Acceleration

The second time derivative of the displacement (the first time derivative of the velocity).

Adaptivity

see mesh adaptivity.

Algebraic Eigenvalue Problem

the eigenvalue problem can be written in the form (K-?M)u=0, which is: stiffness times mode shape minus eigenvalue times mass times mode shape is equal to zero. It is the form that arises naturally from a discrete parameter model in free vibration.

Algebraic Eigenvalue Problem

The eigenvalue problem when written in the form of stiffness times mode shape minus eigenvalue times mass times mode shape is equal to zero. It is the form that arises naturally from a discrete parameter model in free vibration.

Almansi Strain

strain defined in the deformed state as changes in squared length per twice the new squared length. It is given by (dS2 - dS02)/(2 dS2), where dS0 and dS are the undeformed and deformed lengths (see also Green's strain).

Alternating Plasticity

occurs in cyclic loading (q.v.) when there is a progressive increase in total strain with each cycle.

Anisotropy

a material where the response to load depends on the direction within the material. In general, 21 independent constants are required to relate stress and strain.

Arbitrary Lagrangian Eulerian Mesh Updating

an automatic mesh re-zoning algorithm where a manual decision is replaced by regular re-zoning operations carried out at fixed time increments or number of calculation cycles.

Arc Length Method

a non-linear iterative technique used to solve non-linear problems at or near limit points, where there is a change in sign of the slope of the load-displacement curve.

Aspect Ratios

the ratio of the different element side or edge lengths, used for establishing amounts of distortion (q.v.).

Assembly

The process of assembling the element matrices together to form the global matrix. Typically element stiffness matrices are assembled to form the complete stiffness matrix of the structure.

Associative Plasticity

a form of plasticity in which the yield function and the plastic potential are identical.

Augmented Lagrangian Method

a combination of the penalty function and Lagrange multiplier methods (q.v.). Used in contact analysis, where the contact force is defined in terms of the Lagrange multiplier plus a penalty stiffness term.

Automatic Load/Time Incrementation

a method for automatic incrementation in an applied load or time incremental-iterative solution process, i.e. the increment sizes are not specified by the analyst.

Automatic Mesh Generation

The process of generating a mesh of elements over the volume that is being analysed. There are two forms of automatic mesh generation: Free Meshing - Where the mesh has no structure to it. Free meshing generally uses triangular and tetrahedral elements. M

Automatic Node Renumbering Bandwith Profile Wavefront

The process of renumbering the nodes or elements to minimise the bandwidth, the profile or the wavefront of the assembled matrix. This renumbering is normally transparent to the user.

Axisymmetric Element

An element defined by rotating a cross-section about a centre line.

Axisymmetric Thin Shell Axisymmetrical Thick Shell

An element forms an axisymmetric thin shell if a line element is rotated about an axis. An element forms an axisymmetric thick shell if a triangular or quadrilateral element is rotated about an axis.

Bandwidth

The half bandwidth of a matrix is the maximum distance of any non-zero term in the matrix from the leading diagonal of the matrix. The bandwith for a symmetric matrix is then twice this.

Barlow Points

The set of Gauss integration points that give the best estimates of the stress for an element. For triangles and tetrahedra these are the full Gauss integration points. For quadrilateral and brick elements they are the reduced Gauss points.

Basis Space

When an element is being constructed it is derived from a simple regular shape in non-dimensional coordinates. The coordinates used to define the simple shape form the basis space. In its basis space a general quadrilateral is a 2x2 square and a general t

Bauschinger Effect

observed in plasticity when, after initial tensile loading into the plastic region, the yield stress in compression is less than the equivalent value in tension.

Beam Element

A line element that has both translational and rotational degrees of freedom. It represents both membrane and bending actions.

Bending

Bending behaviour is where the strains vary linearly from the centre line of a beam or centre surface of a plate or shell. There is zero strain on the centre line for pure bending. Plane sections are assumed to remain plane. If the stresses are constant n

Bifurcation

occurs on a non-linear load-displacement curve as the load path forks into two or more solution paths that satisfy equilibrium. Only one path is stable, the others being unstable.

Body Force Vector

Mechanical loadings within the interior of the volume, typically inertia loadings in a stiffness analysis.

Boundary Conditions

prescribed degrees of freedom and other quantities within a finite element model, which represent the physical model and are required to produce a unique solution for any type of applied loading.

