CHAPTER 1

Introduction

In this era of computers, general-purpose structural analysis computer programs are available to the engineer. However, many structures are configured so that they are analyzed more accurately as structural members than as three-dimensional systems using a general-purpose computer program. For example, because of the geometry of a train freight car, with its relatively long length and its cross section, which is symmetric about a longitudinal axis, the modeling problem can be reduced from that of a three-dimensional structure to a one-dimensional longitudinal and a two-dimensional cross-sectional analysis. These two uncoupled analyses can be treated as structural member problems that can be solved with stress–strain formulas or simple member analyses. It is the purpose of this book to provide in compact form the formulas or the analysis procedure to treat such member problems.

This book should help meet the need for engineers to have simple, accurate, and comprehensive formulas for stress analysis. The tables permit a problem to be modeled realistically and to be solved accurately.

1.1 NOTATION

The notation used in the formulas is defined in each chapter. Certain symbols are common to several chapters. Occasionally, singularity functions are employed to assist in the concise expression of formulas,

$$< x - a >^n = \begin{cases} 0 & \text{if } x < a \\ (x-a)^n & \text{if } x \geq a \end{cases} \tag{1.1}$$

$$<x-a>^0 = \begin{cases} 0 & \text{if } x < a \\ 1 & \text{if } x \geq a \end{cases} \tag{1.2}$$

$$f\ <x-a> = \begin{cases} 0 & \text{if } x < a \\ f(x-a) & \text{if } x \geq a \end{cases} \tag{1.3}$$

where $f(x-a)$ is a function of $x-a$.

1.2 CONVERSION FACTORS

Some useful conversion factors are provided in Table 1-1.

1.3 SIGN CONVENTIONS AND CONSISTENT UNITS

The sign conventions for the formulas are always evident in that the given formula corresponds to the loading direction shown. An applied load in the opposite direction requires that the load be given a negative sign in the formula.

No units are assigned to any variables in the formulas. Any consistent units can be employed. Some examples of consistent units are listed in Table 1-2.

1.4 SI UNITS

The International System (SI) of units is described in Table 1-3, where useful prefixes are provided. Some factors for conversion to SI units are shown in Table 1-4. Metric conversions for some commonly occurring variables are given in Table 1-5 along with some rounded-off figures that may be easy to remember. These are referred to as *recognition figures* and can be useful in quick calculations. Table 1-6 is similar to Table 1-5 but deals with conversions to the U.S. Customary System.

1.5 TYPICAL DESIGN LOADS AND STRESSES

Table 1-7 provides several typical design loads as well as values of material constants and allowable stresses.

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Tables

TABLE 1-1 CONVERSION FACTORS

Multiply:	By:	To Obtain:
acre	0.4047	ha
acre	4047	m^2
atm	29.92	inch of mercury (32°F)
atm	101,300	N/m^2 (Pa)
atm	14.70	lb/in^2 (psi)
Btu/h	12.96	ft-lb/min
cm/s	1.969	ft/min
cm/s (cm/s^2)	0.010	m/s (m/s^2)
cm/s	0.6	m/min
cm/s (cm/s^2)	0.0328	ft/s (ft/s^2)
cm/s (cm/s^2)	0.3937	in./s ($in./s^2$)
cm/s^2	0.00102	g
circular mil	0.7854	mil^2
cm^3/s	0.002119	ft^3/min
cup	0.24	L (liter)
ft^3/min	471.9	cm^3/s
ft^3/min	0.1247	gal/s
ft^3/min	0.4719	L/s
ft^3/s	448.8	gal/min
degree (degree/s)	0.01745	rad (rad/s)
degree	0.00273	rev
dyne	10^{-5}	N
dyne	0.000002248	lb
fathom	1.829	m
ft	0.3048	m
foot of water (60°F)	0.8843	inch of mercury (60°F)
foot of water (60°F)	2986	N/m^2
foot of water (60°F)	0.4331	lb/in^2
ft/min	0.508	cm/s
ft/min	0.01136	mi/h
ft/s (ft/s^2)	12	in./s ($in./s^2$)
ft/s (ft/s^2)	30.48	cm/s (cm/s^2)
ft/s (ft/s^2)	0.3048	m/s (m/s^2)
ft/s^2	0.0311	*g*
ft/s	1.097	km/h
ft/s	0.5925	knot
ft-lb/s	0.07716	Btu/min
ft-lb	1.356	N · m
fluid ounce	29.57	mL
g (acceleration of gravity at sea level)	32.16	ft/s^2
g	386	$in./s^2$
g	980	cm/s^2
g	9.80	m/s^2

