ENGINEERING MECHANICS
STATICS

Dams &Water Resources Department
First Stage – 2nd Semester
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Lecture Notes Prepared by:

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Course Objectives

- **To understand and use the general ideas of force vectors and equilibrium of particle and rigid body.**
- **To understand and use the general ideas of structural analysis and internal force and friction.**
- **To understand and use the general ideas of center of gravity, centroids and moments of inertia.**

Subjects

1. General principles
2. Force vectors
3. Equilibrium of a particle
4. Force system resultants
5. Equilibrium of a Rigid Body
6. Structural Analysis
7. Internal Forces
8. Friction
9. Center of Gravity and Centroid of Areas
10. Moments of Inertia (Second Moment of Areas)

Textbook

- R. C. Hibbeler, "Engineering mechanics – Statics", 13th edition, 20013.

REFERENCES

1. Andrew Pytel and Jaan Kiusalaas, "Engineering Mechanics – Statics", Third Edition, 2010.
2. J. L. Meriam and L.G. Kraige, "Engineering Mechanics – Vol.1", Fifth Edition, 2002.

CHAPTER 1

CHAPTER OBJECTIVES

- ✓ *To provide an introduction to the basic quantities and idealizations of mechanics.*
- ✓ *To give a statement of Newton's Laws of Motion and Gravitation.*
- ✓ *To review the principles for applying the SI system of units.*
- ✓ *To examine the standard procedures for performing numerical calculations.*
- ✓ *To present a general guide for solving problems.*

1.1 Introduction

Mechanics is a branch of the physical sciences that is concerned with the state of rest or motion of bodies that are subjected to the action of forces. In general, this subject can be subdivided into three branches: rigid-body mechanics, deformable-body mechanics , and fluid mechanics.

The subject of statics developed very early in history because it's principles can be formulated simply from measurements of geometry and force. ***Statics deals with the equilibrium of bodies, that is, those that are either at rest or move with a constant velocity;*** whereas ***dynamics is concerned with the accelerated motion of bodies***. We can consider statics as a special case of dynamics, in which the acceleration is zero; however, statics deserves separate treatment in engineering education since many objects are designed with the intention that they remain in equilibrium..

1.2 Basic Concepts

Before we begin our study of engineering mechanics, it is important to understand the meaning of certain fundamental concepts and principles.

Length: Length is used to ***locate the position*** of a point in space and thereby describe the size of a physical system. Once a standard unit of length is defined, one can then use it to define distances and geometric properties of a body as multiples of this unit.

Time: Although the principles of statics are ***time independent***. This quantity plays an ***important*** role in the study of ***dynamics***.

Mass: Mass is a ***measure of a quantity of matter*** that is used to compare the action of one body with that of another.

Force: Force is considered as a "***push***" or "***pull***" exerted by one body on another. This interaction can occur when there is direct contact between the bodies, such as a person pushing on a wall. A force is completely characterized by its ***magnitude***, ***direction***, and ***point of application***.

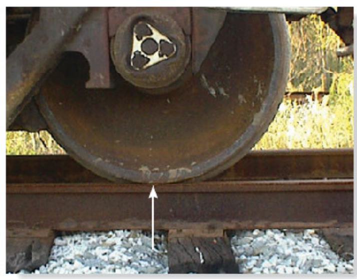
Idealizations: Models or idealizations are used in mechanics in order to simplify application of the theory. Here we will consider three important idealizations.

Three forces act on the ring. Since these forces all meet at point, then for any force analysis, we can assume the ring to be represented as a particle.

Particle: Particle has a ***mass***, but its ***size can be neglected***.

Rigid Body A rigid body can be considered as a ***combination*** of a ***large number*** of ***Particles.***

Concentrated Force: A *concentrated force* represents the effect of a loading which is assumed to act at a point on a body. We can represent a load by a concentrated force, provided the area over which the load is applied is very small compared to the overall size of the body. An example would be the contact force between a wheel and the ground.



Steel is a common engineering material that does not deform very much under load. Therefore, we can consider this railroad wheel to be a rigid body acted upon by the concentrated force of the rail.

Newton's Three Laws of Motion: Engineering mechanics is formulated on the basis of Newton's three laws of motion.

Newton's first law: A ***particle originally*** at ***rest*** or ***moving*** in a straight line with ***constant velocity***, ***tends*** to ***remain*** in this ***State*** provided the particle is not subjected to an unbalanced force (Fig.1-1).

$$\sum_{i=1}^{N} F_i = 0$$

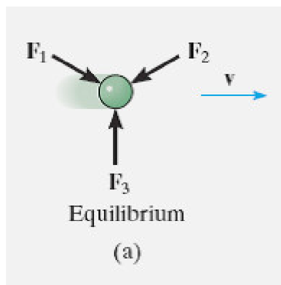


Fig 1-1

Newton's second law: A ***particle acted*** upon by an unbalanced ***force*** "***F***" ***experiences*** an ***acceleration*** "***a***" that has the same direction as the ***force*** and a ***magnitude*** that is directly ***proportional*** to the force (Fig.1-2).

