Strength of Materials and Structures

Fourth edition

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"Only when you climb the highest mountain, will you be aware of the vastness that lies around you."

Oscar Wilde, 1854—1900.

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Chinese Proverb — *It is better to ask a question and look a fool for five minutes, than not to ask a question at all and be a fool for the rest of your life.*

Heaven and Hell — *In heaven you are faced with an infinite number of solvable problems and in hell you are faced with an infinite number of unsolvable problems.*

Principal notation

a length
b breadth
c wave velocity, distance
d diameter
h depth
j number of joints
l length
m mass, modular ratio, number of numbers
n frequency, load factor, distance
p pressure
q shearing force per unit length
r radius
s distance
t thickness
u displacement
v displacement, velocity
w displacement, load intensity, force
x coordinate
y coordinate
z coordinate

A area
C complementary energy
D diameter
E young's modulus
F shearing force
G shearing modulus
H force
I second moment of area
J torsion constant
K bulk modulus
L length
M bending moment
P force
Q force
R force, radius
S force
T torque
U strain energy
V force, volume, velocity
W work done, force
X force
Y force
Z section modulus, force

α coefficient of linear expansion
γ shearing strain
δ deflection
ε direct strain
η efficiency
θ temperature, angle of twist
ν Poisson's ratio

ρ density
σ direct stress
τ shearing stress
ω angular velocity
Δ deflection
Φ step-function

[k] element stiffness matrix
[m] elemental mass matrix

[K] system stiffness matrix
[M] system mass matrix

Note on SI units

The units used throughout the book are those of the Système Internationale d'Unités; this is usually referred to as the SI system. In the field of the strength of materials and structures we are concerned with the following basic units of the SI system:

length	metre (m)
mass	kilogramme (kg)
time	second (s)
temperature	kelvin (K)

There are two further basic units of the SI system – electric current and luminous intensity – which we need not consider for our present purposes, since these do not enter the field of the strength of materials and structures. For temperatures we shall use conventional degrees centigrade (°C), since we shall be concerned with temperature changes rather than absolute temperatures. The units which we derive from the basic SI units, and which are relevant to out fielf of study, are:

force	newton (N)	$kg.m.s^{-2}$
work, energy	joule (J)	$kg.m^2.s^{-2} = Nm$
power	watt (W)	$kg.m^2.s^{-3} = Js^{-1}$
frequency	hertz (Hz)	cycle per second
pressure	Pascal (Pa)	$N.m^{-2} = 10^{-5}$ bar

The acceleration due to gravity is taken as:

$$g = 9.81 ms^{-2}$$

Linear distances are expressed in metres and multiples or divisions of 10^3 of metres, i.e.

Kilometre (km)	10^3 m
metre (m)	1 m
millimetre (mm	10^{-3} m

In many problems of stress analysis these are not convenient units, and others, such as the centimetre (cm), which is 10^{-2} m, are more appropriate.

The unit of force, the newton (N), is the force required to give unit acceleration (ms^{-2}) to unit mass kg). In terms of newtons the common force units in the foot-pound-second-system (with g = 9.81 ms^{-2}) are

1 lb.wt = 4.45 newtons (N)

1 ton.wt = 9.96×10^3 newtons (N)

In general, decimal multiples in the SI system are taken in units of 10^3. The prefixes we make most use of are:

kilo	k	10^3
mega	M	10^6
giga	G	10^9

Thus:

1 ton.wt = 9.96 kN

The unit of force, the newton (N), is used for external loads and internal forces, such as shearing forces. Torques and bending of moments are expressed in newton-metres (Nm).

An important unit in the strength of materials and structures is stress. In the foot-pound-second system, stresses are commonly expressed in lb.wt/in^2, and tons/in^2. In the SI system these take the values:

$$1\ \text{lb.wt/in}^2 = 6.89 \times 103\ \text{N/m}^2 = 6.89\ \text{kN/m}^2$$

$$1\ \text{ton.wt/in}^2 = 15.42 \times 106\ \text{N/m}^2 = 15.42\ \text{MN/m}^2$$

Yield stresses of the common metallic materials are in the range:

$$200\ \text{MN/m}^2 \text{ to } 750\ \text{MN/m}^2$$

Again, Young's modulus for steel becomes:

$$E_{\text{steel}} = 30 \times 106\ \text{lb.wt/in}^2 = 207\ \text{GN/m}^2$$

Thus, working and yield stresses will usually be expressed in MN/m^2 units, while Young's modulus will usually be given in GN/m^2 units.