

# INDEX

## A

Acceleration Records, 15-4, J-1  
Accidental Torsion, 17-12  
Algorithms for  
  Bilinear Plasticity Element, 21-5  
  Correction of Acceleration  
    Records, J-5  
  Damping Element, 21-8  
  Evaluation of Damping, 19-3  
  Fast Nonlinear Analysis, 18-8  
  Friction-Gap Element, 21-12  
  Gap-Crush Element, 21-8  
  Gauss Elimination, C-4  
  Gram-Schmidt, 14-6  
  Inverse Iteration, 14-5  
  Jacobi Method, D-2  
  LDL Factorization, C-16  
  Load Dependent Ritz Vectors,  
    14-17  
  Matrix Inversion, C-9  
  Newmark Integration Method, 20-4  
  Nonlinear Damping, 21-10  
  Partial Gauss Elimination, C-13  
  Solution of General Set of  
    Equations, C-6  
  Solution of Modal Equations, 13-9  
  Static Condensation, C-13  
  Subspace Iteration, 14-6  
  Tension-Gap-Yield Element, 21-7  
  Viscous Element, 21-8  
Anisotropic Material, 1-1  
Arbitrary Dynamic Loading, 13-5  
Arbitrary Frame Element, 4-1  
Arbitrary Shells, 10-3  
Arch Dam, 10-1  
Assumed Displacement, 4-3

Assumed Stress, 4-3  
Automated Computer Program, 5-1  
Axial Deformations, 2-10, 7-5  
Axial Element, 4-2  
Axial Flexibility, 1-11  
Axial Stiffness, 1-11  
Axisymmetric Material Properties,  
  1-10

## B

B Bar Method, 6-2  
Banded Equations, C-15  
Base Shear, 17-2  
Bathe, K. J., 12-10, 14-19  
Bayo, E., 14-19, 15-24  
Beams, 4-1  
Beam-Shell Analysis, 7-12  
Body Forces, 3-8  
Boeing Airplane Company, 5-1  
Boresi, 1-12, 2-14  
Boundary Conditions, 7-1  
Bridge Analysis, 22-2  
Buckling Analysis, 11-3, 18-2  
Building Codes, 17-1  
Bulk Modulus, 1-8

## C

Cable Element, 11-1  
CDC-6400, H-2  
Center of Mass, 7-7  
Cholesky, C-1  
Chopra, A., 12-10  
Clough, Ray W., 3-16, 5-1, 16-15  
Coefficient of Thermal Expansion,  
  1-1  
Compatibility, 1-1, 2-3, 2-13  
Compliance Matrix, 1-3, 1-6, 1-10

Compression Wave Velocity, 1-9  
 Consistent Mass, 3-10, 3-13  
 Constraints, 7-4, 7-14  
 Cook, R., 2-14, 5-15, 5-16  
 Correction for Higher Mode  
     Truncation, 14-13  
 Correction for Static Loads, 14-13  
 Correction Matrix, 6-4, 9-5  
 Cramer's Rule, C-2  
 Cubic Displacement Functions, 22-4,  
     J-3

## D

Damping  
     Classical Damping, 13-3, 19-3  
     Decay Ratio, 19-3  
     Energy Loss Per Cycle, 19-4  
     Equilibrium Violation, 19-4  
     Experimental Evaluation, 19-4  
     Mass Proportional, 19-7  
     Nonlinear, 18-3, 19-9  
     Rayleigh, 19-1, 19-6  
     Stiffness Proportional, 19-7  
 Damping Matrix, 13-3  
 Deformed Position, 2-2, 2-10  
 Der Kiureghian, A., 15-24  
 Determinate Search Method, 14-2  
 Diagonal Cancellation, C-20  
 Diagonal Mass Matrix, 7-7, 7-11  
 Dickens, J., 14-19  
 Direct Flexibility Method, 4-6  
 Direct Stiffness Method, 3-7  
 Displacement Boundary Conditions,  
     7-2  
 Displacement Compatibility, 2-3, 2-7,  
     2-13, 6-1  
 Displacement Seismic Loading, 22-1  
 Displacement Transformation Matrix,  
     2-9, 2-11  
 Distorted Elements, 9-8  
 Doherty, W. P., C-21  
 Double Precision, 7-4

