Young's Modulus

Young's modulus is defined as the ratio of normal stress to the normal strain in the body; it is the internal property of the material that relates stress and strain. Young's modulus is the property of a material with the help of that elastic deformation of material can find out easily. Young's modulus of elasticity is represented by 'E' and can be described with the help of Hooke's law.

Young's modulus is the modulus of elasticity of a material; first observed by the British scientist Thomas young. When a body is subjected to the axial load, it will undergo some deformation, which would be recoverable only if it is under the elastic limit of the body. And this elastic deformation of the body can be calculated with the help of young's modulus and the stress applied over it.

Hooke's law: According to this law, stress induced in a material is directly proportional to the applied strain. Hooke's law is important for the GATE exam. But this law is only valid up to the proportionality limit of the material.

Normal stress: It is the axial force per unit area of the cross-section of material. It can be either tensile stress or compressive stress.

Normal strain: It is the deformation per unit length of the material in the direction of the applied load. The application of load over a body induces strain, and it will cause stress to the body. So, we can say that strain is the cause of stress.

What is Elastic Constant?

Elastic constants are the material's constant parameters, which are used to define the elastic parameters of the structure. It can also be defined as the second derivative of the Gibbs free energy of the material concerning the strain. Elastic constants of material are essential parts of the GATE syllabus and can change after changing the temperature and pressure of the material. Elastic constants can be classified into four types, described as follows:

1. Young's modulus: It relates the normal stress to the normal strain of the body
2. Shear modulus: It relates the shear stress to the shear strain of the material
3. Bulk modulus: It relates the volumetric stress to the volumetric strain of the material.
4. Poisson's ratio: It relates the longitudinal and lateral strain of the material. It is defined as the ratio of lateral strain to the longitudinal strain of the body.

Young's Modulus Formula

Young's modulus value relates the normal stress to the normal strain of the body, so the formula for this can be obtained with the help of Hooke's law of elasticity. According to this, normal stress acting on a cross-section is directly proportional to the applied strain on the body.

So,

This proportionality constant is known as young's modulus of elasticity (E). Hence, E=σ/E

Normal stress can be expressed as normal force per unit area, So, σ=F/A

Normal strain can be expressed as a change in length in longitudinal direction per unit length of the member, So E=ΔL/L.

Unit of Young's Modulus

As we know, Young's modulus is the ratio of the stress to the strain. So, the unit of young's modulus is the same as that of stress because the strain is a unitless quantity. And we also know that stress is defined as the force per unit of normal cross-section area.

The Unit of stress is N/m^2. It is also known as the pascal and commonly represented by the symbol "Pa." MCQ-based questions are formulated in the GATE question paper based on this. Stress is generally expressed in terms of units of MPa, GPa, etc. So, the unit of young's modulus is also written as N/m^2 or Pa.

Young's Modulus Dimensional Formula

Since the Unit for Young's Modulus is N/m^2. therefore the dimensional formula would be:

Young's Modulus Dimensional Formula = $N/m^2 = [kgm/s2]m^2 = ML^{-1}T^{-2}$

Young's Modulus of Steel

Steel is a structural member of high tensile strength. It can also withstand compressive stress and shear stress as well. The steel structure is lightweight; due to its advantages, it is mostly used for railway bridges, industrial roof structures, etc. Steel can be of many types, like mild steel, High yield strength deformed bar, Cold deformed bar, etc. But the modulus of elasticity of all types of steel is taken as its secant modulus of elasticity, having the value of 2×10^5 MPa. Here young's modulus values for other materials are given, which helps a comparative understanding of different materials.

Type of material	Young's Modulus (GPa)
Rubber	0.01 - 0.1
Polyethelene	0.2
Nylon	2 - 4
Brass	100 - 125
Aluminium	69

Young's Modulus Dimensional Formula

The dimensional formula represents a quantity in its basic units, like mass, length, time, and temperature. The dimensional formula of a quantity represents its dependent quantity. The dimensional formula is written regarding the power of these basic quantities.

As young's modulus is equal to the ratio of stress to strain. So its dimensional formula can be written as the dimensional formula of stress. And it can be written as force per unit area. So, the dimensional formula of young's modulus is $MLT^{-2}/L^2 = ML^{-1}T^{-2}$.

Relation Between Young's Modulus and Other Elastic Constants

As we discussed earlier, elastic constants are the constant parameters of material that describe the material properties. These elastic materials constants include young's modulus, Bulk modulus, Shear modulus, and Poisson's ratio. Some relation between these elastic parameters must exist, described as follows. These relations are written by assuming equal volumetric stress conditions.

Relation between young's modulus and bulk modulus: $E = 3K(1-2\mu)$

Relation between young's modulus and shear modulus: $E = 2G(1+\mu)$

Relation between young's modulus, bulk modulus, and shear modulus: $E = 9KG/(G+3K)$