

Advanced Structural Mechanics

Second Edition

Suranaree University of Technology



31051000622965

David Johnson

Contents

Preface to the first edition	v
Preface to the second edition	vii
Examination question sources	ix
1 Elasticity	1
1.1 Introduction	1
1.2 Elasticity theory	2
1.2.1 Stress	3
1.2.2 Displacements and strains	4
1.2.3 Stresses and strains	6
1.3 Plane stress	9
1.3.1 Introduction	9
1.3.2 Theory	10
1.3.3 Stress function solution	15
1.4 Finite element method	16
1.4.1 Triangular element theory	16
1.4.2 Example 1.1 – concrete cube analysis	20
1.4.3 Finite element types	36
1.4.4 Eight-noded isoparametric element	37
1.4.5 Assessment of solution accuracy	45
1.5 Plane strain	48
1.5.1 Introduction	48
1.5.2 Stresses and strains	49
References and further reading	50
Problems	51
2 Torsion	59
2.1 Introduction	59
2.2 Torsional behaviour	61
2.3 Solid sections	62
2.3.1 Circular section	62
2.3.2 Non-circular sections	63

2.3.3	Finite difference solutions	69
2.3.4	Comparison of solution methods	76
2.3.5	Properties of solid sections	77
2.4	Thin-walled sections	77
2.4.1	Singly closed sections	78
2.4.2	Multiply closed sections	81
2.4.3	Open sections	87
2.4.4	Properties of thin-walled sections	91
2.5	Soap-bubble (membrane) analogy	91
2.6	Non-uniform torsion	93
	References and further reading	94
	Problems	95
3	Plates and slabs	101
3.1	Introduction	101
3.2	Physical behaviour	102
3.2.1	Beam analogy	102
3.2.2	Grid analogy	103
3.2.3	Poisson's ratio effect	104
3.3	Elastic plate theory	105
3.3.1	Introduction	105
3.3.2	Displacements and strains	106
3.3.3	Strains, stresses and stress resultants	107
3.3.4	Moments, curvatures and stresses	109
3.3.5	Equilibrium	110
3.3.6	General elastic plate equation	112
3.3.7	Boundary conditions	113
3.3.8	Classical solutions to the plate problem	117
3.4	Finite difference method	118
3.4.1	Introduction	118
3.4.2	Boundary conditions	118
3.4.3	Evaluation of moments and shear forces	120
3.4.4	Examples	120
3.4.5	Extensions and refinements	126
3.5	Grid representation method	126
3.5.1	Grid properties	126
3.5.2	Boundary conditions	128
3.5.3	Load representation	129
3.5.4	Evaluation of moments and shear forces	129
3.5.5	Evaluation of reactions	130
3.5.6	Examples	130
3.5.7	Extensions and refinements	136
3.6	Finite element method	136
3.6.1	Rectangular element theory	136

3.6.2 Example	145
3.6.3 Extensions and refinements	151
3.7 Comparison of analyses	152
3.8 Design moments	152
3.8.1 Introduction	152
3.8.2 Recommendations	153
3.8.3 Example 3.7 – simply supported slab design moments	154
3.8.4 Example 3.8 – fixed-edge slab design moments	154
References and further reading	154
Problems	156
4 Thin shells	165
4.1 Introduction	165
4.1.1 Generation, classification and application	165
4.1.2 Structural behaviour	167
4.1.3 Scope of the chapter	168
4.2 Membrane theory for axisymmetric shells	169
4.2.1 Basic properties	169
4.2.2 Example 4.1 – spherical dome under dead load	176
4.2.3 Limitations of membrane theory	178
4.2.4 Example 4.2 – paraboloid dome under internal pressure	180
4.2.5 Example 4.3 – conical shell under fluid pressure	182
4.3 Bending of circular cylindrical shells	186
4.3.1 Finite element method	186
4.3.2 Example 4.4 – circular tank of uniform thickness	193
4.3.3 Example 4.5 – circular tank of non-uniform thickness	199
4.4 Finite elements for non-cylindrical shells	204
References and further reading	205
Problems	206
5 Structural dynamics	217
5.1 Introduction	217
5.2 Types of vibration	218
5.2.1 Free, undamped vibration	218
5.2.2 Free, damped vibration	221
5.2.3 Forced, damped vibration	223
5.3 Determination of natural frequencies and modes	228
5.3.1 Modelling	228
5.3.2 Theory	228
5.3.3 Example 5.1 – single-storey sway frame	231
5.3.4 Simplified analysis of sway frames	235
5.3.5 Analysis of beams	240

5.3.6 Example 5.4 – cantilever slab	244
5.3.7 Orthogonality of the principal modes	247
5.3.8 Rayleigh quotient	248
5.3.9 Distributed-mass models	250
5.4 Free, undamped vibration analysis	250
5.4.1 Analysis by mode superposition	251
5.4.2 Example 5.5 – three-storey sway frame	253
5.5 Forced, undamped vibration analysis	255
5.5.1 Analysis by mode superposition	256
5.5.2 Example 5.6 – sway frame under ground motion	258
5.6 Harmonically forced, undamped vibration analysis	261
5.6.1 Analysis by mode superposition	261
5.6.2 Example 5.7 – harmonically forced cantilever beam	262
5.7 Specialized problems	263
References and further reading	264
Problems	266
Appendix A Finite difference method	273
A.1 Theory	273
A.1.1 Functions of a single variable	273
A.1.2 Functions of two variables	275
A.2 Practical application	277
References and further reading	280
Appendix B Finite element method	281
B.1 Introduction	281
B.2 Theory	282
References and further reading	285
Solutions to problems	287
Index	299