INTRODUCTION

This text is the suitably revised and extended third edition of the highly successful text initially published in 1977 and intended to cover the material normally contained in degree and honours degree courses in mechanics of materials and in courses leading to exemption from the academic requirements of the Engineering Council. It should also serve as a valuable reference medium for industry and for post-graduate courses. Published in two volumes, the text should also prove valuable for students studying mechanical science, stress analysis, solid mechanics or similar modules on Higher Certificate and Higher Diploma courses in the UK or overseas and for appropriate NVQ* programmes.

The study of mechanics of materials is the study of the behaviour of solid bodies under load. The way in which they react to applied forces, the deflections resulting and the stresses and strains set up within the bodies, are all considered in an attempt to provide sufficient knowledge to enable any component to be designed such that it will not fail within its service life. Typical components considered in detail in this volume include beams, shafts, cylinders, struts, diaphragms and springs and, in most simple loading cases, theoretical expressions are derived to cover the mechanical behaviour of these components. Because of the reliance of such expressions on certain basic assumptions, the text also includes a chapter devoted to the important experimental stress and strain measurement techniques in use today with recommendations for further reading.

Each chapter of the text contains a summary of essential formulae which are developed within the chapter and a large number of worked examples. The examples have been selected to provide progression in terms of complexity of problem and to illustrate the logical way in which the solution to a difficult problem can be developed. Graphical solutions have been introduced where appropriate. In order to provide clarity of working in the worked examples there is inevitably more detailed explanation of individual steps than would be expected in the model answer to an examination problem.

All chapters (with the exception of Chapter 16) conclude with an extensive list of problems for solution of students together with answers. These have been collected from various sources and include questions from past examination papers in imperial units which have been converted to the equivalent SI values. Each problem is graded according to its degree of difficulty as follows:

- A Relatively easy problem of an introductory nature.
- A/B Generally suitable for first-year studies.
- B Generally suitable for second or third-year studies.
- C More difficult problems generally suitable for third year studies.

*National Vocational Qualifications

Gratitude is expressed to the following examination boards, universities and colleges who have kindly given permission for questions to be reproduced:

City University	C.U.
East Midland Educational Union	E.M.E.U.
Engineering Institutions Examination	E.I.E. and C.E.I.
Institution of Mechanical Engineers	I.Mech.E.
Institution of Structural Engineers	I.Struct.E.
Union of Educational Institutions	U.E.I.
Union of Lancashire and Cheshire Institues	U.L.C.I.
University of Birmingham	U.Birm.
University of London	U.L.

Both volumes of the text together contain 150 worked examples and more than 500 problems for solution, and whilst it is hoped that no errors are present it is perhaps inevitable that some errors will be detected. In this event any comment, criticism or correction will be gratefully acknowledged.

The symbols and abbreviations throughout the text are in accordance with the latest recommendations of BS 1991 and PD 5686†.

As mentioned above, graphical methods of solution have been introduced where appropriate since it is the author's experience that these are more readily accepted and understood by students than some of the more involved analytical procedures; substantial time saving can also result. Extensive use has also been made of diagrams throughout the text since in the words of the old adage "a single diagram is worth 1000 words".

Finally, the author is indebted to all those who have assisted in the production of this volume; to Professor H. G. Hopkins, Mr R. Brettell, Mr R. J. Phelps for their work associated with the first edition and to Dr A. S. Tooth[1], Dr N. Walker[2], Mr R. Winters[2] for their contributions to the second edition and to Dr M. Daniels for the extended treatment of the Finite Element Method which is the major change in this third edition. Thanks also go to the publishers for their advice and assistance, especially in the preparation of the diagrams and editing, to Dr. C. C. Perry (USA) for his most valuable critique of the first edition, and to Mrs J. Beard and Miss S. Benzing for typing the manuscript.

E. J. HEARN

† Relevant Standards for use in Great Britain: BS 1991; PD 5686: Other useful SI Guides: *The International System of Units*, N.P.L. Ministry of Technology, H.M.S.O. (Britain). Mechty, *The International System of Units (Physical Constants and Conversion Factors)*, NASA, No SP-7012, 3rd edn. 1973 (U.S.A.) *Metric Practice Guide*, A.S.T.M. Standard E380-72 (U.S.A.).

1. §23.27. Dr. A. S. Tooth, University of Strathclyde, Glasgow.
2. §26. D. N. Walker and Mr. R. Winters, City of Birmingham Polytechnic.
3. §24.4 Dr M. M. Daniels, University of Central England.

NOTATION

Quantity	*Symbol*	*SI Unit*
Angle	$\alpha, \beta, \theta, \gamma, \phi$	rad (radian)
Length	L, s	m (metre) mm (millimetre)
Area	A	m^2
Volume	V	m^3
Time	t	s (second)
Angular velocity	ω	rad/s
Velocity	v	m/s
Weight	W	N (newton)
Mass	m	kg (kilogram)
Density	ρ	kg/m^3
Force	F or P or W	N
Moment	M	N m
Pressure	P	Pa (Pascal) N/m^2 bar ($= 10^5\ N/m^2$)
Stress	σ	N/m^2
Strain	ε	—
Shear stress	τ	N/m^2
Shear strain	γ	—
Young's modulus	E	N/m^2
Shear modulus	G	N/m^2
Bulk modulus	K	N/m^2
Poisson's ratio	v	—
Modular ratio	m	—
Power	—	W (watt)
Coefficient of linear expansion	α	m/m °C
Coefficient of friction	μ	—
Second moment of area	I	m^4
Polar moment of area	J	m^4
Product moment of area	I_{xy}	m^4
Temperature	T	°C
Direction cosines	l, m, n	—
Principal stresses	$\sigma_1, \sigma_2, \sigma_3$	N/m^2
Principal strains	$\varepsilon_1, \varepsilon_2, \varepsilon_3$	—
Maximum shear stress	τ_{max}	N/m^2
Octahedral stress	σ_{oct}	N/m^2

