INDEX

A

Antisymmetric load, 154
Antisymmetric terms, 161
Arc-length method, 365
Area coordinates, 300
Area integrals, evaluation of, 31
Assembly of global equations, 110
Assembly routine, 112
Associated plasticity, 439
Assumed pressure solution, 245
Assumed stress field, 228
Asymmetric load, 154
Auxiliary shape functions, 100
Average nodal stresses, 79
Axial deformation of bars, 2, 387
Axisymmetric analysis, 120, 122
  finite element equations, 123
  mapped quadrilateral element, 146
  triangular element, 125

B

Babuska-Brezzi condition, 245
Backstress vector, 438
Backward Euler integration, 445
Banded storage, 109, 111
Bandwidth, 110
BCIZ triangular plate element, 299
Beam element, 170
Beam sign convention, 172
Bending moment, 171
Bending shape functions, 98, 100
BFS rectangular plate element, 291
Boundary integrals, evaluation of, 32
Buckling analysis, 466, 536
Buckling load, 536
  for trusses, 537
Bulk modulus, 235

C

Cauchy stresses, 467, 481
Compatibility conditions, 217
Compatibility requirement, 91
Completeness requirement, 91
Compressible neo-Hookean material, 499
Conforming elements, 91, 261
Conforming triangular plate elements, 305
Consistency condition, 438, 552
Constant stiffness iteration, 354
Constant-curvature patch test, 289
Constant-strain test, 93
Constant-twist patch test, 287
Constitutive equations, 40, 216, 498
Constrained optimization, 552
Contact constraint, 551
Contact modeling, 558
Contact point calculation, 558
Contact problem, 386, 549
  ANSYS solution, 572

COPYRIGHTED MATERIAL

Contact with friction, 554
Contactor node, 551
Contactor surface, 558
Continuum mechanics, 466, 467
Contraction of tensors, 485
Convergence check, large displacements, 496
Convergence criteria, 348
Convergence requirements, 90, 91
Cosine loading, 120
Cyclic loading, 450
Cylindrical coordinates, 120

D

Deformation dependent load, 466, 529
Deformation gradient, 467
  computation, 468, 480
Derivatives of assumed solution, 30
Derivatives of three-dimensional mapped elements, 60
Deviatoric strains, 236
Deviatoric stresses, 236, 449
Differential area relationships, 474
Differential equation for axial deformation, 3, 23
Differential equation for EBT, 173
Differential volume relationships, 472
Directional derivative, 340, 379
Discretization, 1
Displacement formulation, 218
Displacement gradient, 476
Divergence in Newton-Raphson, 355
Divergence theorem, 23
Double product of tensors, 485, 542
Drop panels, 338

E

Effective plastic strain, 454
Effective stress, 38, 449
Eigenvalues, 228
Elastic solids, 37
Elastic-plastic behavior, 392
Elastic-plastic constitutive matrix, 440
Elastic-to-plastic transition, 442
Elasticity tensor, 490, 498
Elastoplastic strain increment, 441
Element tangent matrices, 493
Elements stresses, computation of, 114
Enhanced displacement method, 191
Equilibrium equations, 41
  cylindrical coordinates, 120
  for EBT, 182
Equivalent frame, 339
Equivalent load vector due to stresses, 498
Equivalent nodal load vector, 45, 51
Error control, 446
Error due to small displacement assumption, 466
Essential boundary conditions, 2
Euler integration, 443
Euler-Bernoulli beam theory (EBT), 170, 171
Eulerian description, 466
Explicit method, 445
Extra zero-energy modes, 91

F

Fe2Quad, 37, 102
  input data, 103
  main program, 107
  program code explanation, 107
  program output, 105
  subroutines, 107
Fifteen-node triangular element, 84
Finite element, 1
First Piola-Kirchhoff stresses, 482
Flat shell element, 332
Flat slab system, 338
Flexibility formulation, 221
Flywheel, 116
Follower force, 466, 529
Foot pedal, 118
Force nonlinearity, 386
Forces on contact surfaces, 564
Forward Euler integration, 445
Four-field beam element for TBT, 198
Four-node rectangular element, 16, 21
Fourier series, 120
  representation of loading, 154
4/1 quadrilateral element, 249
Fourth-order plate differential equation, 267
Fourth-order problems, 2
Fourth-order tensor, 490, 498, 543
Frictional constraint function, 555

