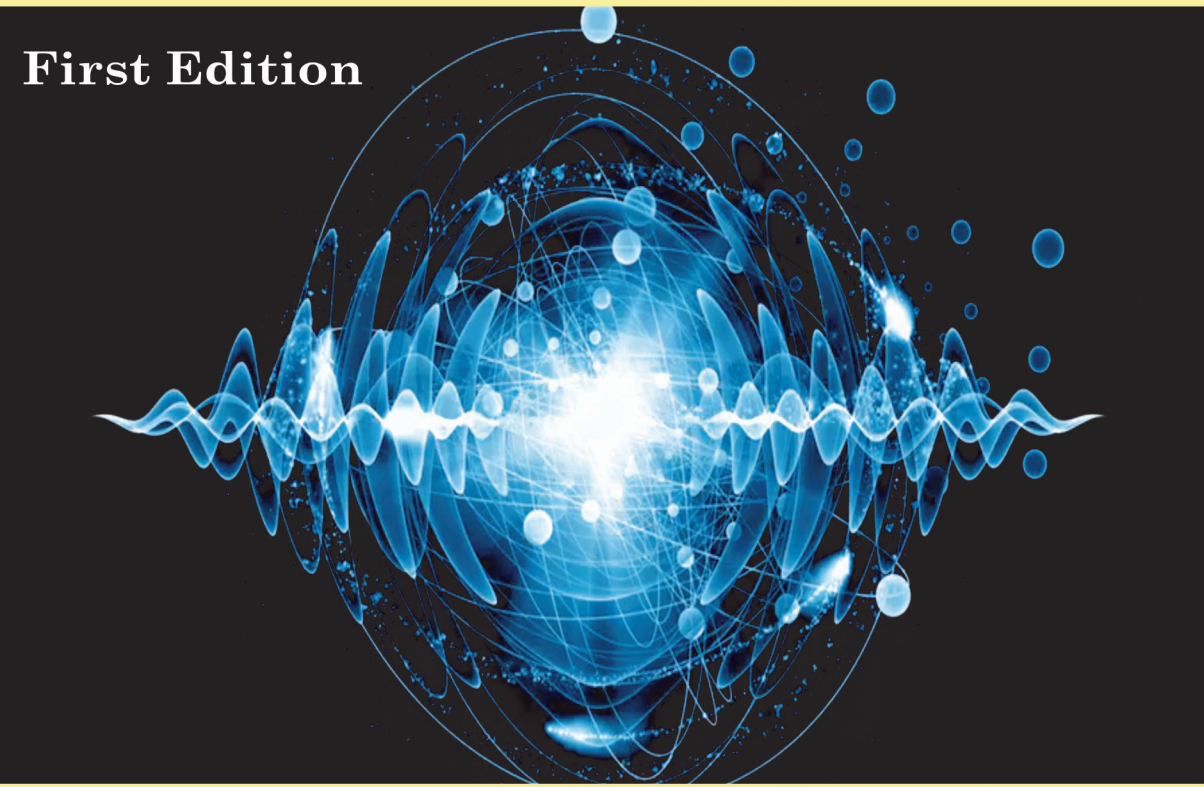
An Introduction to MECHANICS of SOLID

First Edition



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Always Learning

BRIJ BHOOSHAN

AN

INTRODUCTION

TO

MECHANICS OF SOLIDS

Brij Bhooshan Yadav

Asst. Professor, Department of Mechanical Engineering

(B.S.A. Collage of Engg. and Technology, Mathura)

To our

Loving memory

Of

Respected Grand-Parents

DadaJi; DadiJi; NanaJi &NaniJi

and

Lovely Daughter Purvi Bhooshan

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Preface

This book has been developed from subject matter and examples that I have used in my teaching of Solid Mechanics, Structures and Strength of Materials in Universities over the last 12 years. It is intended for engineering degree courses in which solid mechanics and structures form a part. Postgraduates and those preparing for the membership of professional institutions, UPSC by examination in these subjects will also find this book useful.

The text illustrates where and how the necessary techniques are to be employed in each case. The reader will soon recognize, for example, that under elastic loading, the solution to the stress and strain suffered by a material invariably becomes that of satisfying three requirements: equilibrium, compatibility and the boundary conditions.

This textbook contains all to topics in 22 Chapters. We discuss the basic concept of stress and strain in Chapter-1, stress and strain in oblique plane Chapter-2, General analysis of stress strain and their relationship in three dimensional discuss in Chapters 3, 4 and 5. Chapter 6 deals about the theories of failure or yield criterion.

In Chapter 7 deals with concept of shear force and bending moment diagrams and solving the problems with section, point and area methods.

Bending equation in straight beams and un-symmetrical beam discussed in separate Chapters 8 and 15 respectively. Shear stress concept detailed deal in Chapter 9. Deflection obtained from double integration, area-moment methods in all beams like cantilever, simply supported, overhanging, propped, fixed and continues beams discuss in Chapters 10 and 11. Chapter 12 covered the elastic foundation of beams.