TABLE 1-1 (continued) CONVERSION FACTORS

Multiply:	By:	To Obtain:
gal	3.8	L
gallon of water (60°F)	8.345	pound of water (60°F)
gal/s	8.021	ft^3/min
gal/s	227.1	L/min
g	980.7	dyne
g/cm^3	9807	N/m^3
g/cm^2	98.07	N/m^2
ha	2.471	acre
ha	10^4	m^2
hp	1.014	hp (metric)
hp (metric)	0.9863	hp (horsepower)
Hz	1	cycle/s, rev/s
Hz	6.283	rad/s
Hz	360	degree/s
in.	0.0254	m
inch of mercury (32°F)	0.03342	atm
inch of mercury (60°F)	1.131	foot of water (60°F)
inch of mercury (60°F)	3376	N/m^2
inch of mercury (60°F)	0.4898	lb/in^2
inch of water (60°F)	0.03609	lb/in^2
in./s (in./s^2)	0.0833	ft/s (ft/s^2)
in./s (in./s^2)	2.540	cm/s (cm/s^2)
in./s (in./s^2)	0.0254	m/s (m/s^2)
in./s^2	0.00259	*g* (acceleration of gravity)
kg	9.807	N
kg	0.6852177	slug
km/h	0.9113	ft/s
knot	1.688	ft/s
knot	1.151	mi/h
L	2.1134	pint
L	1.0567	quart
L	0.2642	gal
L/min	0.004403	gal/s
mL	0.0338	fluid ounce
m	0.1988	rod
m/min	1.667	cm/s
m/s (m/s^2)	3.28	ft/s (ft/s^2)
m/s (m/s^2)	39.37	in./s (in./s^2)
m/s (m/s^2)	100	cm/s (cm/s^2)
m/s	2.2369	mi/h
m/s^2	0.102	*g* (acceleration of gravity)
mil	0.001	in.
mil^2	1.273	circular mil
mi/h	88.0	ft/min

TABLE 1-1 (continued) CONVERSION FACTORS

Multiply:	By:	To Obtain:
mi/h	0.8690	knot
mi/h	0.477	m/s
N/m^2	9.872×10^{-6}	atm
N/m^2	3.349×10^{-4}	foot of water (60°F)
oz (avoirdupois)	0.9115	oz (troy)
oz (troy)	1.097	oz (avoirdupois)
oz (troy)	0.06857	lb (avoirdupois)
pint	0.4732	L
lb	4.448	N
lb (mass)	0.4535	kg
lb (avoirdupois)	14.58	oz (troy)
lb (avoirdupois)	0.031081	slug
pound of water (60°F)	0.01603	ft^3
pound of water (60°F)	0.1199	gal
lb/in^2	0.06805	atm
lb/in^2	2.309	foot of water (60°F)
lb/in^2	6895	N/m^2
lb/in^2	2.042	inch of mercury (60°F)
lb/in^2	27.71	inch of water (60°F)
quart	0.9463	L
rad (rad/s)	57.30	degree (degree/s)
rad/s	0.1592	rev/s or Hz
rad/s	9.549	rpm
rev (revolution)	6.283	rad
rev/s or Hz (rev/s^2)	6.283	rad/s (rad/s^2)
rev/s or Hz	360	degree/s
rpm	0.1047	rad/s
rpm	6	degree/s
rod	5.029	m
slug	14.5939	kg
slug	32.1740	lb (avoirdupois)
T(°C)	$T(°F) = \frac{9}{5}T(°C) + 32$	T(°F)
ton	2000	lb
ton (metric)	1000	kg