Dovey, H. H., C-21  
 Duhamel Integral, 13-8  
 Dynamic Analysis by  
     Direct Integration, 12-4, 20-1  
     Frequency Domain, 12-6  
     Mode Superposition, 12-5  
     Response Spectrum, 12-5  
 Dynamic Equilibrium Equations, 3-13  
 Dynamic Participation Ratios, 13-14  
 Dynamic Response Equations, 13-4,  
     13-5

## E

Earthquake Excitation Factors, 13-3  
 Earthquake Loading, 12-3  
 Effective Length, 11-11  
 Effective Shear Area, F-5  
 Effective Stiffness, 18-4, 18-15  
 Eigenvalue Problem, D-1, D-6  
 Eigenvalues, 14-1, D-1  
 Eigenvalues of Singular System, D-1  
 Eigenvectors, 14-1, D-1  
 Element Flexibility, 2-11  
 Element Stiffness, 2-11  
 Energy, 3-1  
     Complementary Energy, 3-11  
     Energy Dissipation Elements, 21-1  
     Energy Pump, 3-5  
     External Work, 3-7  
     Kinetic Energy, 3-4, 3-12, 3-15  
     Mechanical Energy, 12-9  
     Minimum Potential Energy, 3-9  
     Potential Energy, 3-4  
     Stationary Energy, 3-9  
     Strain Energy, 3-6, 3-7  
     Zero Strain Energy, 12-9  
 Equilibrium, 1-1, 2-1, 2-2  
 Exponent Range, 7-4  
 External Work, 3-1, 3-7

## F

Fast Nonlinear Analysis Method, 18-1

Finite Element Method, 5-1  
Floor Diaphragm Constraints, 7-4  
FLOOR Program, 8-17  
Fluid Properties, 1-8  
FNA Method, 18-1  
Force Method, 3-10  
Force Transformation Matrix, 2-9  
Frame Element, 4-1  
    Absolute Reference System, 4-11  
    Displacement Transformation, 4-10  
    Geometric Stiffness, 11-2  
    Local Reference System, 4-9  
    Member End Releases, 4-12  
    Member Loading, 4-12  
    Properties, 4-7  
    Properties, 4-7  
Free-Field Displacements, 16-4  
Friction-Gap Element, 21-10

**G**

Gap Element, 18-3  
Gap-Crush Element, 19-9  
Gauss Integration, 5-4  
Gauss Points, 5-4  
Generalized Mass, 13-2  
Geometric Stiffness, 11-1, 11-11  
Givens, 14-18  
Gram-Schmidt Orthogonalization,  
    14-4, 14-18

**H**

Half-Space Equations, 16-14  
Harmonic Loading, 12-7  
Hart, J., 16-15  
Hierarchical Functions, 8-4  
Higher Mode Damping, 22-5  
Hilber, 20-8  
Hoit, M., C-21  
Hourglass Displacement Mode, 5-10  
Householder, 14-18  
Hughes, T. J. R., 20-11

**I**

Ibrahimbegovic, Adnan, 8-17, 9-10  
Impact, 3-14  
Incompatible Displacements, 5-1, 6-2,  
    6-6  
Incremental Solution, 7-4  
Infinitesimal Displacements, 3-2  
Initial Conditions, 13-4  
Initial Position, 2-10  
Initial Stresses, 1-4  
Inverse Iteration, 14-3  
Irons, Bruce M., 5-1, 6-1  
Isoparametric Elements, 5-1  
    Area, 5-9  
    Definition, 5-3  
    Mid-Side Nodes, 5-6  
    Shape Functions, 5-3, 5-6  
Isotropic Materials, 1-5  
Iteration, 7-4  
Itoh, T., 14-19

**J**

Jacobi Method, 14-18, D-2  
Jacobian Matrix, 5-9, 6-1

**K**

K Factor, 11-11  
Kinetic Energy, 1-1  
Kirchhoff Approximation, 8-2, 10-7

**L**

Lagrange Multipliers, 7-16  
Lagrange's Equations of Motion, 3-12  
Lame's Constants, 1-8  
Lanczos Method, 14-11  
Large Strains, 18-1  
LDL Factorization, C-16  
LDR Vectors, 14-1, 14-7, 14-18, 16-9  
Lysmer, J., 16-15

