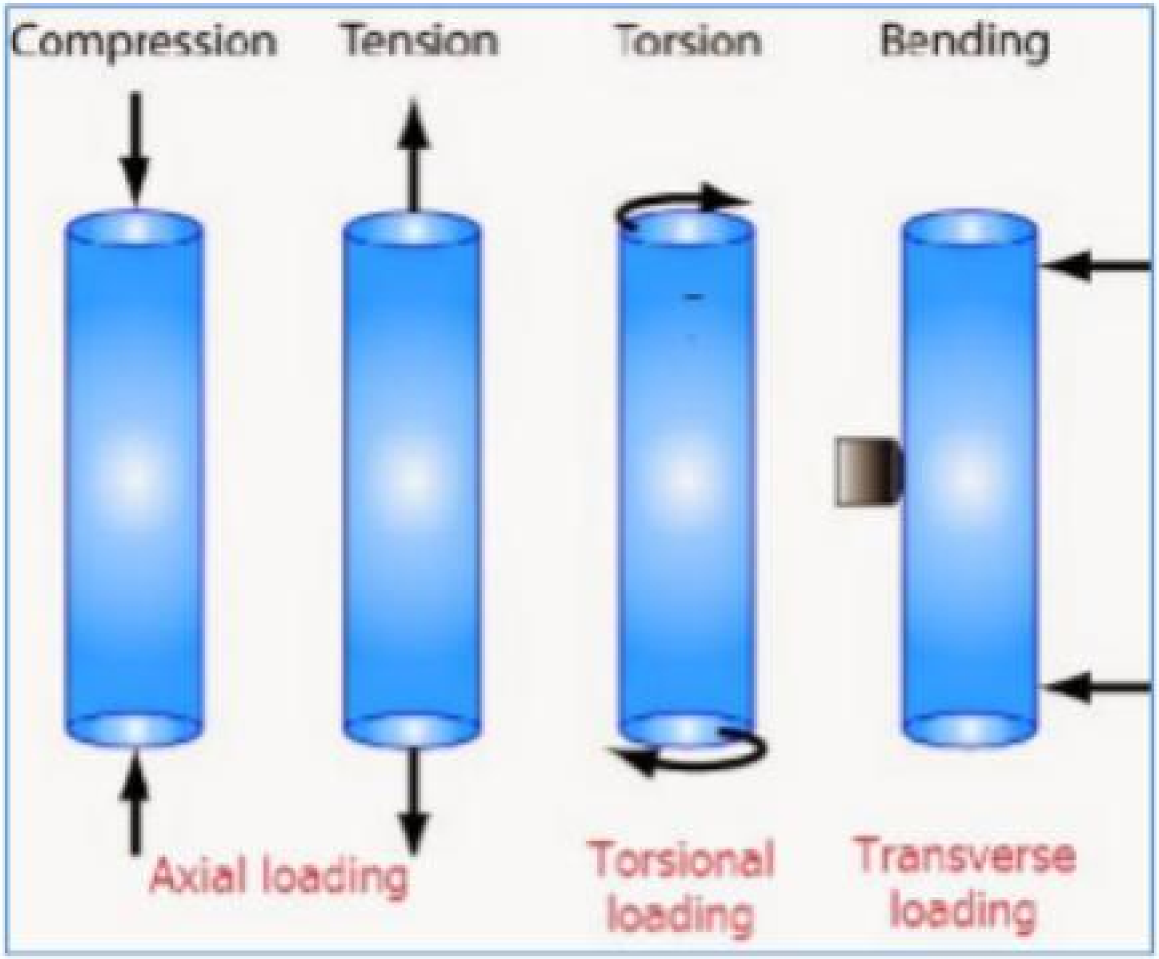
Forces applied perpendicular to the longitudinal axis of a member.

Axial Loading

The applied forces are collinear with the longitudinal axis of the member.

Torsional Loading

Twisting action caused by a pair of externally applied equal and oppositely directed force couples acting on parallel planes or by a single external couple applied to a member that has one end fixed against rotation.



III. Mechanical Characteristics

LOADING CONDITIONS

Static Loading

loading implies a sustained loading of the structure over a period of time, it is slowly applied such that no shock or vibration is generated.

Dynamic Loading

- loads that generate a shock or vibration.

