

# MECHANICS OF STRUCTURES

## Vol. I

[ A TEXT-BOOK FOR ENGINEERING STUDENTS ]

by

S. B. JUNNARKAR

M.B.E., B.A., B.Sc. (Hons.), (Engg.), London

*Formerly,*

Principal, Birla Vishvakarma Mahavidyalaya  
Vallabh Vidyanagar

and N.E.D. Engineering College, Karachi  
Sometime, Dean of the Faculty of Technology including  
Engineering, Maharaja Sayajirao University of Baroda

[ WITH 450 DIAGRAMS, NUMEROUS ILLUSTRATIVE PROBLEMS AND EXERCISES ]

[ NINETEENTH EDITION ]



CHAROTAR PUBLISHING HOUSE  
OPPOSITE AMUL DAIRY, COURT ROAD  
ANAND 388001 INDIA

1987

# MECHANICS OF STRUCTURES

Vol. I

[ A TEXT-BOOK FOR ENGINEERING STUDENTS ]

S. B. JUNNARKAR

M.B.E., B.A., B.Sc.(Hons.), (Engg.), London

*Formerly,*

Principal, Birla Vishvakarma Mahavidyalaya

Vallabh Vidyanagar

and N.E.D. Engineering College, Karachi,

Sometime, Dean of the Faculty of Technology including  
Engineering, Maharaja Sayajirao University of Baroda

[ WITH 450 DIAGRAMS, NUMEROUS ILLUSTRATIVE PROBLEMS AND EXERCISES ]

[NINETEENTH EDITION]



CHAROTAR PUBLISHING HOUSE  
OPPOSITE AMUL DAIRY, COURT ROAD  
ANAND 388 001 (W. RLY.) INDIA

1987

# MECHANICS OF STRUCTURES

## VOL. I

First published	: 1952
Second edition	: 1953
Third edition	: 1955
Fourth edition	: 1957
Fifth edition	: 1958
Sixth edition	: 1959
Seventh edition	: 1960
Eighth edition	: 1961
Ninth edition	: 1962
Tenth edition	: 1963
Eleventh edition	: 1964
Twelfth edition	: 1965
Thirteenth edition	: 1966
Fourteenth edition	: 1968
Fifteenth edition	: 1972
Sixteenth edition	: 1975
Seventeenth edition	: 1981
Eighteenth edition	: 1983
Nineteenth edition	: 1987

All rights reserved by the publishers.

This book or parts thereof may not be reproduced in any form or translated without the permission of the publishers.

### SOLE DISTRIBUTORS:

**CHAROTAR PUBLISHING HOUSE**

Opposite Amul Dairy, Court Road

ANAND 388 001 (W. Rly.) India

Published by P. R. Patel, Pradeep Publications,  
Opposite Amul Dairy, Court Road, Anand 388 001  
Printed by S. Abril S.J. at the Anand Press, Gamdi, Anand.

# MECHANICS OF STRUCTURES

## VOL. I



[ IN MKS UNITS AND SI UNITS ]

**BOOKS**

*by*

**S. B. JUNNARKAR**

---

**ELEMENTS OF APPLIED MECHANICS**

⊙

**KEY TO APPLIED MECHANICS**

⊙

**MECHANICS OF STRUCTURES**

**Vol. I**

⊙

**KEY TO MECHANICS OF STRUCTURES**

**Vol. I**

⊙

**MECHANICS OF STRUCTURES**

**Vol. II**

[Including Theory and Design of Structures]

⊙

**KEY TO MECHANICS OF STRUCTURES**

**Vol. II**

⊙

**MECHANICS OF STRUCTURES**

**Vol. III**

[Including Advanced Theory of Structures]

⊙

**ENGINEERING MECHANICS**

[For Diploma Students]

⊙

**SI UNITS**

To  
*My Students*

## PREFACE

The approach of an average student to the study of this fascinating subject is, somehow, one of unreasoning dread. An attempt has been made in this book to present the principles as simply as possible and to illustrate them with a variety of worked-out examples. A student who goes through the text and takes the trouble of solving the exercises at the end of each chapter will, it is hoped, be better equipped to study with profit the many excellent standard works on the subject.

I am particularly grateful to Mr. R. S. Dighe, B.E., A.M.I.E., of the Faculty of Technology, for undertaking the arduous and monotonous task of checking up all numerical work, which he has done cheerfully. My thanks are due to Mr. T. N. Joshi, B.Sc. (Eng.), of the Faculty of Technology for making all the sketches required for the blocks which were made by Mr. N. B. Joglekar of the Faculty of Fine Arts, to whom I am grateful.