Brittle Fracture

This is the type of fracture occurring for a crack in a material whose behaviour is described as brittle, when any plastic deformation is very limited so that fracturing occurs without significant prior deformation. This is typified by glassy materials a

Bubble Functions

Element shape functions that are zero along the edges of the element. They are non-zero within the interior of the element.

Buckling

Buckling is a geometric instability, generally caused by compressive forces in thin-sectioned bodies. It can be analysed as a special case of geometric non-linearity using eigenvalue analysis.

Buckling (Snap Through)

The situation where the elastic stiffness of the structure is cancelled by the effects of compressive stress within the structure. If the effect of this causes the structure to suddenly displace a large amount in a direction normal to the load direction t

Cam-Clay Model

a model describing the behaviour of clay-type soils, using a hardening/softening elastic-plastic constitutive law based on the critical state framework whose yield surface plots as a logarithmic curve

Cauchy Stress

see true stress.

Cell

a term used in CFD for a discrete area or volume over which the governing equations are integrated, equivalent to an element in finite element methods. The complete group of cells should define the domain under consideration.

Central Difference Method

A method for numerically integrating second order dynamic equations of motion. It is widely used as a technique for solving non-linear dynamic problems.

Characteristic Value

Same as the eigenvalue.

Cholesky Factorisation (Skyline)

A method of solving a set of simultaneous equations that is especially well suited to the finite element method. It is sometimes called a skyline solution. Choose to optimise the profile of the matrix if a renumbering scheme is used.

Closed-Form Displacement Method

for fracture mechanics, a special form of displacement substitution that only uses the calculated values in the crack tip elements.

Coefficient Of Viscous Damping

the constants of proportionality relating the velocities to the forces.

Column Vector (Column Matrix)

An nx1 matrix written as a vertical string of numbers. It is the transpose of a row vector.

Compatibility Equations

Compatibility is satisfied if a field variable, typically the structural displacement, which is continuous before loading is continuous after loading. For linear problems the equations of compatibility must be satisfied. Nonlinearity in or non-satisfactio

Compatibility Of Strains

Compatibility of strain is satisfied if strains that are continuous before loading are continuous after. Admin

Complete Displacement Field

When the functions interpolating the field variable (typically the displacements) form a complete n'th order polynomial in all directions.

Complex Eigenvalues

the eigenvalues of any damped system. If the damping is less than critical they will occur as complex conjugate pairs even for proportionally damped systems. The real part of the complex eigenvalue is a measure of the damping in the mode and should alway

Complex Eigenvectors

the eigenvectors of any damped system. For proportionally damped systems, they are the same as the undamped eigenvectors. For non-proportionally damped systems with damping in all modes less than critical they are complex numbers and occur as complex con

Compressible Flow

flow in gaseous fluids where speeds are sufficiently high, causing significant fluid density changes. It typically occurs when the Mach number (q.v.) exceeds approximately 0.3.

Condensation Static Condensation Modal Condensation

The reduction of the size of a problem by eliminating (condensing out) some degrees of freedom. For static condensation the elimination process is based upon static considerations alone. In more general condensation it can include other effects, typically

Condition Number

The ratio of the highest eigenvalue to the lowest eigenvalue of a matrix. The exponent of this number gives a measure of the number of digits required in the computation to maintain numerical accuracy. The higher the condition number the more chance of nu

Conditional Stability Unconditional Stability

Any scheme for numerically integrating dynamic equations of motion in a step by step form is conditionally stable if there is a maximum timestep value that can be used. It is unconditionally stable (but not necessarily accurate) if any length of time ste

Conduction

a mode of heat transfer in which the heat energy is transferred on a molecular scale with no movement of macroscopic particles (matter) relative to one another: described by Fourier's law.

Congruent Transformation

A transformation of the coordinate system of the problem that preserves the symmetry of the system matrices.

Conjugate Gradient Method

A method for solving simultaneous equations iteratively. It is closely related to the Lanczos method for finding the first few eigenvalues and eigenvectors of a set of equations.

Conservation Of Energy

the energy entering or leaving a volume of fluid due to flow convection and conduction is balanced by the energy of the fluid volume over time and the dissipation due to viscous forces.

Conservation Of Mass

the condition that mass cannot be created or destroyed within a fluid flow system.

Conservative Load

a load that always acts in a fixed direction regardless of the deformation of the body, for example, gravity.