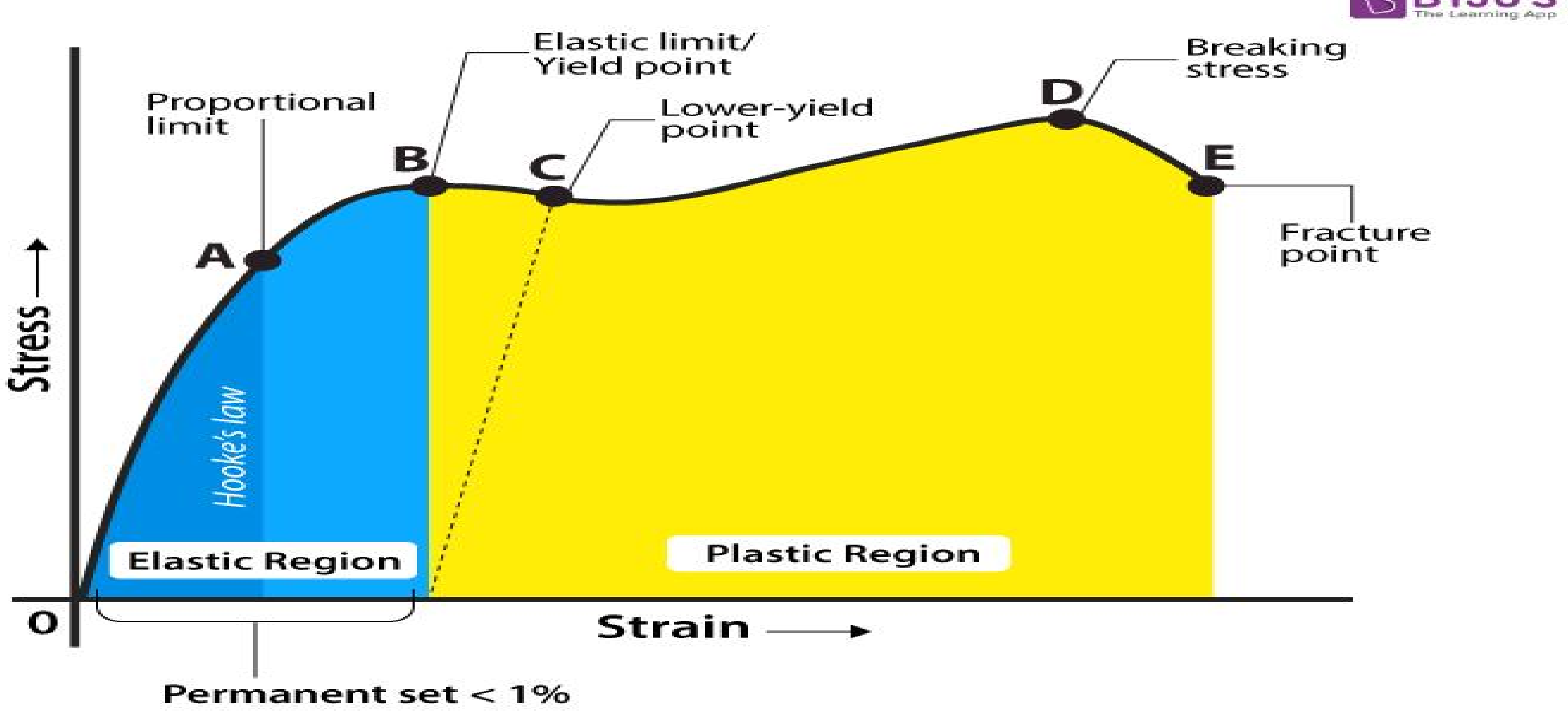
Periodic *– repeat itself with time*

Random *– load patterns never repeat*

Transient *– impulse load that is applied over a short period of time*

III. Mechanical Characteristics

Stress – Strain Relation



III. Mechanical Characteristics

Stress – Strain Relation

Materials deform in response to loads or forces.