I am specially indebted to Mr. R. C. Patel of the Charotar Book Stall, Anand, and to Mr. V. B. Priyani, B.E., A.M.I.E., of Birla Vishvakarma Mahavidyalaya, who spared no efforts in the tedious task of correcting the proofs, and to Mr. K. A. Damle, B.Sc., Librarian of the Faculty of Technology, who checked the final proofs. My thanks are due to Mr. B. G. Marathe, also of the Faculty of Technology, who took considerable pains in preparing the typescript of the text.

I am indebted to the Syndics of the Universities of Cambridge, London and Bombay, for their kind permission to make use of a few problems set at their University Examinations.

I should like to express my sincere appreciation of the great care and trouble which have been taken by the Anand Press, Anand, in the printing and get-up of this book.

In spite of all the pains taken by Mr. R. S. Dighe, it is possible that some errors have escaped our attention. I shall be grateful if they are brought to my notice.

*Faculty of Technology*  
*including Engineering*  
Baroda  
May, 1952

S. B. JUNNARKAR

## SIXTH EDITION

In this revised edition, the metric system of units entirely replaces the F.P.S. system used in the earlier texts. The subject matter has been revised wherever necessary to make it up-to-date. Some typical illustrative examples have also been added.

Poona  
October, 1967

S. B. J.

## SEVENTH EDITION

In this enlarged edition, the text has been revised and brought up-to-date. Many of the old stereo-typed examples have been replaced by fresh ones based on the latest papers set at University and professional examinations.

Appendices on Mohr circle, Unsymmetrical beam-section, Conjugate beam method, Welded joints, etc. have been added.

The reader will notice that the symbols used for Bending Moments, Torques, etc. are kg cm, kg m or t m, instead of cm kg, m kg, m t used hitherto — for reasons stated in the Note on Units at the end of the book.

In the Appendix on SI Units, besides the standard stress-unit  $\text{N/m}^2$ , its approved multiple  $\text{MN/m}^2$ , which, in effect, is  $\text{N/mm}^2$ , has been introduced. A good number of examples in SI units have also been included in the main text at the end of some chapters.

It is hoped that with these additions, the book in its enlarged and revised form, will be found more useful.

Poona  
January, 1972

S. B. J.

## EIGHTH EDITION

In this edition, a chapter on the method of "Tension Coefficients" has been added, as it forms a complement to the study of "Stresses in Frames."

More examples in SI units have been added at the ends of chapters. The appendix on SI units has been revised.

468 C/2 Ganeshkhind Road,  
Poona-16  
October, 1974

S. B. J.



## SEVENTEENTH EDITION

This edition has been thoroughly revised and enlarged. Appendices A—E added in the earlier editions are replaced by adding five new chapters on Unsymmetrical Bending, Conjugate Beam Method, Welded Joints, Shear Centre, Bending Stresses in Curved Bars. This edition covers a sufficiently wide range of topics which are included in the syllabi of the degree and diploma courses. It also includes several illustrative examples, in both the MKS and SI units, based on the types set at the various University examinations in India and abroad. The change over from the MKS to the SI, it will be seen, is not at all difficult.

This edition will also be useful to those preparing for the A.M.I.E. and competitive examinations. The basic approach of the late Principal S. B. Junnarkar, which is noted for its unusual clarity, has been retained.

Thanks are due to Shri S. S. Deo, Shri J. N. Aurangabadkar and Shri C. B. Kugaokar of the Government Polytechnic, Solapur, for their valuable assistance in preparing the manuscript.

We also sincerely thank Prof. S. C. Rangwala, Ahmedabad, and Shri Ramanbhai C. Patel, Anand, for undertaking the dreary task of checking the proofs which they have done with great keenness and enthusiasm. We are equally indebted to Rev. Br. S. Abril and his staff of the Anand Press for the excellent work done by them in bringing out this volume.

Poona

H. V. ADAVI

January 26, 1981

## NINETEENTH EDITION

This edition is reprinted with more attractive and clear printing. A few figures have been replaced by new drawings.

The publishers thank the students and teachers of the subject for their magnificent response to the book.

Suggestions will be gratefully accepted.

