Unit 3
Elasticity and Static Equilibrium of Rigid Body

Introduction to Elasticity and Plasticity

In Grade 9 Physics, you learned how force can cause an object to move. However, force can also change the shape or size of an object. Some objects return to their original shape and size after the force is removed, while others do not. This behavior depends on the material's properties, specifically elasticity and plasticity.

Understanding Elasticity and Plasticity

- **Elasticity:** When a force is applied to an object, like stretching a spring or rubber band, it changes shape. If the object returns to its original shape when the force is removed, it is considered elastic. This reversible change is called *elastic deformation*.
- **Plasticity:** Some materials, like putty or mud, do not return to their original shape after the force is removed. These materials undergo a permanent change, known as *plastic deformation*. Such materials are called plastic.

Importance of Elasticity in Engineering

The elastic properties of materials are crucial in engineering design. For example, when designing buildings, bridges, or vehicles, engineers must understand the elastic behavior of materials like steel or concrete to ensure safety and functionality.

Key Concepts

- **Deformation:** The change in shape or size of an object due to applied force.
- **Elastic Deformation:** A reversible change in shape when the force is removed.
- **Plastic Deformation:** A permanent change in shape due to applied force.

Stress and Strain:

Introduction

In the study of material deformation, two fundamental concepts are stress and strain. These terms describe how materials respond to forces applied to them. By the end of this section, you should be able to:

- Define stress and strain.
- Apply the formulas of stress and strain to solve problems.
- Relate the physical concepts of stress and strain to daily life activities.

Stress

Definition: Stress is the force applied to a material divided by the area over which the force is applied. It quantifies the intensity of the force causing the material to deform.

- **Formula:**

  Stress=$\frac{Force\ (F)}{\mathrm{Area\ (A)}}$

- **Units:** The unit of stress is Newton per square meter (N/m²).

Types of Stress:

1. **Tensile Stress:** Occurs when a force acts to stretch a material.
2. **Compressive Stress:** Occurs when a force acts to compress a material.

Example: Consider a rod of cross-sectional area A and original length L_0. When a force F is applied perpendicular to the cross-section, the rod stretches, increasing its length to L. The stress in the rod can be calculated using the formula:

Tensile Stress=$\frac{F}{\mathrm{A}}$

Strain

Definition: Strain is the measure of deformation experienced by the material in the direction of the applied force. It is the ratio of the change in length to the original length.

- **Formula:**

  Strain=$\frac{\Delta L}{\mathrm{L_0}}$

where ΔL is the change in length and L_0 is the original length.

- **Units:** Strain is a dimensionless quantity because it is a ratio of two lengths.

Example: If the rod mentioned above stretches by a length ΔL, the strain in the rod is given by:

$\text{Strain}=\frac{\Delta L}{L_0}$

Real-Life Application

Stress and strain concepts are vital in designing structures like bridges, buildings, and machinery. Engineers must ensure that the materials used can withstand the stress they will experience without deforming excessively.

Summary

- **Stress** is the force per unit area causing deformation.
- **Strain** is the relative deformation in response to the applied stress.
- These concepts help in understanding how materials will behave under different forces, ensuring safety and reliability in practical applications.

Exercise Example:

1. A force of 9.8 N acts over a cross-sectional area of 2×10−3 m^2. Find the tensile stress. Tensile Stress=$\frac{9.8\,N}{2\times10^{-3}\text{m}^2}$=$4.9\times10^3\,\text{N/m}^2$

Understanding these principles allows you to solve practical problems and design solutions that consider material limits and safety.

Static Equilibrium

Definition of Static Equilibrium: Static equilibrium occurs when an object is at rest and remains at rest without tilting or rotating. In this state, all the forces and torques acting on the object are balanced, meaning the object does not move in any direction.

Key Concept: Static equilibrium is when a body is at rest, and there is no net force or net torque acting on it.

Conditions for Static Equilibrium

To determine whether an object or system is in static equilibrium, two key conditions must be satisfied:

1. First Condition of Equilibrium (Translational Equilibrium):

The first condition ensures that there is no net force acting on the object, meaning the object does not accelerate in any direction. This is mathematically expressed as:

$\Sigma\vec{F}=0$

Where the sum of all forces acting on the object in every direction must equal zero. For example:

- In one dimension (1-D): $\Sigma F_x=0$
- In two dimensions (2-D): $\Sigma F_x=0$ and $\Sigma F_y=0$

2. Second Condition of Equilibrium (Rotational Equilibrium):

The second condition ensures that there is no net torque acting on the object, meaning the object does not rotate. This is expressed as:

$\Sigma\vec{\tau}=0$

Where torque (τ) is the force that causes an object to rotate around an axis or pivot point. The sum of all torques acting on the object must be zero for the object to remain in static equilibrium.

Examples of Static Equilibrium

Example 1: Book at Rest on a Table

- A book placed on a table is an example of static equilibrium.
- The forces acting on the book include the downward force of gravity and the upward normal force from the table.
- These forces are equal in magnitude but opposite in direction, resulting in a net force of zero.
- Since the book is not rotating, the net torque is also zero, satisfying both conditions of static equilibrium.

Example 2: A Balanced Seesaw

- A seesaw balanced by two children is another example of static equilibrium.
- If child A with mass m_A sits at a distance d_A from the pivot and child B with mass m_B sits at a distance d_B, the seesaw is in static equilibrium when the torques due to each child are equal and opposite:

$m_A \cdot g \cdot d_A = m_B \cdot g \cdot d_B$

Where g is the acceleration due to gravity.

Solving Static Equilibrium Problems

To solve problems involving static equilibrium:

1. **Draw a Free-Body Diagram:** Represent all forces acting on the object, including gravity, normal force, and any applied forces.
2. **Choose a Coordinate System:** Break forces into components if necessary.
3. **Apply the First Condition of Equilibrium:** Ensure the sum of all forces in each direction is zero.
4. **Apply the Second Condition of Equilibrium:** Ensure the sum of all torques about any chosen axis is zero.
5. **Solve the Equations:** Use the equations derived from the conditions to find unknown forces, distances, or angles.

Summary

- Static equilibrium occurs when an object is at rest, with no net force or torque acting on it.
- The first condition of equilibrium requires that all external forces on the object balance out, resulting in no acceleration.
- The second condition of equilibrium requires that all torques are balanced, preventing rotation.

Understanding these principles allows you to analyze and solve problems involving objects in static equilibrium, ensuring both stability and balance.