DESIGNING FOR STRENGTH

By the same author

A Background to Engineering Design

Systematic Errors in Engineering Experiments

Designing for Strength

Principles and Practical Aspects of Stress
Analysis for Engineers and Students

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PREFACE

This book is intended to cover strength calculations for general design purposes at a standard suitable for most three-year engineering degree courses, but omitting academic fracture mechanics, soil mechanics, reinforced concrete, advanced civil engineering, aircraft structures and plasticity. The basic plan is to explain the main stress forms first, leading on to a critical examination of material tests and properties. Then before proceeding to applications it is deemed necessary to present a substantial summary of stress concentration data. The applications aspect is treated first in fairly fundamental terms, followed by aspects and procedures specific to structural steelwork and pressure vessels. It concludes with case studies, further discussion of earlier items, some useful tables, derivations and graphical methods, etc. Within some of the chapters the natural break-points between elementary and advanced work have been indicated. Most readers will wish to take a quick look at the advanced sections but defer detailed study of the arguments until a second work-through.

A large amount of important recent material and little-known older material is included in suitably condensed form, with references to readily available publications, as may be seen from the list. These references have all been closely studied by the author. An unusual feature is the inclusion of buckling as a major stress form. Most books leave this to the end as if it were a minor academic refinement instead of a major design criterion. Designers should welcome the frequent reminders to consider the highest equivalent stress, out-of-plane shear and Poisson contraction.

Sections containing particularly recent or rarely seen material of practical relevance are 2.4.2, 3.4.3, 4.4, 4.5, 5.4, 6.4.2, and 7.6 (three supports), 7.8 to 7.10 particularly flange bending effects, 7.12, 8.3.4, 8.5, 9.3, 9.8 and 9.9.

In engineering science we often find that full-size work, analogue or small-scale experiments and calculations all give different results. Sometimes these can be tracked down to one of the following

- (1) genuine size effect, notably the difficulty of scaling object size and material grain size in the same ratio without altering some properties;
- (2) Poisson's ratio differences, notably in photoelastic three-dimensional work;
- (3) loading differences between specimens in testing machines and details within real structures;

(4) communication problems – many experiments and their logging are carried out by assistants rather than by the authors of the papers; this leaves room for misunderstandings, oversights and insufficient precautions against systematic errors;

(5) computing problems – many papers give the very basic equations and the conclusions without describing the routes between them; in computation it is often necessary to simplify the route and it is not always obvious what physical features have been concealed thereby.

It is always difficult to steer a middle course between long tedious explanations and too much brevity. In case the book is used without the benefit of teaching staff, the earlier parts are explained fairly fully. In the advanced sections it is assumed that the reader has also advanced in knowledge and familiarity with the material, so the explanations are more condensed in the interests of smoothness. The basic examples are set out in some detail to help in avoiding misunderstandings; advanced examples are treated more concisely, as befits more advanced students.

Bearing in mind that this is a degree-standard text with much new material, it is hoped that the presentation adopted will please most of the people most of the time.

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Special thanks are due to Alan Chidgey for a number of improvements in chapter 9, consisting of additional points, rectification of misleading impressions, etc.