Consistent Displacements And Forces

The displacements and forces act at the same point and in the same direction so that the sum of their products give a work quantity. If consistent displacements and forces are used the the resulting stiffness and mass matrices are symmetric.

Consistent Tangent Stiffness Method

a technique in plasticity analysis using stiffnesses at each iteration that accurately incorporates the current state of plasticity.

Constant Strain Constant Stress

For structural analysis an element must be able to reproduce a state of constant stress and strain under a suitable loading to ensure that it will converge to the correct solution. This is tested for using the patch test.

Constitutive Equation

a description of any linear or non-linear material behaviour law, usually relating strain, stress and temperature.

Constitutive Relationships

The equations defining the material behaviour for an infinitesimal volume of material. For structures these are the stress-strain laws and include Hookes law for elasticity and the Prandle-Reuss equations for plasticity.

Constrained Methods

non-linear solution procedures in which the solution is constrained to follow a certain path during the iteration process, e.g. arc length methods (q.v.).

Constraint Equations (Multi Point Constraints)

If one group of variables can be defined in terms of another group then the relationship between the two are constraint equations. Typically the displacements on the face of an element can be constrained to remain plane but the plane itself can move.

Constraints

fixed relationships between the basic degrees of freedom in a finite element model.

Contact Instability

this occurs in contact analysis when instabilities are generated due to local mesh density and hourglassing. They can cause convergence problems.

Contact Problems

A contact problem occurs when two bodies that are originally apart can come together, or two bodies that are originally connected can separate.

Continuous Mass Models

the system mass is distributed between the degrees of freedom in a kinematically equivalent manner. The mass matrix is not diagonal.

Continuous Models

The model is defined in terms of partial differential equations rather than in finite degree of freedom matrix form.

Continuum Region Element (Cre) Method

a single element test where the element is defined within a region where there is a known stress field. Point loads and nodal displacements can then be calculated and applied over the element, whose shape can vary at will, to test the element's response.

Contour Plotting

A graphical representation of the variation of a field variable over a surface. A contour line is a line of constant value for the variable. A contour band is an area of a single colour for values of the variable within two limit values.

Convected Coordinate Formulation (Also Called Co-Rotational Formulation)

a geometrically non-linear formulation in which a local cartesian coordinate system is attached to the element and is allowed to continuously translate and rotate with the element during deformation.

Convection

a mode of heat transfer between a fluid and solid boundary. The heat energy is transferred by the movement of macroscopic fluid particles.

Convergence

for any non-linear solution procedure, convergence is achieved when sufficient iterations within a given increment of time or load have produced an equilibrium state to within a given convergence criterion.

Convergence Requirements

For a structural finite element to converge as the mesh is refined it must be able to represent a state of constant stress and strain free rigid body movements exactly. There are equivalent requirements for other problem types.

Convolution Integral (Duhamel Integral)

The integral relating the dynamic displacement response of the structure at any time t to the forces applied before this time.

Coordinate System

The set of displacements used to define the degrees of freedom of the system.

Corresponding Forces And Displacements

A force and a displacement are said to correspond if they act at the same point and in the same direction. Forces and translational displacements can correspond as can moments and rotations. Corresponding forces and displacements can be multiplied togethe

Coulomb Damping (Also Called Dry Friction Damping)

a damping model in which the damping force is a constant and always opposes the velocity of motion.

Coupled Problems

these occur when multiple geometric domains are to be linked or when different physical states are to be solved, in each case in a dependent manner.

Crack Closure Work Methods

these calculate the energy release rate by two finite element calculations, calculating the point force needed to either open or close the crack over a short length after the first run, and equating this work done to the required energy change; several v

Crack Element (Crack Tip Element)

An element that includes special functions to model the stress field at the tip of a crack. This is commonly achieved by using quadratic elements with mid side nodes at the quarter chord points.

Crack Profile Or Front

The sharp end of a crack inside a three dimensional body, which is a curve of known position and of finite length, and which can vary with time. Any two dimensional section cutting this crack profile will contain a part of the crack ending in a crack tip

Crack Propagation (Fracture Mechanics)

The process by which a crack can propagate through a structure. It is commonly assumed that a crack initiates when a critical value of stress or strain is reached and it propagates if it can release more than a critical amount of energy by the crack openi

Crack Tip

The sharp end of a crack inside a given two dimensional body, at a point whose position is known and which may move over time.