TABLE 1-2 CONSISTENT UNITS

Quantity	U.S. Customary (foot)	Old Metric (meter)	International Metric (SI) (meter)
Length	ft	cm	m
Force and weight, W	lb	kg	N
Time	s	s	s
Angle	rad	rad	rad
Moment of inertia	ft^4	cm^4	m^4
Mass, $= W/g$	lb-s^2/ft (slug)	kg-s^2/cm	kg
Area	ft^2	cm^2	m^2
Mass moment of inertia	lb-s^2-ft	kg-s^2-cm	kg · m^2
Moment	lb-ft	kg-cm	N · m
Volume	ft^3	cm^3	m^3
Mass density	lb-s^2/ft^4	kg-s^2/cm^4	kg/m^3
Stiffness of linear spring	lb/ft	kg/cm	N/m
Stiffness of rotary spring	lb-ft/rad	kg-cm/rad	N · m/rad
Torque	lb-ft	kg-cm	N · m
Stiffness of torsional spring	lb-ft/rad	kg-cm/rad	N · m/rad
Stress or pressure	lb/ft^2	kg/cm^2	N/m^2 (Pa)

TABLE 1-3 INTERNATIONAL SYSTEM (SI) OF UNITS

Quantity	Name of Unit	SI Symbol	Unit Formula
	Units Pertinent to Structural Mechanics		
BASE			
Length	meter	m	
Mass	kilogram	kg	
Time	second	s	
Temperature	kelvin	K	
DERIVED			
Area	square meter	m^2	
Volume	cubic meter	m^3	
Force	newton	N	$kg \cdot m/s^2$
Stress, pressure	pascal	Pa	N/m^2
Work, energy	joule	J	$N \cdot m$
Power	watt	W	$N \cdot m/s$
SUPPLEMENTARY			
Plane angle	radian	rad	

Prefix	Symbol	Multiplication Factor	Exponential Form
		Preferred Prefixes	
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^{9}
mega	M	1 000 000	10^{6}
kilo	k	1 000	10^{3}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
		Not Recommended for Common Use[a]	
hecto	h	100	10^{2}
deka	da	10	10^{1}
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}

[a] Except when expressing area and volume. The prefixes c and d can also be used with properties of certain standard structural sections.

TABLE 1-4 CONVERSION TO SI UNITS

Example: To convert from psi to pascal, multiply by $6.894\,757 \times 10^3$. Then 1000 psi is 6.894 757 MPa.

To Convert from:	To:	Multiply by:
	Acceleration	
ft/s^2	m/s^2	0.3048
ft/s^2	cm/s^2	30.48
g	m/s^2	9.80
g	cm/s^2	980
$in./s^2$	m/s^2	0.0254
$in./s^2$	cm/s^2	2.540
	Area	
ft^2	m^2	9.290304×10^{-2}
in^2	m^2	6.451600×10^{-4}
	Energy and Work	
Btu	J	1.055056×10^3
cal	J	4.186800
erg	J	1.000000×10^{-7}
ft-lb	J	1.355818
W-s	J	1.000000
	Energy/Area (Toughness)	
erg/cm^2	J/m^2	1.000000×10^{-3}
$ft\text{-}lb/in^2$	J/m^2	2.101522×10^3
$in.\text{-}lb/in^2$	J/m^2	1.751268×10^2
	Force	
dyne	N	1.000000×10^{-5}
kg	N	9.806650
lb	N	4.448222
poundal	N	1.382550×10^{-1}
	Length	
Å	m	1.000000×10^{-10}
ft	m	3.048000×10^{-1}
in.	m	2.540000×10^{-2}
mi (U.S. nautical)	m	1.852000×10^3
mi (U.S. statute)	m	1.609344×10^3
yd	m	0.9144