Anand

—PUBLISHERS

April 7, 1987

# CONTENTS

	PAGES
<b>CHAPTER I</b>	
<b>SI UNITS</b>	
Introductory — Basic units — Derived units — Force: Work: Power — Multiples and sub-multiples of SI units — Supplementary units — General — Some important formulas — Conversion from MKS to SI . . . . .	1-7
<b>CHAPTER II</b>	
<b>SIMPLE STRESSES AND STRAINS</b>	
Stress — Simple stresses and strains — Elastic limit — Hooke's law — Loading beyond the elastic limit — Ultimate stress: Working stress — Lateral strain — Poisson's ratio — Bars of varying section — Bars of uniformly tapering section — Bars of composite section — Stresses due to changes of temperature — Shrinking-on — Stresses on inclined sections of a bar under tension or compression — Simple shear — State of simple shear: Stresses on inclined sections — Linear diagonal strain — Relation between the Moduli of Elasticity and Rigidity for a given material — Bulk Modulus — Salient Points — Examples II . . . . .	8-89
<b>CHAPTER III</b>	
<b>PRINCIPAL PLANES AND PRINCIPAL STRESSES</b>	
Introductory — Principal planes — Principal stresses — Graphical method — Two equal and like Principal stresses — Two equal and unlike Principal stresses — More graphical methods — Principal stresses and Principal planes — Mohr's Circle Method — Principal strains — Salient Points — Examples III . . . . .	90-135
<b>CHAPTER IV</b>	
<b>IMPACT OR SHOCK LOADING: STRAIN ENERGY</b>	
Introductory — Strain-energy, Resistance-Deformation diagram — Gradual, sudden, impact shock loading — Proof Resilience — Shear Resilience — Strain-energy in terms of principal stresses — Relation between the elastic moduli — Criterion of design — Salient Points — Examples IV . . . . .	136-166

## CHAPTER V

## BEAMS AND BENDING — I

Bending Moments and Shear Forces — Definitions — Actions on the cross-section of a beam — S.F. and B.M. diagrams — Relation between S.F. and B.M. at a cross-section of a beam — S.F. and B.M. diagrams for beams with variable loading — Graphical methods — Inclined beams and beams with oblique loading — Beam with end couples — Beam with intermediate couple — Salient Points — Examples V . 167-244

## CHAPTER VI

## BEAMS AND BENDING— II

Stresses in beams — Stresses in a beam section — Theory of simple bending — Neutral axis — Moment of resistance — Assumptions made in simple theory of bending — Beams of rectangular section — Moments of inertia of sections — Strength of sections — Standard sections — I-section — Moment of inertia of unsymmetrical sections — Built-up sections — Graphical methods — Modulus figure — Beams of uniform strength — Resistance to shear force: Shear stresses — Shear stresses in beams of rectangular and circular sections — Shear stresses in beams of I-section — Shear stresses in angle and Tee-sections — Shear stresses in built-up sections — Beam of square section with one diagonal horizontal — Principal stresses and Principal planes at a point in a beam section — Curves of Principal stresses — Principal stresses in an I-section — Beams of composite section — Flitched beams — Salient Points — Examples VI . 245-345

## CHAPTER VII

## BEAMS AND BENDING— III

Deflections of beams — Strength and stiffness of beams — Bending into a circular arc — Relation between slope, deflection and radius of curvature — Axes of reference — Cantilevers — Propped cantilevers — Deflection of cantilevers and simply supported beams — Relation between maximum stress and maximum deflection — Propped beams — Rigid and elastic props — Simply supported beam with an eccentric load  $W$  — Macaulay's Method — Variable loading on a beam of uniform section — Moment-area Method — Impact loading on beams — Strain-energy

of beams — Unit-load and unit-couple methods — Strain-energy due to shear in a beam — Laminated springs — Beams of variable section — Graphical methods — Composite beams — Salient Points — Examples VII . . . 346-431

## CHAPTER VIII

### BEAMS AND BENDING—IV

Fixed and Continuous Beams — Fixed beams — B.M. and S.F. diagrams — Support moments — Effect of sinking of a support — Review of methods — Degree of Restraint at supports — Continuous Beams — Clapeyron's Theorem of Three Moments — Supports not at the same level — Fixed ends — Slope-deflection method — Salient Points — Examples VIII . . . 432-487

