



NAFEMS

National Agency
for Finite Element
Methods & Standards



A FINITE ELEMENT PRIMER

Contents

Preface

1. Introduction

1.1	Finite Element Method	1
1.2	Matrix Notation	4

2. Structural Analysis

2.1	Fundamentals. Equilibrium. Compatibility. Stress-Strain	9
2.2	The Principle of Virtual Displacements, and Energy Methods	13
2.3	Framework analysis and assembly of \mathbf{K}	15
2.4	Framework and element stiffnesses	18

3. General Continuum

3.1	Fundamentals again	22
3.2	The P.V.D. again	26

4. Beams

4.1	Exact solution	29
4.2	Finite element solution	32
4.3	Rigid-jointed frameworks	39
4.4	Stiffness transformation	40

5. Two-dimensional Membranes

5.1	Fundamental assumptions	43
5.2	Rectangular elements	47
5.3	Triangular elements	52
5.4	The isoparametric curved quad	56
5.5	Numerical integration	61
5.6	Initial strains	65

CONTENTS

6. Bricks, Plates and Shells	68
6.1 Introduction	68
6.2 Solid elements	75
6.3 Plate bending elements	79
6.4 Shell elements	
7. Mesh Specification	
7.1 Introduction	85
7.2 Geometry specification	86
7.3 Mesh generation	90
7.4 Mesh density	94
7.5 Choice of element type	102
7.6 Testing element and mesh suitability	105
7.7 Material properties	112
7.8 The use of symmetry	115
8. Assembly and Solution	
8.1 Introduction	124
8.2 Checking procedures	126
8.3 Element generation and assembly problems	127
8.4 Excessive element distortion	128
8.5 Incorrect element connections	131
8.6 Incorrect mixing of elements	132
8.7 Graphical checks	133
8.8 Ill-conditioning	140
8.9 Solution diagnostics	141
8.10 Other program checks and diagnostics	145
8.11 Results presentation	146
8.12 Improving solution efficiency and accuracy	147
8.13 Use of program restarts	151
8.14 Substructuring	152
9. Results Processing	
9.1 Introduction	154
9.2 Displacement results	155
9.3 Stresses	156
9.4 Element stresses	158
9.5 Stress averaging	159
9.6 Methods of stress averaging	160
9.7 Stress presentation	162

9.8	Element strains	164
9.9	Calculation of reaction forces	165
9.10	Graphical presentation of results	166
9.11	Using the results to refine the mesh	168
10.	Dynamics	
10.1	Introduction	170
10.2	Undamped free vibration	173
10.3	Modelling considerations for dynamic analysis	180
10.4	Forced response	184
10.5	Methods for calculating forced response	186
10.6	Damping idealisation	190
10.7	Condensation and dynamic substructuring	196
10.8	Primary and secondary components	200
10.9	Number of nodes for dynamic analysis	202
10.10	Calculation of dynamic stresses	206
10.11	Results recovery	207
10.12	Structural modifications	208
10.13	Wave propagation	209
10.14	Seismic analysis	210
10.15	Random vibrations	212
11.	Nonlinear Analysis	
11.1	Introduction	215
11.2	Gross deformation	217
11.3	Incremental solutions	224
11.4	Inelastic material behaviour	227
12.	Modelling	
12.1	Introduction	232
12.2	Basic	232
12.3	Linear and non-linear problems	233
12.4	Joints	234
12.5	Offsets	235
12.6	Supports	239
12.7	The use of constraint equations	242
12.8	Comparison of the forms of constraints	247
12.9	Relationship between the forms of constraints	248

CONTENTS

12.10 Using mixtures of element types	249
12.11 Modelling material properties	251
12.12 Loadings	257
12.13 Modelling considerations including loading effects	261
13. Other Field Problems	
13.1 Introduction	262
13.2 The method of weighted residuals	263
13.3 The heat conduction problem	265
13.4 Other field problems	270
References	272
Index	273