Quantity	*Symbol*	*SI Unit*
Deviatoric stress	σ'	N/m^2
Deviatoric strain	ε'	—
Hydrostatic or mean stress	$\bar{\sigma}$	N/m^2
Volumetric strain	Δ	—
Stress concentration factor	K	—
Strain energy	U	J
Displacement	δ	m
Deflection	δ or y	m
Radius of curvature	ρ	m
Photoelastic material fringe value	f	N/m^2/fringe/m
Number of fringes	n	—
Body force stress	X, Y, Z F_R, F_θ, F_Z	N/m^3
Radius of gyration	k	m
Slenderness ratio	L/k	—
Gravitational acceleration	g	m/s^2
Cartesian coordinates	x, y, z	—
Cylindrical coordinates	r, θ, z	—
Eccentricity	e	m
Number of coils or leaves of spring	n	—
Equivalent J or effective polar moment of area	J_{eq} or J_E	m^4
Autofrettage pressure	P_A	N/m^2 or bar
Radius of elastic–plastic interface	R_p	m
Thick cylinder radius ratio R_2/R_1	K	—
Ratio elastic–plastic interface radius to internal radius of thick cylinder R_p/R_1	m	—
Resultant stress on oblique plane	p_n	N/m^2
Normal stress on oblique plane	σ_n	N/m^2
Shear stress on oblique plane	τ_n	N/m^2
Direction cosines of plane	l, m, n	—
Direction cosines of line of action of resultant stress	l', m', n'	—
Direction cosines of line of action of shear stress	l_s, m_s, n_s	—
Components of resultant stress on oblique plane	p_{xn}, p_{yn}, p_{zn}	N/m^2
Shear stress in any direction ϕ on oblique plane	τ_ϕ	N/m^2
Invariants of stress	I_1 I_2 I_3	N/m^2 $(N/m^2)^2$ $(N/m^2)^3$
Invariants of reduced stresses	J_1, J_2, J_3	
Airy stress function	ϕ	—

Quantity	*Symbol*	*SI Unit*
'Operator' for Airy stress function biharmonic equation	∇	—
Strain rate	$\dot{\varepsilon}$	s^{-1}
Coefficient of viscosity	η	
Retardation time (creep strain recovery)	t'	s
Relaxation time (creep stress relaxation)	t''	s
Creep contraction or lateral strain ratio	$J(t)$	—
Maximum contact pressure (Hertz)	p_0	N/m^2
Contact formulae constant	Δ	$(N/m^2)^{-1}$
Contact area semi-axes	a, b	m
Maximum contact stress	$\sigma_c = -p_0$	N/m^2
Spur gear contact formula constant	K	N/m^2
Helical gear profile contact ratio	m_p	—
Elastic stress concentration factor	K_t	—
Fatigue stress concentration factor	K_f	—
Plastic flow stress concentration factor	K_p	—
Shear stress concentration factor	Kt_s	—
Endurance limit for *n* cycles of load	S_n	N/m^2
Notch sensitivity factor	q	—
Fatigue notch factor	K_f	—
Strain concentration factor	K_ε	—
Griffith's critical strain energy release	G_c	
Surface energy of crack face	γ	N m
Plate thickness	B	m
Strain energy	U	N m
Compliance	C	$m\,N^{-1}$
Fracture stress	σ_f	N/m^2
Stress Intensity Factor	K or K_I	$N/m^{3/2}$
Compliance function	Y	—
Plastic zone dimension	r_p	m
Critical stress intensity factor	K_{IC}	$N/m^{3/2}$
"J" Integral	J	
Fatigue crack dimension	a	m
Coefficients of Paris Erdogan law	C, m	—
Fatigue stress range	σ_r	N/m^2
Fatigue mean stress	σ_m	N/m^2
Fatigue stress amplitude	σ_a	N/m^2
Fatigue stress ratio	R_s	—
Cycles to failure	N_f	—
Fatigue strength for *N* cycles	σ_N	N/m^2
Tensile strength	σ_{TS}	N/m^2
Factor of safety	F	—

Quantity	*Symbol*	*SI Unit*
Elastic strain range	$\Delta\varepsilon_e$	—
Plastic strain range	$\Delta\varepsilon_p$	—
Total strain range	$\Delta\varepsilon_t$	—
Ductility	D	
Secondary creep rate	ε_s^0	s^{-1}
Activation energy	H	N m
Universal Gas Constant	R	J/kg K
Absolute temperature	T	°K
Arrhenius equation constant	A	—
Larson–Miller creep parameter	P_1	
Sherby–Dorn creep parameter	P_2	
Manson–Haford creep parameter	P_3	
Initial stress	σ_i	N/m^2
Time to rupture	t_r	s
Constants of power law equation	β, n	—