Crack Tip Elements

finite elements sited around crack tips, modified to contain displacement variations representing the singular strain fields that exist there, thereby giving greater accuracy than the standard polynomial variations.

Crack Tip Equations

These are mathematical equations which are valid for elastic crack tip conditions, relating components of stress and displacement with local geometric position relative to the crack tip. The equations give the stress intensity factors.

Crack Tip Opening Displacement (Ctod)

This is a measure of how much the crack tip opens up under load when significant plastic deformation occurs in that region. It is useful as a fracture parameter.

Crank-Nicholson Scheme

A method for numerically integrating first order dynamic equations of motion. It is widely used as a technique for solving thermal transient problems.

Creep Laws

the laws that govern time dependent creep, based on simple experimental tests. Typical laws are those of Norton, Prandtl, and Bailey.

Creep Strain

irrecoverable permanent strain due to time dependent creep.

Critical Damping

the damping value for which the impulse response is just oscillatory.

Critical Values

These are numerical quantities representing the various fracture parameters, at those levels of load that cause some relevant fracture event to happen. For example, the critical value of the stress intensity factor is the fracture toughness.

Critically Damped System

the dividing line between under damped and over damped systems where the equation of motion has a damping value that is equal to the critical damping.

Critically Damped System Critical Damping

The dividing line between under damped and over damped systems where the equation of motion has a damping value that is equal to the critical damping.

Cyclic Loading

loads that repeatedly oscillate between maximum and minimum values over time.

Cyclic Symmetry

geometric repetition in the form of cyclic sectors that can be used to minimise mesh modelling.

Cyclic Symmetry

A generalisation of axisymmetry. The structure is composed of a series of identical sectors that are arranged circumferentially to form a ring. A turbine disc with blades attached is a typical example.

Damage Tolerance

a design and operational philosophy in which products are regularly inspected for damage, crack growth, etc., so that continued operation with the damage will not produce an imminent failure.

Damped Eigenvalues

Same as complex eigenvalues.

Damped Eigenvectors

Same as complex eigenvectors.

Damping

any mechanism that dissipates energy; important in dynamics analysis.

Damping Factor (Decay Factor)

The damping factor is the ratio of the actual damping to the critical damping. It is often specified as a percentage. If the damping factor is less than one then the system can undergo free vibrations. The free vibrations will decay to zero with time. If

Damping Factor/Ratio

the ratio of the viscous damping coefficient to the critical damping value.

Degenerate Elements

Elements that are defined as one shape in the basis space but they are a simpler shape in the real space. A quadrilateral can degenerate into a triangle. A brick element can degenerate into a wedge, a pyramid or a tetrahedron. Degenerate elements should b

Degrees Of Freedom

The number of equations of equilibrium for the system. In dynamics, the number of displacement quantities which must be considered in order to represent the effects of all of the significant inertia forces.

Delamination

the separation of layers of composites under stress.

Det(J) Det J

The Jacobian matrix is used to relate derivatives in the basis space to the real space. The determinant of the Jacobian - det(j) - is a measure of the distortion of the element when mapping from the basis to the real space.

Deterministic Analysis

The applied loading is a known function of time.

Deviatoric Stress And Strain

represents the shear component of stress and strain, i.e. the remainder after deducting the hydrostatic component (q.v.). The deviatoric components govern plastic and creep flows, where there is change in shape but not of volume.

Diagonal Decay

When a matrix is factorised into a triangular form the ratio of a diagonal term in the factorised matrix to the corresponding term in the original matrix decreases in size as one moves down the diagonal. If the ratio goes to zero the matrix is singular an

Diagonal Generalised Matrix

The eigenvectors of a system can be used to define a coordinate transformation such that, in these generalised coordinates the coefficient matrices (typically mass and stiffness) are diagonal

Die-Away Length

If there is a stress concentration in a structure the high stress will reduce rapidly with distance from the peak value. The distance over which it drops to some small value is called the die-away length. A fine mesh is required over this die-away length

Direct Integration

The name for various techniques for numerically integrating equations of motion. These are either implicit or explicit methods and include central difference, Crank-Nicholson, Runge-Kutta, Newmark beta and Wilson theta.

Direction Cosines

The cosines of the angles a vector makes with the global x,y,z axes.

Discrete Crack Model

in non-linear concrete analysis, a model that attempts to follow individual cracks.