TABLE 1-4 (continued) CONVERSION TO SI UNITS

To Convert from:	To:	Multiply by:
	Mass	
grain	kg	6.479891×10^{-5}
lb (mass)	kg	4.535924×10^{-1}
slug	kg	14.59390
	Mass per Volume (Density)	
g/cm^3	kg/m^3	1.000000×10^{3}
lb (mass)/in^3	kg/m^3	2.767990×10^{4}
slug/ft^3	kg/m^3	5.153788×10^{2}
	Power	
Btu/h	W	2.930711×10^{-1}
ft-lb/s	W	1.355818
hp	W	7.456999×10^{2}
	Pressure or Stress	
atm (760 torr)	Pa	1.013250×10^{5}
bar	Pa	1.000000×10^{5}
centimeter of mercury (0°C)	Pa	1.33322×10^{3}
centimeter of water (4°C)	Pa	98.0638
dyne/cm^2	Pa	1.000000×10^{-1}
kg/cm^2	Pa	9.806650×10^{4}
kg/mm^2	Pa	9.806650×10^{6}
N/m^2	Pa	1.000000
lb/in^2 (psi)	Pa	6.894757×10^{3}
torr (mmHg, 0°C)	Pa	1.33322×10^{2}
	Temperature	
degree Celsius (°C)	K (kelvin)	$T(\mathrm{K}) = T(^\circ\mathrm{C}) + 273.15$
degree Fahrenheit (°F)	K	$T(\mathrm{K}) = \dfrac{T(^\circ\mathrm{F}) + 459.67}{1.8}$
°F	°C	$T(^\circ\mathrm{C}) = \frac{5}{9}T(^\circ\mathrm{F}) - 32$
	Time	
day	s	8.640000×10^{4}
hour	s	3.600000×10^{3}
year	s	3.153600×10^{7}

TABLE 1-4 (continued) CONVERSION TO SI UNITS

To Convert from:	To:	Multiply by:
	Velocity	
ft/min	m/s	5.080000×10^{-3}
ft/s	m/s	0.3048
ft/s	cm/s	30.48
in./s	m/s	0.0254
in./s	cm/s	2.540
km/h	m/s	2.777778×10^{-1}
mi/h	m/s	4.470400×10^{-1}
	Viscosity	
cP (centipoise)	Pa · s	1.000000×10^{-3}
P (poise)	Pa · s	1.000000×10^{-1}
lb-s/ft^2	Pa · s	47.88026
	Volume	
barrel (oil, 42 U.S. gal)	m^3	1.589873×10^{-1}
fluid ounce	m^3	2.957353×10^{-5}
ft^3	m^3	2.831685×10^{-2}
gal (Imperial liquid)	m^3	4.546122×10^{-3}
gal (U.S. liquid)	m^3	3.785412×10^{-3}
in^3	m^3	1.638706×10^{-5}
L	m^3	1.000000×10^{-3}
	Special Conversion	
ksi-$\sqrt{\text{in.}}$	MPa · $\sqrt{\text{m}}$	1.098843

TABLE 1-5 COMMON CONVERSION FACTORS AND SI RECOGNITION FIGURES

Units		
U.S. Customary System (USCS)	International System (SI)	Suggested SI Recognition Figure
	Length	
1 in.	25.4 mm	25 mm
1 in.	2.54 cm	2.5 cm
10 in.	254 mm	250 mm
1 ft	0.3048 m	0.3 m
10 ft	3.048 m	3 m
1 mi	1609 m	1.6 km
1 yd	0.9144 m	0.9 m
	Area	
1 acre	4046.86 m^2	4050 m^2
1 acre	0.4047 ha	0.4 ha
1 ft^2	0.09290 m^2	0.1 m^2
1 ha	10^4 m^2	10^4 m^2
1 in^2	645.16 mm^2	645 mm^2
1 mi^2	2.59 km^2	2.6 km^2
1 yd^2	0.836 m^2	0.85 m^2
	Temperature	
32°F	273 K	0°C (270 K), 1K = 1°C; use of °C is permissible in SI
	Velocity	
1 ft/min	0.00508 m/s	5 mm/s
1 mi/h	1.609 km/h = 0.447 m/s	1.6 km/h 0.45 m/s ≈ 1/2 m/s
	Power	
1 hp (550 ft-lb/s)	745.7 W	0.75 kW
ft-lb/s	1.3558 W	1.4 W
	Volume	
1 ft^3	0.0283 m^3	0.03 m^3
1 yd^3	0.765 m^3	0.8 m^3
1 gal	0.003785 m^3	0.004 m^3