Chapter 13 deals with energy methods, which is one of the most important topics and hence, is discussed in more detail. We discuss the theorems Castigliano′s, Maxwell′s Reciprocal, Maxwell-Belt Reciprocal, and detailed discuss about concept of strain energy with generalization form. Concept of shear stresses flow and shear centre discuss in Chapter 16. Chapter 14 covered the curved bars, and also using the concept of energy method.

Elastic stability of columns is covered in Chapter 18, with beam columns.

Torsion discuss in great detail with circular and non-circular in Chapter 19. Chapter 20 covered springs with flat, spiral and laminated types.

Analysis of thick-walled cylindrical problems like composite tubes under internal and external pressure, rotating discs, shafts, spheres, cylinders with thermal stresses are discussed in Chapter 22.

In this textbook we provide the solutions of problems of different competitive examinations like Engg. Services, IAS, UPSC, GATE, and many other universities.

M.K.S. units have been adopted in this edition for the purpose of useful to students.

I wish to thank my colleagues and seniors Dr. Pankaj Upadhyay (Ex. HOD, ME, Dept.), Mr. Sudeer Kumar Bajpai, Mr. Ram Chandra Gupta (HOD, EE Dept.), Mr. Pawan Kulshreshth, Mr. Girraj Singh, Mr. Deepak Parashar, Mr. Girijapati Sharma, Mr. Kumar Gaurav, Mr. Vinay Gupta, and Mr. Sharad Mishra for their valuable suggestions.

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The author thanks are due to his parents (Ram Kumar – Giriraj Kishori, Arun Kumar – Brij Bhan Kishori), wife, Brother Krishna Bhooshan, Amit Bhooshan, Sumit Bhooshan, and daughter Purvi Bhooshan without whose cooperation and encouragement this book would have never been materialized.

Although every care has been taken to make the book free of errors, yet the author shall be obliged, if errors present are brought to his notice. Feedback and suggestions are always most welcome of the book.

Brij Bhooshan

List of Symbols

A	Area
A_f, A_w	Area of flange; area of web
θ	Angle, angle of rotation of beam axis, rate of twist of a bar in torsion (angle of twist per unit length)
θ_p	Angle to a principal plane or to a principal axis
θ_s	Angle to a plane of maximum shear stress
l	Length, distance, curvature shortening
a, b, c	Dimensions, distances
C or G	Centroid
r, R	Radius, radius of curvature ($r = l/k$), radial distance in polar coordinates
A, B, C, D	Constant of integration
y	Distance from neutral axis to outer surface of a beam
D	Diameter/ outer diameter
d	Diameter / inside diameter, dimension, distance
E	Modulus of elasticity
e	Eccentricity, dimension, distance, unit volume change (dilatation)
F	Force; shear force
q	Shear flow, shape factor for plastic bending, flexibility, frequency (Hz)
f_T	Torsional flexibility of a bar
G	Modulus of elasticity in shear
G	Acceleration of gravity
H	Height, distance, horsepower
h	Height, dimensions
I	Moment of inertia (or second moment) of a plane area
I_{xx}, I_{yy}, I_{zz}	Moments of inertia with respect to x, y, and z axes
I_{xy}	Product of inertia with respect to x-y axes
I_p	Polar moment of inertia
I_1, I_2	Principal moments of inertia
J	Torsion constant
K	Bulk modulus of elasticity
k	Spring constant, stiffness, effective length factor for a column, Curvature ($k = 1/r$), radius of gyration

k_T	Torsional stiffness of a bar
L, l	Length, distance
l_e	Effective length of a column
M	Bending moment, couple
N	Axial force, revolutions per minute (rpm)
fos, f_s	Factor of safety
O	Origin of coordinates, Center of curvature
P	Load, concentrated load, power, pressure (force per unit area)
F_{cr}	Critical load for a column
F_e	Euler load
F_r	Rankine load
q, w	Intensity of distributed load (force per unit distance)
Z	Section modulus of the cross section of a beam
s	Distance, distance along a curve
T	Tensile force, twisting couple or torque, temperature
t	Thickness, time, intensity of torque (torque per unit distance)
t_f, t_w	Thickness of flange; thickness of web
U	Strain energy
V	Shear force, volume, vertical force or reaction
v	Deflection of a beam, velocity
W	Load, weight, work
x, y, z	Rectangular axes (origin at point O)
ΔT	Temperature differential
ε	Normal strain, lateral strain in uniaxial stress
ε_{xx}, ε_{yy}, ε_{zz}	Normal strains in x, y, and z directions
ε_1, ε_2, ε_3	Principal normal strains
ε_{rr}	Radial strain
$\varepsilon_{\theta\theta}$	Circumferential strain
ε_θ	Normal strain for inclined axes
ε_t	Thermal strain
ε_y	Yield strain
μ	Poisson′s ratio
α	Angle, coefficient of thermal expansion, direction cosine
β	Angle, direction cosine
γ	Shear strain, direction cosine, weight density (weight per unit volume)
γ_{xy}, γ_{yz}, γ_{zx}	Shear strains in xy, yz and zx planes
δ	Deflection of a beam, displacement, elongation of a bar or spring
σ	Normal stress
σ_{xx}, σ_{yy}, σ_{zz}	Normal stresses on planes perpendicular to x, y and z axes
σ_{xy}, σ_{yz}, σ_{zx}	Normal stresses on planes perpendicular to xy, yz and zx plane
σ_n	Normal stress on an inclined plane