**M**

Mass, Generalized, 13-2  
 Mass Density, 1-10  
 Mass Participation Ratios, 13-11  
 Mass Participation Rule, 13-12  
 Massless Foundation Approximation,  
 16-11  
 Master Node, 7-7  
 Material Interface, 2-5  
 Material Properties Summary, 1-9  
 Material Property Transformation,  
 E-1  
 Matrix Inversion, C-1, C-9  
 Matrix Multiplication, B-1  
 Matrix Notation, B-1  
 Matrix Transpose, B-4  
 Mechanical Energy, 12-9  
 Membrane Element, 9-1  
 Mesh Transitions, 7-14  
 Method of Joints, 2-7  
 Modal Damping, 13-3  
 Modal Participation Factors, 13-3  
 Mode Shapes, 13-1  
 Mode Superposition Analysis, 13-1  
 Mode Truncation, 22-15  
 Modulus of Elasticity, 1-1  
 Moment Curvature, 1-12  
 Momentum, Conservation, 3-13  
 Multi-Support Earthquake Motions,  
 16-6, 22-1

**N**

Newmark Integration Method, 20-2  
   Alpha Modification, The, 20-9  
   Average Acceleration Method,  
   20-5  
   Stability, 20-4  
   Summary of Methods, 20-9  
   Wilson's Modification, 20-6  
 Newton's Second Law, 3-5, 12-1  
 Nonlinear Elements, 21-1

Nonlinear Equilibrium Equations,  
 18-3  
 Nonlinear Stress-Strain, 18-2  
 Non-Prismatic Element, 4-1  
 Normal Rotations, 9-1  
 Numerical Accuracy, C-20  
 Numerical Damping, 13-5  
 Numerical Integration Rules, G-1  
   Gauss 1D Rule, 5-4  
   5 Point 2D Rule, G-1  
   8 Point 2D Rule, G-1  
   6 Point 3D Rule, G-10  
   14 Point 3D Rule, G-8  
 Numerical Operation, Definition, B-6,  
 H-1  
 Numerical Problems, 7-3  
 Numerical Truncation, 7-3

**O**

Orthogonal Damping Matrices, 19-7  
 Orthogonality Conditions, 13-2  
 Orthotropic Materials, 1-5

**P**

Paging Operating System, H-3  
 Partial Gauss Elimination, 4-13, C-13  
 Participating Mass Ratios, 13-11  
 Patch Test, 2-3, 6-1, 8-9  
 P-Delta Effects, 11-1, 17-3, 18-1  
 Penalty Functions, 7-16  
 Penzien, J., 15-24, 16-15  
 Periodic Dynamic Loading, 13-10  
 Piece-Wise Linear Loading, 13-1  
 Pivoting, C-6  
 Plane Strain, 1-6  
 Plane Stress, 1-7  
 Plasticity Element, 21-3  
 Plate Bending Elements, 8-1  
   Constant Moment, 8-9  
   Convergence, 8-11  
   DKE, 8-12  
   DSE, 8-12, 10-6

- Examples, 8-11
- Patch Test, 8-9
- Point Load, 8-13
- Positive Displacements, 8-5
- PQ2, 8-11
- Properties, 8-8
- Reference Surface, 8-1
- Shearing Deformations, 8-2
- Strain-Displacement Equations, 8-7
- Thin Plates, 8-1
- Torsion, 8-16
- Triangular Element, 8-10
- Point Loads, 2-2
- Poisson's Ratio, 1-1, 6-3
- Popov, Egor P., 1-12
- Principal Directions, 17-10
- Principal Stresses, D-4
- Profile Storage of Stiffness Matrix, C-15

## Q

- Quadrature Rules, G-1, G-2
- Quadrilateral Element, 5-7, 8-3, 9-2, 10-2

## R

- Radiation Boundary Conditions, 16-11
- Rafai, M.S., 6-2
- Rank Deficient Matrix, 5-11
- Rayleigh Damping, 19-1, 19-6
- Recurrence Solution for Arbitrary Dynamic Loading, 13-10
- Relative Displacements, 22-2
- Relative Rotations, 9-6, 9-7
- Response Spectrum Analyses, 15-1
  - CQC Modal Combination, 15-8
  - CQC3 Direction Combination, 15-15
  - Definitions, 15-2
  - Design Spectra, 15-12
  - Limitations, 15-21