Discrete Parameter Models (Discretised Approach)

The model is defined in terms of an ordinary differential equation and the system has a finite number of degrees of freedom.

Displacement Control

when displacements are selected as the controlling parameter in a non-linear solution (as opposed to load or time control).

Displacement Method (Displacement Solution)

A form of discrete parameter model where the displacements of the system are the basic unknowns.

Displacement Substitution Method

a method of calculating the stress intensity factor at a given crack tip using the local displacements from FE analysis and known crack tip equations.

Displacement Vector

The nodal displacements written as a column vector.

Dissimilar Shape Functions Incompatible Shape Functions

If two connecting elements have different shape functions along the connection line they are said to be incompatible. This should be avoided since convergence to the correct solution cannot be guarantied.

Distortion (Also Called Shape Sensitivity)

an indication of how much an element's shape differs from the theoretical shape for that element type.

Distortion Element Distortion

Elements are defined as simple shapes in the basis space, quadrilaterals are square, triangles are isosoles triangles. If they are not this shape in the real space they are said to be distorted. Too much distortion can lead to errors in the solution

Domain Integrals

used in fracture mechanics to evaluate fracture parameters at a crack tip, calculated using an expression integrated over an area inside a given path surrounding the tip (also called thick contours; the area form of the J-integral (q.v.)).

Drucker-Prager Equivalent Stresses

An equivalent stress measure for friction materials (typically sand). The effect of hydrostatic stress is included in the equivalent stress.

Drucker-Prager Yield Criterion

an elasto-plastic material model using both hydrostatic and deviatoric stresses, that is an inverted cone in principal stress space. Used in soil mechanics.

Ductile Fracture

This is the type of fracture occurring for a crack in a material whose behaviour is ductile, i.e. when plastic deformation is considerable. Such fracturing occurs, after some general plastic deformation as the load builds up, in metals at temperatures ab

Dynamic Contact

the analysis of contacting surfaces when inertia effects cannot be ignored.

Dynamic Flexibility (Also Called Receptance)

the factor relating the steady state displacement response of a system to a sinusoidal force input.

Dynamic Flexibility Matrix

the matrix relating the complete set of steady state displacement responses to all possible sinusoidal force inputs. It is always symmetric for linear systems. It is the Fourier transform of the impulse response matrix.

Dynamic Modelling

A modelling process where consideration as to time effects in addition to spatial effects are included. A dynamic model can be the same as a static model or it can differ significantly depending upon the nature of the problem.

Dynamic Stiffness Matrix

if the structure is vibrating steadily at a frequency w then the dynamic stiffness matrix is (K+iwC-w2M).

Dynamic Stresses

Stresses that vary with time and space.

Dynamic Substructuring

Special forms of substructuring used within a dynamic analysis. Dynamic substructuring is always approximate and causes some loss of accuracy in the dynamic solution.

Effective Strain (Also Called Equivalent Strain)

A scalar quantity defined (usually as the von Mises strain) to represent the individual strain components at any reference point also used for strain rates.

Effective Stress (Also Called Equivalent Stress)

A scalar quantity defined (usually as the von Mises stress, q.v.) to represent the individual stress components at any reference point.

Eigenvalues

the roots of the characteristic equation of a dynamic system. If the system has n equations of motion then it has n eigenvalues. The square root of the eigenvalues are the resonant frequencies. These are the frequencies that the structure will vibrate at

Eigenvalues Latent Roots Characteristic Values

The roots of the characteristic equation of the system. If a system has n equations of motion then it has n eigenvalues. The square root of the eigenvalues are the resonant frequencies. These are the frequencies that the structure will vibrate at if given

Eigenvectors

the displaced shape that corresponds to the eigenvalues. If the structure is excited at a resonant frequency then the shape that it adopts is the mode shape corresponding to the eigenvalue.

Eigenvectors Latent Vectors Normal Modes

The displacement shape that corresponds to the eigenvalues. If the structure is excited at a resonant frequency then the shape that it adopts is the mode shape corresponding to the eigenvalue. Latent vectors and normal modes are the same as eigenvectors.

Elastic Follow-Up

a structural phenomenon in which creep strain concentrates in rapidly creeping regions which are also relatively stiff; also analogously in plasticity.

Elastic Foundation

If a structure is sitting on a flexible foundation the supports are treated as a continuous elastic foundation. The elastic foundation can have a significant effect upon the structural response.