NOTATION

<i>A</i>	cross-sectional area usually with subscript; axial length of flanges
<i>a</i>	general-purpose length notation
<i>B</i>	breadth
<i>b</i>	general-purpose length notation
<i>C</i>	speed of stress waves as specified locally; torsional stress constant (torque/ τ); spring constant D/d
<i>D, d</i>	diameters
<i>E</i>	Young's modulus
<i>E'</i>	wide-beam modulus $E/(1-\nu^2)$
<i>e</i>	extension, eccentricity of loading
<i>F</i>	force
<i>f</i>	frequency (spring surge); f_f = flexibility factor; f_s = stress factor (pipe bends)
<i>G</i>	modulus of rigidity
<i>g</i>	gravitational acceleration
<i>H</i>	height of beam section
<i>h</i>	general height; sag of catenary
<i>I</i>	second moment of area
<i>J</i>	polar moment
<i>K</i>	torsional stiffness constant for non-circular sections
<i>k</i>	radius of gyration, usually k_y or the lowest (oblique in angle sections), $k = \sqrt{(I/A)}$, also stiffeners or thermal conductivity
<i>L</i>	length, span of beam
<i>M</i>	bending moment; M_f = fixing moment; M_c = central moment; M_j = junction moment (corner moment)
<i>m</i>	coefficient used in flange theory
<i>N</i>	number of active turns in helical spring
<i>n</i>	end-fixing constant in Euler strut calculation
<i>P</i>	force, usually vertical point load; P_{ce} = critical elastic buckling load
<i>p</i>	fluid pressure; contact pressure; force per unit contact area
<i>Q</i>	force, usually horizontal
<i>R</i>	resilience, dx/dP ; reaction force; radius of curvature or large radius
<i>r</i>	radius
<i>S, s</i>	distance along a curve
<i>T</i>	torque; tension in catenary; thickness (larger of two thicknesses)
<i>t</i>	thickness; temperature

U	strain energy
V	volume
w	load per unit length
x, y	cartesian coordinates, defined locally if necessary
Z	section modulus, $I/y_{\max}$
z	defined locally as required
α	coefficient of linear thermal expansion mm/mm °C
Δ	deflection
ϵ, e	strain
θ	angle
ν	Poisson's ratio
ρ	density
σ	direct stress, usually tensile if positive (except when discussing buckling)
σ_y	yield stress except in sections 2.5, 2.6 and A.11 (defined locally as stress in y direction)
σ_{ce}	mean compressive stress when member is at critical elastic buckling load
σ_d	design stress (pressure vessels, chapter 9)
σ_r	radial stress
τ	shear stress; τ_{ce} = critical elastic stress for shear buckling of beam web
ϕ	shear angle, general angle if defined locally
ψ	angle
ω	angular velocity

SUMMARY OF USEFUL FORMULAE

Some are accurate, others approximate for quick-checking work.

I = second moment of area (moment of inertia) as used in bending equations

I/y , sometimes called Z = section modulus in bending (elastic) when $\sigma = M/Z$

J = polar moment as used in torsion formulae for circular shafts

J/r = torsional modulus convenient for finding stress when $\tau = \text{torque} \times r/J$

K , C are torsional constants for long non-circular bars, equivalent to J and J/r

$I = \frac{\pi D^4}{64}$	$J = \frac{\pi D^4}{32}$
Solid Rod	$Z = \frac{\pi D^3}{32}$	$\frac{J}{r} = \frac{\pi D^3}{16}$
$I \approx \frac{1}{3} D^3 t$	$J \approx \frac{2}{3} D^3 t$
Tube	$Z \approx \frac{2}{3} D^2 t$	$J/r \approx \frac{1}{4} D^2 t$
$I_x = \frac{BT^3}{12}$	$K = \frac{1}{3} BT^3 \left(1 - 0.63 \frac{T}{B} + 0.053 \frac{T^5}{B^5} \right)$
	$Z_x = \frac{BT^2}{6}$	$C = \frac{B^2 T^2}{3B + 1.8T}$
$I_x \approx 0.55 B t_f H^2$	$K \approx \frac{2}{3} B t_f^3 \text{ if } t_w \ll B$
	$Z_x \approx 1.1 B t_f H$	$C \approx \frac{2}{3} B t_f^2$
$I_x = \frac{BH^3 - bh^3}{12}$	$K \approx \frac{2B^2 H^2 t}{B + H + 7t}$
	$Z \approx 1.2 B t_f H$	$C \approx \frac{8B^2 H^2 t}{(B + H)^2}$

Figure P.1

SELECTED BENDING MOMENT FORMULAE FROM CHAPTER 7

Figure P.2