If "F" is applied to a particle or mass "m", this law may be expressed mathematically as:

$$F = m.a \qquad ......(1.1)$$

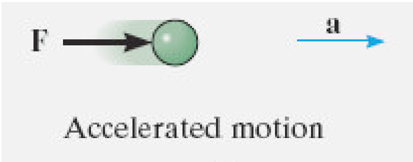


Fig 1-2

Newton's third Law: The ***mutual forces*** of action between two particles are ***equal, opposite,*** and ***collinear*** (Fig. 1-3).

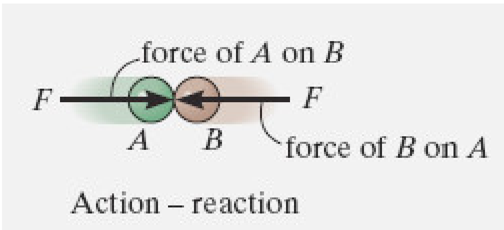


Fig 1-3

Newton's Law of Gravitational Attraction: Shortly after formulating his three laws of motion. Newton postulated a law governing the ***gravitational attraction between any two particles.*** Stated mathematically.

$$F = G\frac{m_1 m_2}{r^2} \qquad .... (1.2)$$

Where:

F: Force of ***gravitational*** between the two particles.

G: ***Universal constant of gravitation***, according to experimental evidence.

$$G = 66.73\ 10^{-12}\ \frac{m^3}{kg\ s^2}$$

m_1 , m_2 : mass of each of the two particles.
r : distance between the two particles.

Weight: Weight refers to the ***gravitational attraction*** of the ***earth*** on a body or quantity of mass. The weight of a particle having a mass is stated mathematically.

$$W = mg \quad \text{........ (1.3)}$$

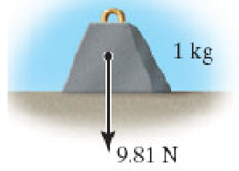


Fig 1-4

Measurements give: $g = 9.8066 \ m/s^2$
Therefore, a body of ***mass 1 kg*** has a ***weight of 9.81*** **N**, a 2 kg body weights 19.62 N, and so on (Fig. 1-4).

Units of Measurement:

- **SI units:** The ***international System of units***. Abbreviated **SI** is a ***modern version*** which has received worldwide recognition. As shown in Tab 1.1. The SI system defines ***length in meters (m)***, ***time in seconds (s)***, and ***mass in kilograms (kg).*** In the SI system the unit of force, the ***Newton*** is a ***derived unit***. Thus, 1 Newton (**N**) is equal to a force required to give 1 kilogram of mass and acceleration of **1** m/s^2.
- **US customary:** In the ***U.S. Customary*** system of units (***FPS***) ***length*** is measured in ***feet (ft)***, ***time*** in ***seconds (s)***, and ***force*** in ***pounds (lb)***. The unit of ***mass***, called a ***slug***, ***1 slug*** is equal to the amount of ***matter*** accelerated at ***1*** ft/s^2 when acted upon by a ***force of 1 lb*** (1 $slug$=1 $lb \ s^2/ft$). Therefore, if the measurements are made at the "standard location," where g = 32.2 ft/s^2 , then from Eq. 1.3 ,

$$m = W/g \qquad (g = 32.2 \text{ ft/s}^2) \quad \text{.......(1.4)}$$

And so a body weighing 32.2 lb has a mass of 1 slug, a 64.4-lb body has a mass of 2 slugs, and so on.

TABLE 1–1 Systems of Units

Name	Length	Time	Mass	Force
International System of Units SI	meter m	second s	kilogram kg	newton* N $\left(\frac{kg \cdot m}{s^2}\right)$
U.S. Customary FPS	foot ft	second s	slug* $\left(\frac{lb \cdot s^2}{ft}\right)$	pound lb

*Derived unit.

Conversion of Units:

Table 1.2 provides a set of direct conversion factors between FPS and SI units for the basic quantities. Also in the FPS system, recall that:

1 ft=12 in inches 1 mile=5280 ft 1 kp kilo pound =1000 lb 1 ton=2000 lb

TABLE 1–2 Conversion Factors

Quantity	Unit of Measurement (FPS)	Equals	Unit of Measurement (SI)
Force	lb		4.448 N
Mass	slug		14.59 kg
Length	ft		0.3048 m

Prefixes: When a ***numerical quantity*** is either very ***Large*** or very ***small***, the units used to define its size may be modified by using a ***prefix***. Some of the prefixes used in the SI system are shown in Table 1.3. Each represents a ***multiple*** or ***submultiples*** of a unit which, if applied successively, moves the decimal point of a numerical quantity to every third place. For example, 4000000 N = 4000 kN (kilo-Newton) = 4MN (Mega-Newton), or 0.005 m = 5 mm (millimeter).