## CHAPTER IX

### DIRECT AND BENDING STRESSES

Combined bending and direct stress — Eccentric loading — Limit of eccentricity — Wind pressure on walls and chimney shafts — Coefficient of wind resistance — Water and earth pressure — Salient Points — Examples IX . . . 488-522

## CHAPTER X

### COLUMNS AND STRUTS OF UNIFORM SECTION

Axial loading — Euler's formula for long columns — Empirical formula — Rankine's formula — Design of struts and columns — Johnson's parabolic formula — Straight-line formula — Long columns under eccentric loading — Initial curvature of long column — Axial loading — Perry-Robertson formula — I.S.I. formula — Struts with transverse loading — Salient Points — Examples X . . . 523-577

## CHAPTER XI

### RADIAL PRESSURE—CYLINDRICAL AND SPHERICAL SHELLS

Thin seamless cylindrical shells — Riveted boiler shells — Thin spherical shells — Wire-bound thin pipes or shells — Thick cylinders: Lamé's formula—Design of thick cylindrical shells — Compound cylinders — Shrink-fit allowance — Initial difference of radii at junction — Thick spherical shells — Salient Points — Examples XI . . . 578-622

## CHAPTER XII

**RIVETED JOINTS**

Introductory — Forms of riveted joints — Possible ways of failure of a riveted joint — Strength of a riveted joint — Design of a riveted joint — Riveted joints in boiler-shells — Riveted joints in structural steel work — Diamond riveting — Pitch of rivets in built-up girders — Eccentric loading on rivets — Examples XII . . . . . 623-649

## CHAPTER XIII

**SHAFTS AND SPRINGS IN TORSION**

Torsion—Torsional stresses and strains—Power transmitted: Design of shafts — Keys and couplings — Combined bending and torsion — Combined bending and torsion and axial thrust — Torsional resilience of shafts — Shafts of non-circular sections — Closely coiled helical springs — Axial loading and axial moment — Open coiled helical springs — Examples XIII . . . . . 650-697

## CHAPTER XIV

**ELEMENTS OF REINFORCED CONCRETE**

Reinforced concrete beams — Assumptions made in simple theory — Simply reinforced rectangular beam — Economic percentage of reinforcement — Design of slabs — Adhesion and Bond — Shear stresses — Short columns under axial loading — Examples XIV . . . . . 698-723

## CHAPTER XV

**STRESSES IN FRAMES: STATIC LOADING**

Method of sections — Pratt truss — Warren truss — Warren girder — Cantilever truss — Steel trestles — K-truss — Space frames — Sheer legs — Derrick crane — Tripods — Examples XV . . . . . 724-755

## CHAPTER XVI

**METHOD OF TENSION COEFFICIENTS**

Introductory — Tension coefficients — Plane frames — Space frames — Examples XVI . . . . . 756-782

## CHAPTER XVII

**UNSYMMETRICAL BENDING**

Principal axes of a section — Circle of inertia — Momental ellipse — Unsymmetrical bending — Z-Polygon — Examples XVII . . . . . 783-814

## CHAPTER XVIII

**CONJUGATE BEAM METHOD**

Area moment method — Conjugate Beam — Examples XVIII . . . . . 815-829

## CHAPTER XIX

**WELDED JOINTS**

Introductory — Forms of welded joints — Strength of a welded joint — Eccentric loading — Examples XIX . . . . . 830-847

## CHAPTER XX

**SHEAR CENTRE**

Shear stress distribution in thin-walled open sections — Examples XX . . . . . 848-863

## CHAPTER XXI

**BENDING STRESSES IN CURVED BARS**

Pure bending of curved bars — Stresses in beams of large initial curvature — Rectangular cross-section — Trapezoidal cross-section —  $\perp$  Cross-section — I-section — Circular cross-section — Crane Hooks — Stresses in curved bars of small initial curvature — Piston rings — Examples XXI . 864-888

INDEX . . . . . 889-892

# Chapter 1

## SI UNITS

**1-1. Introductory:** To students of science, who are used to *absolute* units of measurements, there is nothing novel about the SI units (Système Internationale d'Unités) which, essentially, are the *absolute* units of the current m.k.s. system.

Most systems adopt three basic units of Length, Mass and Time, besides using some other arbitrary units for purposes of measurement. The SI rationalizes the available units and streamlines them into a coherent logical system. It reduces the number of *basic* units — arbitrarily selected — to a minimum and derives all the other units required, from these basic units.

The symbols and notation of SI units and their derivatives are standardized to avoid any possibility of confusion.