$\sigma_1, \sigma_2, \sigma_3$	Principal normal stresses
σ_{rr}	Radial stress
$\sigma_{\theta\theta}$	Circumferential stress
σ_{allow}	Allowable stress (or working stress)
σ_{cr}	Critical stress for a column ($\sigma_{\text{cr}} = F_{\text{cr}} / A$)
σ_{t}	Thermal stress
$\sigma_{\text{yp}}, \sigma_{\text{ut}}$	Ultimate stress; yield stress
σ_{oct}	Octahedral stress
τ	Shear stress
τ_{oct}	Octahedral shear stress
$\tau_{xy}, \tau_{yz}, \tau_{zx}$	Shear stresses on planes perpendicular to the *x, y* and *z* axes and acting parallel to the *y, z* and *x* axes
τ_{t}	Tangential shear stress
τ_{θ}	Shear stress on an inclined plane
$\tau_{\text{yp}}, \tau_{\text{ut}}$	Ultimate stress in shear; yield stress in shear

Greek Alphabet

α	Alpha	β	Beta
γ	Gamma	δ	Delta
ε	Epsilon	ζ	Zeta
η	Neta	θ	Theta
λ	Lambda	π	Pi
μ	Mu	ρ	Rho
ν	Nu	χ	Chi
ξ	Xi	σ	Sigma
τ	Tau	φ	Psi
ψ	Psi	ω	Omega
ϕ	Phi	κ	Kappa

Systeme International d′Unit′es (SI Units)

Conversion Factors

To Convert	*to*	*Multiply by*
kgf	newton	9.8066
kgf/cm^2	Pa	9.8066×10^4
newton	kgf	0.10197
Pa	N/m^2	1
kPa	kgf/cm^2	0.010197
HP	kW	0.746
kW	kNm/s	1

Base Units

Quantity	*Unit (Symbol)*
length	meter (m)
mass	kilogram (kg)
time	second (s)
force	newton (N)
pressure	pascal (Pa), N/m^2

SI Prefixes

Prefix	*Symbol*	*Multiplication factor*
tera	T	10^{12}
giga	G	10^{9}
mega	M	10^{6}
kilo	k	10^{3}
hecto	h	10^{2}
deka	da	10^{1}
deci	d	10^{-1}
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}
nano	n	10^{-9}
pico	p	10^{-12}

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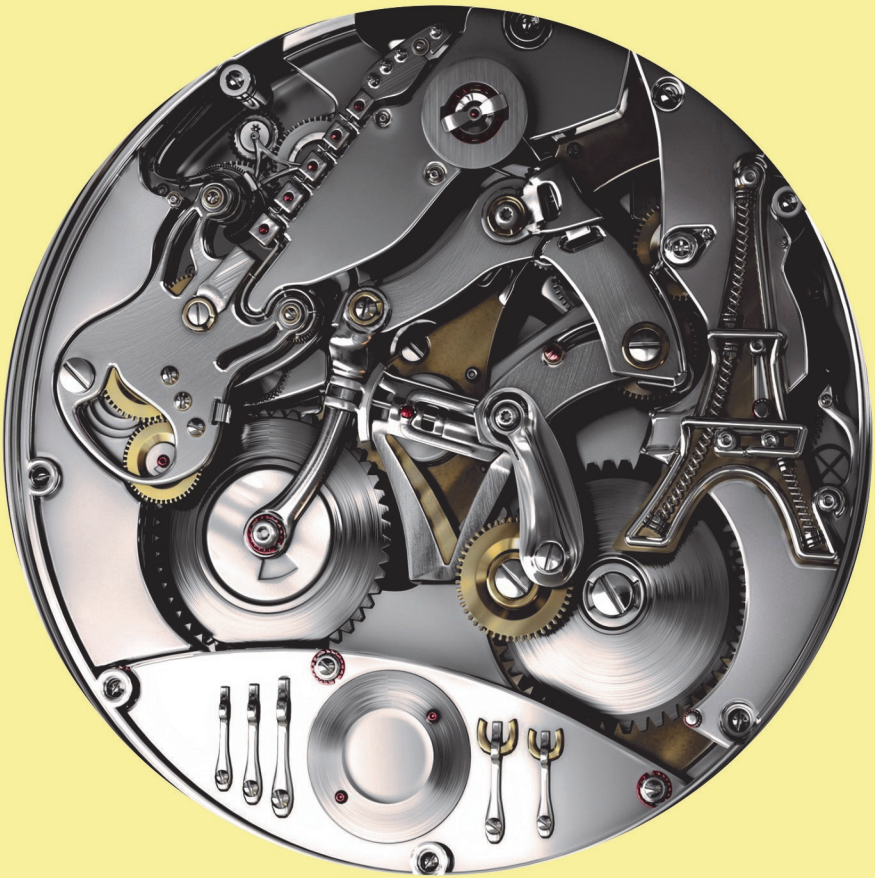

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