Elastic Stiffness

If the relationship between loads and displacements is linear then the problem is elastic. For a multi-degree of freedom system the forces and displacements are related by the elastic stiffness matrix.

Elastic Unloading

this can occur in regions of structures that have become plastic and then have their stresses reduced to become elastic again, with plastic strains remaining.

Elastic-Plastic Fracture Mechanics

see post yield fracture mechanics.

Element

In the finite element method the geometry is divided up into elements. Each element has nodes associated with it. The behaviour of the element is defined in terms of the freedoms at the nodes.

Element Assembly

Individual element matrices have to be assembled into the complete stiffness matrix. This is basically a process of summing the element matrices. This summation has to be of the correct form. For the stiffness method the summation is based upon the fact t

Element Strains Element Stresses

Stresses and strains within elements are usually defined at the Gauss points (ideally at the Barlow points) and the node points. The most accurate estimates are at the reduced Gauss points (more specifically the Barlow points). Stresses and strains are us

Element Types

a formal definition of individual element formulations.

Energy Difference Technique

used in fracture mechanics to evaluate the potential energy release rate at a single crack tip from the potential energies of two finite element runs differing only by a small change in crack length.

Energy Methods Hamiltons Principle

Methods for defining equations of equilibrium and compatibility through consideration of possible variations of the energies of the system. The general form is Hamiltons principle and sub-sets of this are the principle of virtual work including the princi

Energy Release Rate

see strain energy release rate.

Engineering Normalisation Mathematical Normalisation

Each eigenvector (mode shape or normal mode) can be multiplied by an arbitrary constant and still satisfy the eigenvalue equation. Various methods of scaling the eigenvector are used Engineering normalisation - The vector is scaled so that the largest abs

Engineering Strain (Also Called Nominal Strain)

the ratio of the change in length over a given length to the original length.

Equilibrium Equations

Internal forces and external forces must balance. At the infinitesimal level the stresses and the body forces must balance. The equations of equilibrium define these force balance conditions.

Equilibrium Finite Elements

Most of the current finite elements used for structural analysis are defined by assuming displacement variations over the element. An alternative approach assumes the stress variation over the element. This leads to equilibrium finite elements.

Equivalent Material Properties

Equivalent material properties are defined where real material properties are smeared over the volume of the element. Typically, for composite materials the discrete fibre and matrix material properties are smeared to give average equivalent material prop

Equivalent Strain

see effective strain.

Equivalent Stress

see effective stress.

Ergodic Process

A random process where any one sample record has the same characteristics as any other record.

Eulerian Formulation

a geometrically non-linear formulation where the equilibrium conditions are evaluated in the deformed configuration (q.v. also Lagrangian formulation).

Eulerian Method Lagrangian Method

For non-linear large deflection problems the equations can be defined in various ways. If the material is flowing though a fixed grid the equations are defined in Eulerian coordinates. Here the volume of the element is constant but the mass in the element

Exact Solutions

Solutions that satisfy the differential equations and the associated boundary conditions exactly. There are very few such solutions and they are for relatively simple geometries and loadings.

Explicit Solution Scheme

an algorithm, used in many time or load dependent analyses, whereby the solution for the next increment of time or load is obtained entirely from the solution and conditions at the previous step (q.v. also implicit solution). It is used in both static an

Extrapolation Interpolation

The process of estimating a value of a variable from a tabulated set of values. For interpolation values inside the table are estimated. For extrapolation values outside the table are estimated. Interpolation is generally accurate and extrapolation is onl

Faceted Geometry

If a curved line or surface is modelled by straight lines or flat surfaces then the modelling is said to produce a faceted geometry.

Fail-Safe

a design philosophy in which products are designed in such a way that failures prior to the required operational life are not catastrophic.

Fast Fourier Transform

a method for calculating Fourier transforms that is computationally very efficient.

Field Problems

Problems that can be defined by a set of partial differential equations are field problems. Any such problem can be solved approximately by the finite element method.

Finite Differences

A numerical method for solving partial differential equations by expressing them in a difference form rather than an integral form. Finite difference methods are very similar to finite element methods and in some cases are identical.

Finite Volume Methods

A technique related to the finite element method. The equations are integrated approximately using the weighted residual method, but a different form of weighting function is used from that in the finite element method. For the finite element method the G

Flexibility Matrix Force Method

The conventional form of the finite element treats the displacements as unknowns which leads to a stiffness matrix form. Alternative methods treating the stresses (internal forces) as unknowns leads to force methods with an associated flexibility matrix.