TABLE 1–3 Prefixes

	Exponential Form	Prefix	SI Symbol
Multiple			
1 000 000 000	10^9	giga	G
1 000 000	10^6	mega	M
1 000	10^3	kilo	k
Submultiple			
0.001	10^{-3}	milli	m
0.000 001	10^{-6}	micro	μ
0.000 000 001	10^{-9}	nano	n

*The kilogram is the only base unit that is defined with a prefix.

Important Points

- Statics is the study of bodies that are at rest or move with constant velocity.
- A particle has a mass but a size that can be neglected, and a rigid body does not deform under load.
- Concentrated forces are assumed to act at a point on a body.
- Newton's three laws of motion should be memorized.
- Mass is measure of a quantity of matter that does not change from one location to another. Weight refers to the gravitational attraction of the earth on a body or quantity of mass. Its magnitude depends upon the elevation at which the mass is located.
- In the SI system the unit of force, the newton, is a derived unit. The meter, second, and kilogram are base units.
- Prefixes G, M, k, m, μ, and n are used to represent large and small numerical quantities. Their exponential size should be known, along with the rules for using the SI units.
- Perform numerical calculations with several significant figures, and then report the final answer to three significant figures.
- Algebraic manipulations of an equation can be checked in part by verifying that the equation remains dimensionally homogeneous.
- Know the rules for rounding off numbers.

EXAMPLE 1.1

Convert 2 km/h to m/s How many ft/s is this?

SOLUTION

Since 1 km = 1000 m and 1 h = 3600 s, the factors of conversion are arranged in the following order, so that a cancellation of the units can be applied:

$$2\text{ km/h} = \frac{2\text{ km}}{\text{h}}\left(\frac{1000\text{ m}}{\text{km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$

$$= \frac{2000\text{ m}}{3600\text{ s}} = 0.556\text{ m/s} \qquad \textit{Ans.}$$

From Table 1–2, 1 ft = 0.3048 m. Thus,

$$0.556\text{ m/s} = \left(\frac{0.556\text{ m}}{\text{s}}\right)\left(\frac{1\text{ ft}}{0.3048\text{ m}}\right)$$

$$= 1.82\text{ ft/s} \qquad \textit{Ans.}$$

NOTE: Remember to round off the final answer to three significant figures.

EXAMPLE 1.2

Convert the quantities 300 lb · s and 52 slug/ft^3 to appropriate SI units.

SOLUTION

Using Table 1–2, 1 lb = 4.448 2 N.

$$300\text{ lb}\cdot\text{s} = 300\text{ lb}\cdot\text{s}\left(\frac{4.448\text{ N}}{1\text{ lb}}\right)$$

$$= 1334.5\text{ N}\cdot\text{s} = 1.33\text{ kN}\cdot\text{s} \qquad \textit{Ans.}$$

Since 1 slug = 14.593 8 kg and 1 ft = 0.304 8 m, then

$$52\text{ slug/ft}^3 = \frac{52\text{ slug}}{\text{ft}^3}\left(\frac{14.59\text{ kg}}{1\text{ slug}}\right)\left(\frac{1\text{ ft}}{0.304\,8\text{ m}}\right)^3$$

$$= 26.8(10^3)\text{ kg/m}^3$$

$$= 26.8\text{ Mg/m}^3 \qquad \textit{Ans.}$$

EXAMPLE 1.3

Evaluate each of the following and express with SI units having an appropriate prefix: (a) (50 mN)(6 GN), (b) (400 mm)$(0.6\ \text{MN})^2$, (c) 45 MN^3/900 Gg.

SOLUTION

First convert each number to base units, perform the indicated operations, then choose an appropriate prefix.

Part (a)

$$\begin{aligned}(50\ \text{mN})(6\ \text{GN}) &= [50(10^{-3})\ \text{N}][6(10^{9})\ \text{N}]\\ &= 300(10^{6})\ \text{N}^2\\ &= 300(10^{6})\ \text{N}^2\left(\frac{1\ \text{kN}}{10^3\ \text{N}}\right)\left(\frac{1\ \text{kN}}{10^3\ \text{N}}\right)\\ &= 300\ \text{kN}^2 \qquad \textit{Ans.}\end{aligned}$$

NOTE: Keep in mind the convention $\text{kN}^2 = (\text{kN})^2 = 10^6\ \text{N}^2$.