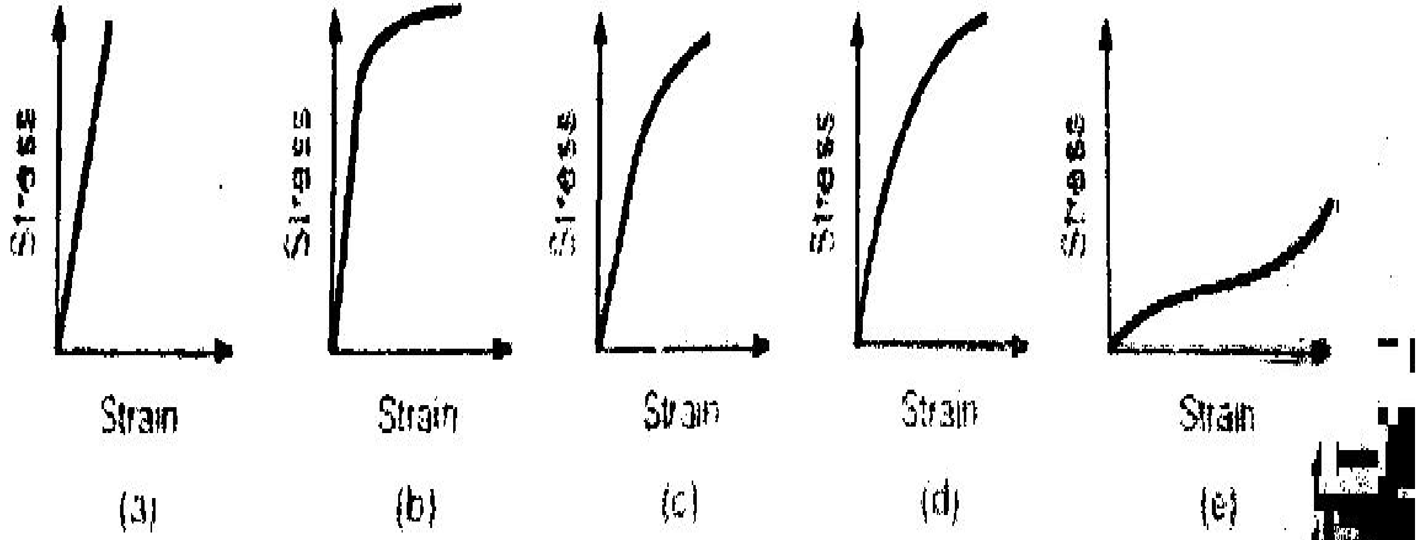


FIGURE 1.2 Typical uniaxial stress–strain diagrams for some engineering materials: (a) glass and chalk, (b) steel, (c) aluminum alloys, (d) concrete, and (e) soft rubber.

III. Mechanical Characteristics

2. Elastic Behavior

Materials deform in response to loads or forces.
If a material exhibits true elastic behavior, it must have an instantaneous response (deformation) to load, and the material must return to its original shape when the load is removed.
The elasticity is the property of a substance to deform with external forces and return to its original shape when the stress is removed.

Modulus of Elasticity

– is the proportional constant between normal stress and normal strain.