Fluidity Parameter

in elastic-viscoplastic analysis, a parameter used in the evaluation of the viscoplastic strain rate.

Follower Forces

forces that change their direction to follow geometric deformation during a large deformation analysis.

Forced Response

the dynamic motion resulting from a time varying forcing function.

Forcing Function

the dynamic forces that are applied to a system.

Forcing Functions

The dynamic forces that are applied to the system.

Fourier Expansions Fourier Series

Functions that repeat themselves in a regular manner can be expanded in terms of a Fourier series.

Fourier Transform

a method for finding the frequency content of a time varying signal. If the signal is periodic it gives the same result as the Fourier series.

Fourier Transform Pair

the Fourier transform and its inverse which, together, allow the complete system to be transformed freely in either direction between the time domain and the frequency domain.

Fracture Parameters/Criteria

These are numerical quantities which represent the conditions at a crack tip in a given geometry at a given load level, e.g. , CTOD.

Framework Analysis

If a structure is idealised as a series interconnected line elements then this forms a framework analysis model. If the connections between the line elements are pins then it is a pin-jointed framework analysis. If the joints are rigid then the lines must

Free Vibration

the dynamic motion that results from specified initial conditions. The forcing function is zero.

Frequency Domain

a structure's forcing function and the consequent response is defined in terms of their frequency content. The inverse Fourier transform of the frequency domain gives the corresponding quantity in the time domain.

Frictional/Frictionless Contact

in contact analysis, the state of different surfaces coming into contact. Frictional is when the surfaces are sufficiently rough that friction is important and either sticking or slipping can occur. Frictionless is when the surfaces are assumed to be per

Frontal Solution Wavefront Solution

A form of solving the finite element equations using Gauss elimination that is very efficient for the finite element form of equations.

Froude Number

a fluid flow measure of the ratio of inertia forces to gravitational forces, typically used in free surface flows.

Gap Chattering

this occurs in contact analysis when certain gaps repeatedly open and close. This is an effect of the contact algorithm and can cause convergence problems.

Gap Elements

see contact elements.

Gauss Point Extrapolation Gauss Point Stresses

Stresses calculated internally within the element at the Gauss integration points are called the Gauss point stresses. These stresses are usually more accurate at these points than the nodal points.

Gaussian Elimination

A form of solving a large set of simultaneous equations. Within most finite element systems a form of Gaussian elimination forms the basic solution process.

Gaussian Integration Gaussian Quadrature

A form of numerically integrating functions that is especially efficient for integrating polynomials. The functions are evaluated at the Gauss points, multiplied by the Gauss weights and summed to give the integral.

Generalised Coordinates

A set of linearly independent displacement coordinates which are consistent with the constraints and are just sufficient to describe any arbitrary configuration of the system. Generalised coordinates are usually patterns of displacements, typically the sy

Generalised Mass

The mass associated with a generalised displacement.

Generalised Stiffness

The stiffness associated with a generalised displacement.

Geometric Stiffness Stress Stiffness

The component of the stiffness matrix that arises from the rotation of the internal stresses in a large deflection problem. This stiffness is positive for tensile stresses and negative for compressive stresses. If the compressive stresses are sufficiently

Geometrical Errors

Errors in the geometrical representation of the model. These generally arise from the approximations inherent in the finite element approximation.

Global Stiffness Matrix

The assembled stiffness matrix of the complete structure.

Green'S Strain

a strain measure used in geometric non-linear analysis and defined, with reference to the original configuration, as the change in the squared length divided by twice the original squared length. It is given by (dS2 - dS02)/(2 dS02), where dS0 and dS are

Gross Deformations

Deformations sufficiently high to make it necessary to include their effect in the solution process. The problem requires a large deflection non-linear analysis.

Gross Yielding

in elastic-plastic analysis, where widespread plasticity exists.

Guard Vectors

The subspace iteration (simultaneous vector iteration) method uses extra guard vectors in addition to the number of vectors requested by the user. These guard the desired vectors from being contaminated by the higher mode vectors and speed up convergence.

Guyan Reduction Method

A method for reducing the number of degrees of freedom in a dynamic analysis. It is based upon a static approximation and always introduces some error in the computed dynamic solution. The error depends upon the choice of master freedoms.