G

Galerkin method, 3
  classical form, 341
Gap, 550, 554
Gap calculation, 558, 560
Gauss quadrature, 25
  for area integrals, 26
  for one-dimensional integrals, 25
  for volume integrals, 28
Gauss's divergence theorem, 23
General form finite element equations
  general elasticity, 41
  Lagrange multiplier formulation for contact, 567
  Mindlin plate, 316
  penalty formulation for contact, 569

Generalized patch test, 96
Geometric nonlinearity, 386, 466
Green-Gauss theorem, 24
Green-Lagrange strain, 467, 476

H

Half-bandwidth, 110
Hardening
  isotropic, 391
  kinematic, 391
  mixed, 392
HCT triangular plate element, 306
Hermite interpolation, 14
Heterosis element, 323
Hybrid formulation, 170
Hyperelastic material, 499

I

Implicit method, 445
Incompatible elements, 90
Incompressible solid, 234
Incremental stress-strain, 437
  no hardening, 451
Inf-sup condition, 245
Initial strains, 40
Integration by parts, 4
  in two dimensions, 24
Integration over volume, 61
Internal force vector, 348
Interpenetration, 552
Interpolation functions, 12
  for eight-node element, 19
  for eight-node solid element, 58
  for five-node element, 20
  for seven-node element, 19
  for six-node element, 20
  for tetrahedral element, 45
  for triangle, 22
  for 20-node solid element, 59
Interpolation-extrapolation of stresses, 78
Isotropic hardening, 391, 438, 453
Isotropic material, 40, 121
Iterative improvement of stresses, 82

J

J_2 plasticity, 455
Jacobian matrix, 60

K

Kinematic hardening, 391, 438, 456
Kinematic nonlinearity, 386
Kirchhoff material, 498
Kirchhoff plate element, 273
Kirchhoff plate theory, 261, 262

L

Lagrange interpolation, 14
  for rectangular elements, 16
Lagrange multiplier, 565
Lagrangian description, 466
Lamé's constant, 499
Large displacements, 466
Left Cauchy-Green tensor, 500
Line integrals, 67
Linear assumed solution, 3
Linear-displacement test, 94, 95
Linearization, 340, 379, 388
  of inverse of a matrix, 382
  of square of a matrix, 381
  of system of equations, 380
  of weak form, 488
Linearized buckling, 466, 536
Linearized equations, 347
Linearized weak form for axial deformation, 389
Linearized work from pressure loading, 529
Linked interpolation element for TBT, 205
Linked interpolation f unctions, 205
Load factor, 359
Load increments, 359
Load parameter, 359
Loading/unloading/reloading, 394, 414

M

Mapped elements, 28
Mapped solid elements, 57
Mass matrix, 145
Mass matrix for axisymmetric triangular element, 145
Master surface, 558
Material description, 466
Material nonlinearity, 386
Mathematica/MATLAB implementations
  arc-length, method, 378
  axisymmetric analysis using mapped quadrilateral elements, 154
  axisymmetric analysis using triangular elements, 145
  bar with Ramberg-Osgood model, 424
  BCIZ triangular plate element, 303
  BFS rectangular plate element, 298
  classical Galerkin solution of nonlinear differential equation, 343
  contact problem, 572
  deformation dependent loading, 536
  deformation gradient calculation, 472