- Numerical Evaluation, 13-8
- Principal Stresses, 15-22
- SRSS Directional Combination, 15-17
- SRSS Modal Combinations, 15-8
- Story Drift, 15-21
- Stress Calculations, 15-22
- Typical Curves, 15-4
  - 100/30 and 100/40 Directional Combination Rules, 15-17
- Rigid Body Constraints, 7-11
- Rigid Body Displacements, 4-4, 7-11
- Rigid Body Rotation, 7-8
- Rigid Elements, 7-3
- Rigid Zones, 7-14
- Ritz Method, 14-1
- Rotation Definition, 2-4

## S

- SAFE Program, 8-17
- Scaling of Results, 17-11
- Scordelis-Lo Barrel Vault, 10-5
- Section Forces, 4-6
- Section Properties, 4-6
- Selective Integration, G-11
- SHAKE Program, 16-2
- Shape Functions, 5-3
- Shear Locking, 6-2, 9-9
- Shear Modulus, 1-6, 1-7, 1-8, 1-9
- Shear Wall Analysis, 7-13
- Shear Wave Velocity, 1-9
- Shearing Deformations, 4-8, 8-2, F-1
- Shell Elements, 10-1
- Shifting of Eigenvalues, 14-6
- Significant Figures, 7-4
- Simo, J. C., 6-2
- Simpson's Rule, 5-4
- Site Response Analysis, 16-2
- Slave Nodes, 7-9
- Soil-Structure Interactions, 16-1
- Solution of Equations, 2-11, 12-7, C-1

Sparse Matrix, 7-10  
 Speed of Computers, H-1  
 Spline Functions, J-4  
 Static Condensation, 4-13, 6-5, 8-10,  
 13-1, C-13  
 Static Load Participation Ratios,  
 13-13  
 Statically Determinate Structures, 2-7  
 Statically Indeterminate Structures,  
 3-1, 3-10  
 Step by Step Integration, 20-1  
 Strain Compatibility, 2-3  
 Strain Displacement Equations  
   2D Plane Elements, 9-5  
   3D Linear Solids, 2-4  
   3D Nonlinear Solids, 11-11  
   Plate Bending, 8-7  
 Strain Energy, 1-1  
 Strang, G., 6-1  
 Stress Continuity, 2-5  
 Stress Definition, 1-2  
 Stress Resultant, 2-2  
 Stress-Strain Relationship, 1-1, 9-6  
 Structural Design, 7-3  
 Sturm Sequence Check, 14-3  
 Subspace Iteration, 14-5  
 Substructure Analysis, C-13

## T

Tapered Rod Analysis, 5-5  
 Taylor, R. L., 6-1, 20-8  
 Tension Only Element, 18-3  
 Tension-Gap-Yield Element, 21-6  
 Tetrahedral Elements, 5-14  
 Thermal Strains, 1-3  
 Thermal Stresses, 1-4  
 Time Increment, 13-5, 13-8  
 Time Step Size, 22-9  
 Torsional Effects on Buildings, 17-12

Torsional Flexibility, 4-8  
 Torsional Force, 1-11  
 Torsional Moment of Inertia, 1-11  
 Torsional Stiffness, 1-11, 4-8  
 Triangular Elements, 5-14, 9-8, 10-4  
 Truncation Errors, 7-3  
 Truss Element, 2-7

## U

Undamped Free Vibration, 12-8  
 Uplifting Frame, 18-9, 18-13

## V

Vector Cross Product, A-2  
 Vector Notation, A-1  
 Vectors Used to Define Local  
   Reference System, A-4  
 Vertical Earthquake Response, 14-15  
 Virtual Displacements, 3-3  
 Virtual Work, 3-1  
 Viscous Damping, 19-1  
 Volume Change, 1-8

## W

Watabe, M., 15-24  
 Wave Loading, 13-10  
 Wave Propagation, 1-10, 16-11  
 WAVES Program, 16-2, 16-15  
 Wind Loading, 13-10

## Y

Young's Modulus, 1-6, 1-8  
 Yuan, M., 14-19

## Z

Zero Energy Mode, 9-7