Part (b)

$$\begin{aligned}(400\ \text{mm})(0.6\ \text{MN})^2 &= [400(10^{-3})\ \text{m}][0.6(10^{6})\ \text{N}]^2\\ &= [400(10^{-3})\ \text{m}][0.36(10^{12})\ \text{N}^2]\\ &= 144(10^{9})\ \text{m}\cdot\text{N}^2\\ &= 144\ \text{Gm}\cdot\text{N}^2 \qquad \textit{Ans.}\end{aligned}$$

We can also write

$$\begin{aligned}144(10^{9})\ \text{m}\cdot\text{N}^2 &= 144(10^{9})\ \text{m}\cdot\text{N}^2\left(\frac{1\ \text{MN}}{10^6\ \text{N}}\right)\left(\frac{1\ \text{MN}}{10^6\ \text{N}}\right)\\ &= 0.144\ \text{m}\cdot\text{MN}^2 \qquad \textit{Ans.}\end{aligned}$$

Part (c)

$$\begin{aligned}\frac{45\ \text{MN}^3}{900\ \text{Gg}} &= \frac{45(10^{6}\ \text{N})^3}{900(10^{6})\ \text{kg}}\\ &= 50(10^{9})\ \text{N}^3/\text{kg}\\ &= 50(10^{9})\ \text{N}^3\left(\frac{1\ \text{kN}}{10^3\ \text{N}}\right)^3\frac{1}{\text{kg}}\\ &= 50\ \text{kN}^3/\text{kg} \qquad \textit{Ans.}\end{aligned}$$

Exercises

Exercise 1.1:

Convert 2 $\frac{km}{h}$ to $\frac{m}{s}$. How many $\frac{ft}{s}$ is this?

Ans: $2\frac{km}{h} = 0.556\frac{m}{s} = 1.82\frac{ft}{s}$

Exercise 1.2:

Convert the quantities 300 lb.s and 52 $\frac{slug}{ft^3}$ to appropriate SI units.

Ans: $300\ lb.s = 1.33\ kN.s$ $\quad 52\frac{slug}{ft''} = 26.8\frac{Mg}{m^3}$

Exercise 1.3:

Evaluate each of the following and express with SI units having an appropriate prefix: (a) $(50\ mN)(6\ GN)$ (b) $(400\ mm)(0.6\ MN)^2$ (c) $\frac{45\ MN^3}{900\ Gg}$

Ans: $(50\ mN)(6\ GN) = 300\ kN^2$ $\quad (400\ mm)(0.6\ MN)^2 = 144\ Gm.N^2$ $\quad 45\frac{MN^3}{900Gg} = 50\frac{kN^3}{kg}$

Exercise 1.4:

Round off the following numbers to three significant figures:

(a) 4.65735 m (b) 55.578 s (c) 4555 N (d) 2768 kg

Ans: $(a)\ 4.66\ m$ $\quad (b) 55.6\ s$ $\quad (c) 4.56\ kN$ $\quad (d) = 2.77Mg$

Exercise 1.5:

Represent each of the following combinations of units in the correct SI form using an appropriate prefix:

(a) μMN (b) N/μm (c) MN/ks^2 (d) kN/ms.

Ans: $(a)\ N$ $\quad (b)\frac{MN}{m}$ $\quad (c)\frac{N}{s^2}$ $\quad (d)\frac{MN}{s}$

Exercise 1.6:

Represent each of the following combinations of units in the correct SI form:

(a) Mg/ms (b) N/mm (c) mN/(kg. μs).

Ans: (a) $\frac{Mg}{ms} = \frac{Gg}{s}$ $\quad$ (b) $\frac{N}{mm} = \frac{kN}{m}$ $\quad$ (c) $\frac{mN}{kg.\mu s} = \frac{kN}{kg.s}$

Exercise 1.7:

A rocket has a mass of 250 10^3 slugs on earth. Specify (a) its mass in SI units and (b) its weight in SI units. If the rocket is on the moon, where the acceleration due to gravity is g_m=5.30 ft/s^2, determine to 3 significant figures (c) its weight in units, and (d) its mass in SI units.

Ans: (a) 3.65 Gg $\quad$ (b) $W_e = 35.8$ MN $\quad$ (c) $W_m = 5.89$ MN $\quad m_m = m_e = 3.65$ Gg

Exercise 1.8:

If a car is traveling at 55 mi/h, determine its speed in kilometers per hour and meters per second.

Ans: $(a)\ 88.514\frac{km}{h}$ $\quad (b) 24.6\ \frac{m}{s}$

Exercise 1.9:

The Pascal (Pa) is actually a very small units of pressure. To show this, convert 1 Pa=1 N/m^2 to lb/ft^2. Atmospheric pressure at sea level is 14.7 lb/in^2. How many Pascals is this?

Ans: $(a)\ 1\ Pa = 20.9\ 10^{-3}\ \frac{lb}{ft^2}$ $\quad (b) 1\ ATM = 101.34\ kPa$