Mathematica/MATLAB implementations (*continued*)
elasticity problem using mapped solid element, 77
elasticity problem using tetrahedrals, 57
elastic-plastic bar, 414
elastic-plastic truss, 434
finite element solution of nonlinear differential equation, 353
Fourier series loading, 166
4/1 *u*/*p* element, 253
gap/interpenetration calculation, 564
heterosis plate element, 325
hyperelastic material model, 509
linearized buckling of trusses, 542
mapped element computations, 33
multifield Mindlin plate element, 331
MZC rectangular plate element, 283
Newton-Raphson solution, 365
9/3 *u*/*p* element, 258
quadrilateral element for geometric nonlinearity, 528
quadrilateral Mindlin plate element, 323
shell element, 336
state determination for von Mises plasticity, 462
stress interpolation selection, 234
Mean stress, 235
Mindlin plates, displacement-based elements, 314
Mindlin plate theory, 261, 311
Mixed beam elements
for EBT, 173
for TBT, 193
Mixed formulation, 170, 173
for elastic solids, 224
for Kirchhoff plates, 307
for nearly incompressible solid, 240
Mixed hardening, 392
Modified forward Euler, 446
Modified Risk method, 365
Mohr's circle, 114
Moment, 171
Moment intensities, 263
Moment of inertia, 172
Moment-curvature relationship, 172
Multifield elements for Mindlin, 325
Multifield formulation, 170
for elastic solids, 215
MZC rectangular plate element, 275

N

Nearly incompressible solid, 234
Neo-Hookean material, 499
Neutral axis, 171, 180
Newton-Raphson method, 340, 346
Nine-node rectangular element, 18
9/3 quadrilateral element, 254
Nodal averages to minimize least-squares error, 80
Nodal degrees of freedom, 2
Nonassociated plasticity, 439
Nonconforming elements, 91, 261
Nonlinear axial deformation element, 390
Nonlinear differential equation, 341, 344
Nonlinear displacement bc, 386
Nonlinear force bc, 386
Nonlinear problems, 340
Nonlinear solids, 437
Nonlinear strain-displacement, 386
Nonlinear stress-strain, 386
Nonlinearities, sources, 386
Nonlinearity
force, 386
geometric, 386
kinematic, 386
material, 386, 434
Nonwork mode, 230
Normal constraint function, 552
Normal contact, 549
Normal slope discontinuity, 283, 298
Number of stress parameters
minimum, 228
optimum, 228
Numerical integration, 25

O

One-dimensional plasticity, 391
Optimal locations for calculating stresses, 77

P

Parasitic shear, 98
Patch test, 37, 90
comments, 96
generalized, 96
for plane elasticity, 92
for plate elements, 284
Penalty method for boundary conditions, 112
Penalty parameter, 569
Piola-Kirchhoff stresses, 467, 481
Plane strain analysis, 238
Plane strain, hyperelastic material, 501
Plane stress analysis, 238
Plane stress, hyperelastic material, 502
Plastic constitutive matrix
isotropic hardening, 456
kinematic hardening, 459
no hardening, 453
Plastic flow, 439
Plastic modulus, 392, 455

Plastic potential, 438
Plastic step, 443
Plastic strain, 393
Plastic work, 438
Plate bending rigidity, 264, 314
Plate bending strains, 312
Plate boundary conditions, 272
Plate constitutive equations, 263
Plate equilibrium equations, 266
Plate moment-curvature relationships, 264
Plate section rotations, 262
Plate stress computations, 267
Plate transverse shear strains, 312
Plates, 261
Poisson ratio locking, 238
Potential energy, 123
Prescribed displacement patch test, 285, 303
Pressure, 235
Pressure loading, 489
Principal stresses, 114
Principle of virtual displacement, 43
Procedure for stress interpolation, 230
Punching shear, 338

Q

Quadrilateral with additional bending modes, 98

R

Ramberg-Osgood model, 414
Rank deficiency, 228
Rank of element stiffness matrix, 228
Rayleigh-Ritz method, 5
Rectangular Kirchhoff plate element, 275
Reduced integration, 170
Reinforced concrete slab, 338
Remedies for shear locking, 190
Restrictions on mapping of areas, 29
Return to yield surface, 448
Right Cauchy-Green tensor, 500
Rigid-body displacement test, 93, 94, 95
Rigid-body modes, 91, 228
Rik's method, 365
Rotating bar, 6, 7
Rotating disk, 129
  analytical solution, 135
  finite element solution, 130

