

CONTENTS

PREFACE	v
ACKNOWLEDGMENTS	vii
LIST OF SYMBOLS	ix
PART A INTRODUCTION AND BACKGROUND MATERIAL	1
1 INTRODUCTION	3
1-1 Background and applications	3
1-2 General description of the method	5
1-3 Summary of the analysis procedure	10
1-4 Fundamentals for the understanding of the method	15
References	16
Further reading	17
2 MATRIX TECHNIQUES	18
2-1 Matrix notation	18
2-2 Solution of large systems of algebraic equations	19
2-3 Eigenvalue problems	22
2-4 Solution of propagation problems	24
References	26
Further reading	28
3 BASIC EQUATIONS FROM SOLID MECHANICS	29
3-1 Stress	29
3-2 Strain and kinematics	30
3-3 Linear constitutive equations	32
3-4 Two-dimensional specializations of elasticity	35
3-5 Nonlinear material behavior	41
3-6 Material characterization	49
References	50
Further reading	51

	4 VARIATIONAL METHODS	52
4-1	Calculus of variations	52
4-2	Variational principles of solid mechanics	57
4-3	Applications to the finite element method	61
	References	62
	Further reading	62
PART B	THE THEORY OF THE FINITE ELEMENT METHOD	65
	5 THE BASIC COMPONENT—A SINGLE ELEMENT	67
5-1	The concept of an element	67
5-2	Various element shapes	72
5-3	Displacement models	77
5-4	Isoparametric elements	88
5-5	Element stresses and strains	102
5-6	Direct formulation of element stiffness and loads	106
5-7	Variational formulation of element stiffness and loads	113
5-8	Consistent loads vs. lumped formulation	124
5-9	Condensation of internal degrees of freedom	125
5-10	Summary and examples	126
	References	148
	Further reading	150
	Exercises	150
	6 THE OVERALL PROBLEM—AN ASSEMBLAGE OF ELEMENTS	154
6-1	Discretization of a body or structure	154
6-2	Mesh refinement vs. higher order elements	173
6-3	Interconnections at nodes	176
6-4	Effect of displacement models on interelement compatibility	178
6-5	Construction of stiffness matrix and loads for the assemblage	181
6-6	Boundary conditions	190
6-7	Solution of the overall problem	194
6-8	Examples	198
	References	206
	Further reading	210
	Exercises	210
	7 TECHNIQUES FOR NONLINEAR ANALYSIS	215
7-1	Initial strains	215
7-2	Nonlinear problems	217
7-3	Basic nonlinear solution techniques	219

7-4	Computer aspects of nonlinear techniques	227
7-5	Problems involving material nonlinearity	229
7-6	Problems involving geometric nonlinearity	238
7-7	Problems involving both material and geometric nonlinearity	242
	References	242
	Further reading	244
	8 GENERALIZATION OF THE THEORY	245
8-1	Generalized terminology and concepts	245
8-2	The six-step finite element procedure in general terms	248
8-3	Fields of application	249
8-4	Mathematical bases of the finite element method	258
	References	261
	Further reading	264
	PART C APPLICATIONS	265
	9 STRUCTURAL MECHANICS	267
9-1	Summary of applications in structural mechanics	267
9-2	Finite element methods for structural mechanics	269
9-3	Special techniques	275
9-4	Example: Plane stress analysis of a gravity dam	281
9-5	Example: Axisymmetric stress analysis of a bolt-nut system	283
9-6	Example: Analysis of prestressed concrete reactor vessel	285
9-7	Example: Comparison of plate bending finite elements	287
9-8	Example: Analysis of an arch dam	291
9-9	Example: Axisymmetric shell applications	295
9-10	Example: Ship structures	300
9-11	Example: Analysis of folded plate by separation of variables	303
9-12	Example: Nonlinear analysis of thin plates	303
	References	309
	Further reading	312
	10 SOIL AND ROCK MECHANICS	314
10-1	Summary of applications	314
10-2	Use of the finite element method in soil and rock mechanics	316
10-3	Example: Analysis of slopes in soils	329
10-4	Example: Bearing capacity and settlement analysis	331
10-5	Example: Static analysis of an earth dam	334
10-6	Example: Soil-structure interaction	336
10-7	Example: Slopes in jointed rocks	339

10-8	Example : Deep boreholes	340
10-9	Example : Tunnels	344
	References	345
	Further reading	350
11 DYNAMICS, INCLUDING EARTHQUAKE ANALYSIS		352
11-1	Summary of applications in dynamics	352
11-2	Formulation of inertial properties	353
11-3	Formulation of damping properties	358
11-4	Solution of transient problems by mode superposition	360
11-5	Example : Free vibration of thin plates	361
11-6	Example : Free vibration of cylindrical shells	363
11-7	Example : Response of earth dam by mode superposition	364
11-8	Example : Nonlinear dynamic analysis of underground structures	371
11-9	Example : Analysis of an earth dam failure	374
	References	377
	Further reading	379
12 TORSION, HEAT CONDUCTION, SEEPAGE		380
12-1	Use of the finite element method	380
12-2	Example of a formulation : Seepage	384
12-3	Numerical example : Steady confined seepage	387
12-4	Torsion of prismatic shafts	389
12-5	Example : Transient heat conduction	393
12-6	Example : Steady confined seepage under a sheet-pile wall	393
12-7	Example : Transient confined seepage in layered aquifers	397
12-8	Example : Steady unconfined seepage through an earth dam	397
12-9	Example : Transient unconfined seepage	399
	References	403
	Further reading	405
13 THERMOELASTICITY, CONSOLIDATION, HYDROELASTICITY		406
13-1	Example : Stress analysis for thermal and pore pressure effects	407
13-2	Example : Heating of linear thermoelastic half space	407
13-3	Example : Terzaghi's consolidation	411
13-4	Example : Motion of fluid in flexible container	412
	References	414
	Further reading	415

14 MISCELLANEOUS APPLICATIONS	416
14-1 Example : Viscous behavior of clay soils	417
14-2 Example : Creep in concrete dams	422
14-3 Example : Flow of ideal fluids	423
14-4 Example : Flow of viscous fluids	426
14-5 Example : Oscillations of harbors and lakes	428
References	432
Further reading	433
15 CONCLUSION—ADVANTAGES AND LIMITATIONS OF THE METHOD	435
15-1 Advantages	435
15-2 Limitations	437
15-3 Conclusions	438
Further reading	438
APPENDIX I ILLUSTRATIVE COMPUTER CODE	439
I-1 Introduction	439
I-2 Explanation of subroutines	440
I-3 Flow chart	441
I-4 Definition of variables	442
I-5 Guide for data input	444
I-6 Fortran listing	447
I-7 Sample input/output	458
I-8 Possible modifications	461
References	461
Further reading	462
APPENDIX II ABBREVIATIONS FOR REFERENCES	463
Author Index	465
Subject Index	469