TABLE 1-5 (continued) COMMON CONVERSION FACTORS AND SI RECOGNITION FIGURES

Units		
U.S. Customary System (USCS)	International System (SI)	Suggested SI Recognition Figure
	Pressure	
1 psf	47.88 Pa	48 Pa
1 psi	6.894 kPa	6.9 kPa
	Weight or Force	
1 lb (force)	4.448 N	4.5 N
1 kip (1000 lb)	4.448 kN	4.5 kN
	Line Loads	
1000 lb/in.	175.13 kN/m	175 kN/m
1000 lb/ft	14.59 kN/m	15 kN/m
	Mass	
1 lb (mass)	0.4536 kg	0.5 kg
1 slug	14.5939 kg	15 kg
1 ton	907.185 kg	907 kg
	Stress or Pressure	
1 psi (lb/in^2)	6.895 kN/m^2 (kPa)	7 kN/m^2
1000 psi (1 ksi)	6.895 MN/m^2 (MPa)	7 MN/m^2
1 psf	47.88 N/m^2 (Pa)	48 N/m^2
1 atm (760 torr)	1.01325×10^5 Pa	10^5 Pa

TABLE 1-6 COMMON CONVERSION FACTORS AND U.S. CUSTOMARY RECOGNITION FIGURES

Units		
International System (SI)	U.S. Customary System (USCS)	Suggested U.S. Customary Recognition Figure
1 mm	0.03937 in.	0.04 in.
1 cm	0.3937 in.	0.4 in.
1 m	3.2808 ft	3.3 ft
	= 1.0936 yd	1.1 yd
1 km	0.621371 mi	0.62 mi
1 m^2	10.7639 ft^2	10.8 ft^2
1 m^3	35.3147 ft^3	35 ft^3
1 km^2	0.386102 mi^2	0.4 mi^2
	= 247.105 acres	250 acres
	= 100 ha	100 ha
1 m/s	2.23694 mi/h	2.25 mi/h

TABLE 1-7 TYPICAL VALUES OF DESIGN LOADS, MATERIAL PROPERTIES, AND ALLOWABLE STRESSES

Quantity	U.S. Customary System (USCS)	International System (SI)
	Design Loads	
Wind pressure	30 lb/ft^2	1.4 kN/m^2 (kPa)
Snow		
Moderate climate		
Flat	20 lb/ft^2	960 N/m^2 (Pa)
45° slope	10 lb/ft^2	480 N/m^2 (Pa)
Cold Climate		
Flat	40 lb/ft^2	2 kN/m^2 (kPa)
45° slope	10 lb/ft^2	480 N/m^2 (Pa)
	Allowable Loads	
Soil		
Ordinary clay and sand mixture	2–3 tons/ft^2	200–300 kPa
Hard clay and firm coarse sand	4–6 tons/ft^2	400–600 kPa
Bedrock	> 15 tons/ft^2	> 1400 kPa
Wood, yellow pine	1600 psi	11 MPa
Concrete	1000 psi	7 MPa
Steel	20,000 psi	140 MPa
	Moduli of Elasticity	
Wood, yellow pine	1.6×10^6 psi	11 GN/m^2 (GPa)
Aluminum	10.1×10^6 psi	70 GPa
Concrete	2×10^6 psi	14 GPa
Steel	30×10^6 psi	207 GPa
	Weights	
Steel	490 lb/ft^3	76.98 kN/m^3
Wood	40 lb/ft^3	6.3 kN/m^3
Concrete	150 lb/ft^3	24 kN/m^3
Water	62.4 lb/ft^3	9.804 kN/m^3
Aluminum	169.3 lb/ft^3	26.60 kN/m^3
Snow		
Freshly fallen	5 lb/ft^3	800 N/m^3
Packed	12 lb/ft^3	1.9 kN/m^3
Wet	50 lb/ft^3	7.9 kN/m^3
Sand		
Dry	100 lb/ft^3	15.7 kN/m^3
Wet	115 lb/ft^3	18.1 kN/m^3

TABLE 1-7 (continued) TYPICAL VALUES OF DESIGN LOADS, MATERIAL PROPERTIES, AND ALLOWABLE STRESSES

	Density (Mass)	
Water	0.9356×10^{-4} lb-s^2/in^4	1000 kg/m^3
Steel	7.3326×10^{-4} lb-s^2/in^4	7835.9 kg/m^3
	Acceleration of Gravity (g)	
	32.174 ft/s^2 (386.087 in./s^2)	9.8066 m/s^2
	Coefficients of Friction	
Iron on stone	0.5	
Timber on stone	0.4	
Timber on timber	0.3	
Brick on brick	0.7	