# VIBRATION PROBLEMS IN ENGINEERING

### FIFTH EDITION

#### W. WEAVER, JR.

Professor Emeritus of Structural Engineering
Stanford University

#### The Late S. P. TIMOSHENKO

Professor Emeritus of Engineering Mechanics Stanford University

#### The Late D. H. YOUNG

Professor Emeritus of Civil Engineering.
Stanford University



A WILEY-INTERSCIENCE PUBLICATION

#### JOHN WILEY & SONS

New York / Chichester / Brisbane / Toronto / Singapore

## **CONTENTS**

**PREFACE** 

1	SYS	TEMS WITH ONE DEGREE OF FREEDOM	1	
	1.1	Examples of One-Degree Systems / 1		
	1.2	Undamped Free Translational Vibrations / 2		
	1.3	Rotational Vibrations / 12		
	1.4	Energy Method / 18		
	1.5	Rayleigh's Method / 24		
	1.6	Forced Vibrations: Steady State / 39		
	1.7	Forced Vibrations: Transient State / 48		
	1.8	Free Vibrations with Viscous Damping / 52		
	1.9	Forced Vibrations with Viscous Damping / 61		
	1.10	Equivalent Viscous Damping / 69		
	1.11	General Periodic Forcing Functions / 76		
	1.12	Arbitrary Forcing Functions / 84		
		Arbitrary Support Motions / 93		
		Response Spectra / 99		
	1.15	Step-by-Step Response Calculations / 107		
		References / 113		
		Problems / 114		
2	SYSTEMS WITH NONLINEAR CHARACTERISTICS			
	2.1	Examples of Nonlinear Systems / 139		
	2.2	Direct Integration for Velocity and Period / 149		
	2.3	Approximate Methods for Free Vibrations / 157		

хi

vii

		Forced Nonlinear Vibrations / 166 Piecewise-Linear Systems / 175 Numerical Solutions for Nonlinear Systems / 190 References / 207 Problems / 208	
3	SYS	TEMS WITH TWO DEGREES OF FREEDOM	217
		Displacement Equations: Flexibility Coefficients / 225 Inertial and Gravitational Coupling / 233 Undamped Free Vibrations / 241 Undamped Forced Vibrations / 251 Free Vibrations with Viscous Dampling / 260	
4	SYS	TEMS WITH MULTIPLE DEGREES OF FREEDOM	275
		Frequencies and Mode Shapes for Undamped Systems / 276 Principal and Normal Coordinates / 287 Normal-Mode Response to Initial Conditions / 295 Normal-Mode Response to Applied Actions / 301 Normal-Mode Response to Support Motions / 309 Iteration Method for Frequencies and Mode Shapes / 318 Damping in Multidegree Systems / 333	
5	CON	TINUA WITH INFINITE DEGREES OF FREEDOM	363
	5.1 5.2 5.3 5.4 5.5 5.6 5.7 5.8	Introduction / 363 Free Longitudinal Vibrations of Prismatic Bars / 364 Forced Longitudinal Response of Prismatic Bars / 373 Normal-Mode Method for Prismatic Bars / 380 Prismatic Bar with a Mass or Spring at the End / 387 Bars Subjected to Longitudinal Support Motions / 395 Torsional Vibrations of Circular Shafts / 401 Transverse Vibrations of Stretched Wires / 409	

	5.10 5.11 5.12 5.13 5.14 5.15 5.16 5.17 5.18 5.19 5.20 5.21	Transver Vibration Effects of Forced Condition Beams of Beams of Ritz Met Vibration Coupled	erse Vions of Rote Respons Cubject Travel f Axia on East thod for sof different response of the response of th	abrations of Prismatic Beams / 416 abrations of a Simple Beam / 422 Beams with Other End Conditions / 425 ary Inertia and Shearing Deformations / 433 anse of a Simple Beam / 436 anse of Beams with Other End / 442 ated to Support Motions / 444 ased by Moving Loads / 448 al Force on Vibrations of Beams / 454 atic Supports or Elastic Foundations / 456 atic Supports or Elastic Foundations / 456 are Calculating Frequencies / 461 Nonprismatic Beams / 466 areal and Torsional Vibrations of Beams / 474 Circular Rings / 478	
	5.23	Transve	rse Vi rse Vi ices	brations of Membranes / 484 brations of Plates / 495 / 505	
6		ITE-ELE NTINUA		T METHOD FOR DISCRETIZED	511
	6.3 6.4	Stresses Equation One-Direction	and Sons of Imensions of	Strains in Continua / 513 Motion for Finite Elements / 516 conal Elements / 520 Beams by Finite Elements / 534 / 542	
BI	BLIC	GRAPI	łY		551
A	PPEN	DIX A		TEMS OF UNITS AND MATERIAL DPERTIES	553
			A.1 A.2	Systems of Units / 553 Material Properties / 555	
AI	PEN	DIX B	COM	IPUTER PROGRAMS	557
			B.1 B.2	Introduction / 557 Step-by-Step Solutions for Linear One-Degree Systems / 558	
			B.3	Numerical Solutions for Nonlinear One-	

#### **CONTENTS**

**B.5** 

B.6	Program Notation / 567 Flowcharts for Programs / 569		
ANSWERS TO PRO		58	
INDEX		. '	60

Step-By-Step Solutions for Linear Multidegree Systems / 565

B.4 Iteration of Eigenvalues and Eigenvectors / 562