III. Mechanical Characteristics

Poisson’s Ratio

– ratio of the lateral strain to the axial strain

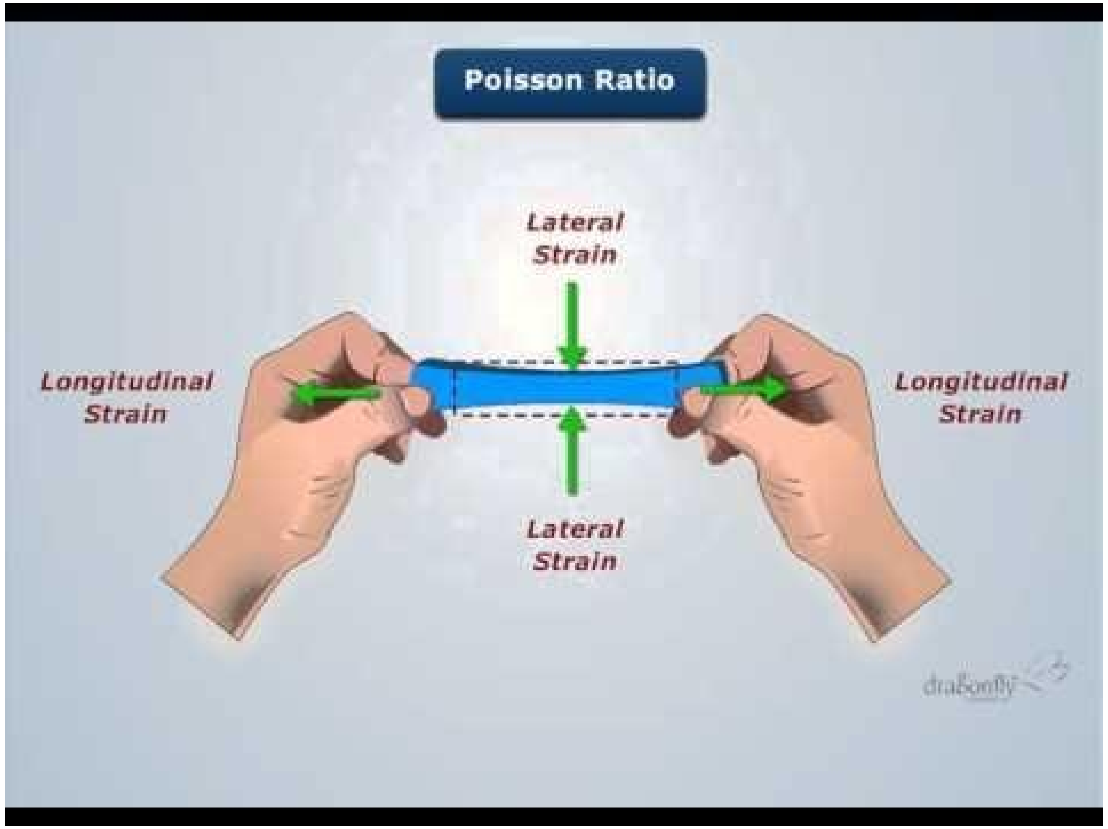
Theoretical Ranges: ***-1 to 0.5***

For solids: ***0.10 to 0.45***

*For materials that does not change its volume****: 0.5***

$$\nu = -\frac{\text{Strain in direction of load}}{\text{Strain at right angle to load}}$$

$$\nu = -\frac{\varepsilon_{lateral}}{\varepsilon_{axial}}$$



III. Mechanical Characteristics

Values of Modulus of Elasticity and Poisson's Ratio

Material	Modulus of Elasticity [GPa]	Poisson's Ratio
Aluminum	69–75	0.35
Brick	10–17	0.23–0.42
Concrete	14–40	0.11–0.23
Epoxy	3–140	0.35–0.45
Glass	62–70	0.27
Limestone	58	0.2–0.5
Steel	200	0.29
Wood	6–15	0.29–0.47

III. Mechanical Characteristics

3. Elastoplastic Behavior

As the stress applied on the specimen is increased, the strain will proportionally increase up to a point, after this point the strain will increase with little additional stress. In this case, the stress level at which the behavior changes from elastic to plastic is the Elastic Limit.

Materials that do not undergo plastic deformation prior to failure, such as concrete, are said to be brittle, whereas materials that display appreciable plastic deformation, such as mild steel, are ductile

III. Mechanical Characteristics

Elastoplastic response
– first portion is an elastic response followed by a combined elastic and plastic response.

Strain hardening
– increases the stress required to cause plastic deformation, it allows more stress to be applied without permanent deformation

Strain softening
– plastic deformation causes weakening of the material

Proportional limit
– lowest point, defined as the transition point between linear and nonlinear behavior.

III. Mechanical Characteristics

4. Viscoelastic Behavior

Viscosity *is a measure of a fluid's resistance to flow. Viscoelasticity is the property of materials that exhibit both viscous and elastic characteristics when undergoing deformation. Typical viscoelastic materials used in construction applications are asphalt and plastics. Some of the properties of viscoelastic materials are their ability to: creep, recover, undergo stress relaxation.*

III. Mechanical Characteristics

*5. **Ductility** is the ability of material to undergo large deformations without rupture before failure”.*

- *Ductility in concrete is defined by the percentage of steel reinforcement with in it. Mild steel is an example of a ductile material that can be bent and twisted without rupture.*
- *If ductile members are used to form a structure, the structure can undergo large deformations before failure. This is beneficial to the users of the structures, as in case of overloading, if the structure is to collapse, it will undergo large deformations before failure*

III. Mechanical Characteristics

*6. **Brittleness** is a property of material that will fail suddenly without undergoing noticeable deformations.*

- *Concrete is an example of brittle material. To avoid failure of structure the structural engineer must take all provisions to increase the ductility of structure. By suitably anchoring the reinforcement, the ductility of a structure can be increased to a greater extent with little increase in cost.*

III. Mechanical Characteristics

7. Temperature And Time Effects

- *Viscoelastic materials, such as plastics and asphalt, are greatly affected by temperature, even if the temperature is changed by only a few degrees.*
- *Metals or concrete, are less affected by temperatures, especially when they are near ambient temperature.*
- *Ferrous metals, including steel, demonstrate a change from ductile to brittle behavior as the temperature drops below the transition temperature.*

III. Mechanical Characteristics

7. Temperature And Time Effects

In addition to temperature, some materials, such as viscoelastic materials, are affected by the load duration,

(1) The longer the load is applied, the larger is the amount of deformation or creep.

(2) Increasing the load duration and increasing the temperature cause similar material responses.

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General Luna Road, Baguio City, Philippines 2600
(074)442-3306
ub@e.ubaguio.edu
www.ubaguio.edu

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