**1-2. Basic units:** SI uses *six* arbitrarily chosen *basic* units, listed below:

**BASIC SI UNITS**

No.	Physical quantity	Name of SI units	Symbol
1.	Length	metre	m
2.	Mass	kilogramme	kg
3.	Time	second	s
4.	Electrical current	ampere	A
5.	Temperature	kelvin	K
6.	Luminous intensity	candela	cd

The temperature  $t$  °C implies that  $T = (t + 273.15)$  °K.

**1-3. Derived units: Force: Work: Power:** Practically all other units used in Science and Technology are derived from these basic units. We have said that the SI systematizes them into a *coherent* logical scheme. A system is coherent, if the product or quotient of any two unit quantities in the system is the unit of the resulting derived quantity. When the unit of length is multiplied by the unit of length, the result is the unit of area. When the unit of length is divided by the

unit of time, the result is the unit of velocity. When the unit of mass is multiplied by the unit of acceleration, the result is the unit of force.

### **Force:**

The unit of force called the "*Newton*" is that force which, when applied to a body having a mass of one kilogramme gives it an acceleration of one metre per second squared. It will be noticed that this is also the *absolute* unit of force in the m.k.s. system. Newton's Second Law of Motion says that the rate of change of momentum in a moving body is proportional to the impressed force and takes place in the direction of the force. Expressed as an equation,  $P = \lambda \cdot mf$ , the value of the constant  $\lambda$ , depending on the unit of force selected. In the SI, the *unit* of force is that, which in a *unit* mass produces *unit* acceleration, so that the constant  $\lambda$  is, ipso facto, *unity*. In SI, the main departure from the traditional metric system is the adoption of "Newton" as the standard unit of force. Its symbolic notation is "N".

One kilo-Newton (kN) =  $10^3$  Newtons.

One mega-Newton (MN) =  $10^6$  Newtons.

One giga-Newton (GN) =  $10^9$  Newtons.

Incidentally, *SI* has discarded the *gravitational unit*, which has been universal hitherto.

### **Work: Energy:**

The unit of work or energy is a *Newton-metre* (N-m) called the *joule* (J) and is the work done when the point of application of a force of one Newton is displaced through a distance of one metre in the direction of the force.

One kilojoule (kJ) =  $10^3$  joules.

### **Power:**

Power is defined as *the rate of doing work*. The unit of power is called the watt (W) and is equal to one joule or *Newton-metre per second* (J/s or N-m/s).

One kilo-watt (kW) =  $10^3$  watts

One mega-watt (MW) =  $10^6$  watts.



A horse power (h.p.) as a measure of power has no place in the SI, as the watt (W), the kilo-watt (kW) and the mega-watt (MW) meet all the requirements for measurement of power.

**1-4. Multiples and Sub-multiples of SI units:** While the essential SI units with their derivatives are well-defined, it is often necessary to use the multiples and sub-multiples of these. Thus, while a metre (m) is the standard unit of length, we use a kilometre (km) to measure long distances. One kilometre =  $10^3$  metres. Similarly, while a watt (W) is the standard unit of power, it is too small a unit and so we use a kilo watt (kW) or a mega-watt (MW) for measurement of power. These multiples and sub-multiples are in decimals.

Decimal multiples and sub-multiples of SI units are formed by means of prefixes as detailed below:

Factor by which the unit is multiplied	Prefix	Symbol
$10^{12}$	tera	T
$10^9$	giga	G
$10^6$	mega	M
$10^3$	kilo	k
$10^2$	hecto	h
$10^1$	deca	da
$10^{-1}$	deci	d
$10^{-2}$	centi	c
$10^{-3}$	milli	m
$10^{-6}$	micro	$\mu$
$10^{-9}$	nano	n
$10^{-12}$	pico	p
$10^{-15}$	femto	f
$10^{-18}$	atto	a

In SI, the use of prefixes representing 10 raised to powers which are multiples of 3 is preferred. Therefore, the use of prefixes — hecto, deca, deci and centi is not recommended.

In forming decimal multiples and sub-multiples of a derived SI unit, as far as possible, only one prefix should be used; preferably it should be attached to the numerator. For example, for pressure or stress — which is force per unit area — the standard unit is Newton per metre squared —  $\text{N/m}^2$ . [1 Pascal (Pa) =  $1 \text{ N/m}^2$ .] If a multiple or sub-multiple has to be used,