S

Secant iteration, 443
Second moment of area, 172
Second Piola-Kirchhoff stresses, 482
Second-order problem, 2
Section rotation, 183
Selective reduced integration, 190, 321
Serendipity shape functions, 19
Shear correction factor, 181
Shear force, 172
Shear intensities, 263
Shear locking, 170, 183, 187, 189, 204, 211
  in plates, 321
Shear modulus, 40
Shells, 261, 331
Shifted deviatoric stresses, 458
Sine loading, 120
Slave surface, 558
Small displacement, 39
Solids of revolution, 120
Solution procedures for nonlinear problems, 354
Sources of nonlinearities, 386
Spatial description, 466
Spurious pressure mode, 245
Square plate subjected to distributed load, 279
Stabilization matrix, 332
State determination, 390, 394, 440
  large displacements, 496
Static condensation, 37, 84, 227
Steps in finite element solution, 2
Storage of global stiffness matrix, 109
Strain decomposition, 393
Strain energy density function, 499
Strain energy for EBT, 183
Strain hardening, 391
Strain tensor, 477
Strain-displacement relationships, 39, 216
  in cylindrical coordinates, 121
  nonlinear, 478
Strain-hardening parameter, 392
Strains, 39
Stress calculations, 77
Stress correction, 448
Stress equilibrium equations, 41, 215
Stress extrapolation, 79
Stress formulation, 221
Stress interpolation functions, 221
Stress invariant, 449
Stress modes, 230
Stress resultants, 263
Stress resultants on arbitrary plane, 265
Stress tensor, 38, 477
Stress vector, 38, 477
Substructuring, 37, 85
Superelements, 85
Superposition, 120
Support reactions, computation of, 113
Surface forces, 38
Surface integrals, 63

Symmetric banded storage, 109
Symmetric load, 154
Symmetric terms, 157

T

Tangent element equations, 348
Tangent matrix, 347
Tangent modulus, 393
Target node, 551
Target surface, 558
Temperature effects, 40
Tensor notation, 477
Tetrahedral element, 45
  for three-dimensional elasticity, 49
Thermal stresses, 135
Thick plates, 311
Thickness change, 503
Thin plates, 262, 267
  displacement-based elements, 270
Timoshenko beam theory (TBT), 170, 180
Total Lagrangian formulation, 466, 484
Trace of a matrix, 485
Transformation matrix for shells, 332
Transformed equations for a shell element, 335
Transverse shear strain, 181
Triangle by collapsing quadrilateral, 22
Triangular element, 21
Triangular Kirchhoff plate element, 299
Truss element, 425
Trusses, 424
Two-node axial deformation element, 2, 5
Two-node element for nonlinear differential equation, 345
Two-node element for TBT, 184
Two-node mixed beam element, 174

U

u/*p* elements, 243
u/*p* formulation, 240, 249
u/*p* quadrilateral elements, 246
Unbalance, 498
Unbalanced force vector, 348
Unsymmetric loading, 120
Updating element state, 398

V

Virtual displacements, 42, 485
Virtual strains, 42
Volumetric locking, 212
Volumetric strain, 234
von Mises failure criterion, 38
von Mises plasticity, state determination, 459
von Mises stress, 449
von Mises yield criterion, 449

W

Weak form
  for contact
    Lagrange multiplier, 565
    penalty formulation, 568
  in current configuration, 483
  small displacement, 41
  for thin plates, 270
Weighted nodal average, 80
Weighting functions for mixed formulation, 173
Work hardening, 450
Work mode, 230

Y

Yield criteria, 393
Yield function, 438
Yield stress, 392
Yield surface, 438
Yield surface intersection, 443
Yield surface translation, 438

Z

Zero eigenvalue, 228
Zero-energy modes, 91