Gyroscopic Forces

Forces arising from Coriolis acceleration. These can destabilise a dynamic response and cause whirling.

Hardening

in non-linear material behaviour, the change in the current yield stress as plastic or creep straining occurs, such as work and strain hardening in plasticity, and time and strain hardening in creep.

Hardening Structure

A structure where the stiffness increases with load.

Harmonic Loading

A dynamic loading that is periodic and can be represented by a Fourier series.

Heat Conduction

The analysis of the steady state heat flow within solids and fluids. The equilibrium balance between internal and external heat flows.

Hermitian Shape Functions

Shape functions that provide both variable and variable first derivative continuity (displacement and slope continuity in structural terms) across element boundaries.

Hidden Line Removal

Graphical plots of models where non-visible mesh lines are not plotted.

Hierarchical Elements

element families with varying shape function orders such that the stiffness matrix of each order contains the stiffness matrices of each of the lower ordered elements as sub-matrices.

High Aspect Ratio Low Aspect Ratio

The ratio of the longest side length of a body to the shortest is termed its aspect ratio. Generally bodies with high aspect ratios (long and thin) are more ill-conditioned for numerical solution than bodies with an aspect ratio of one.

Holonomic Constraints

Constraints that can be defined for any magnitude of displacement.

Hookes Law

The material property equations relating stress to strain for linear elasticity. They involve the material properties of Youngs modulus and Poisson ratio.

Hourglass Effects

spurious element deformations due to zero energy modes (q.v.).

Hourglass Mode

Zero energy modes of low order quadrilateral and brick elements that arise from using reduced integration. These modes can propagate through the complete body.

H-Refinement P-Refinement

Making the mesh finer over parts or all of the body is termed h-refinement. Making the element order higher is termed p-refinement.

Hybrid Elements

Elements that use stress interpolation within their volume and displacement interpolation around their boundary.

Hydrostatic (Also Called Volumetric) Stress And Strain

is the average of the direct stress or strain components at any point of reference, ignoring the shear components. It causes change in volume but not change in shape of an element of material (q.v. also deviatoric stress and strain).

Hydrostatic Stress

The stress arising from a uniform pressure load on a cube of material. It is the average value of the direct stress components at any point in the body.

Hyperelasticity

a material which possesses an elastic potential function, known as the strain energy function, which is a scalar function of strain and whose derivatives with respect to each strain component gives the corresponding stress component.

Hysteretic Damping

a model for the dissipation of energy in which the damping force is proportional to the amplitude of the displacement and opposes the velocity of motion.

Ill-Conditioning Errors

Numerical (rounding) errors that arise when using ill-conditioned equations.

Ill-Conditioning Ill-Conditioned Equations

Equations that are sensitive to rounding errors in a numerical operation. The numerical operation must also be defined. Equations can be ill-conditioned for solving simultaneous equations but not for finding eigenvalues.

Implicit Solution Scheme

an algorithm, usable in many types of non-linearity, whereby the solution for the next increment of time or load is obtained from the solution at the previous step and conditions from the current step (q.v. also explicit solution). It is used in both sta

Impulse Response Function

the response of a system to an applied impulse.

Incompressibility

straining with zero volumetric strain (i.e. no change in volume).

Incompressible Flow

flow where the density is not a function of pressure and so remains constant, with a Mach number (q.v.) below approximately 0.3.

Incremental Formulation

the splitting up of applied load or time into small quantities (increments or steps) such that within each a meaningful converged solution can be conducted.

Incremental Solution

A solutions process that involves applying the loading in small increments and finding the equilibrium conditions at the end of each step. Such solutions are generally used for solving non-linear problems.

Inelastic Material Behaviour

A material behaviour where residual stresses or strains can remain in the body after a loading cycle, typically plasticity and creep.

Inertance (Also Called Accelerance)

the ratio of the steady state acceleration response to the value of the forcing function.

Inertia Force

the force that is equal to the mass times the acceleration.

Initial Buckling

The load at which a structure first buckles.

Initial Stiffness Method

a modified Newton-Raphson solution in which the initial linearly elastic, small displacement, stiffness matrix is used throughout the analysis.

Integration By Parts

A method of integrating a function where high order derivative terms are partially integrated to reduce their order.

Interpolation Functions Shape Functions

The polynomial functions used to define the form of interpolation within an element. When these are expressed as interpolations associated with each node they become the element shape functions.

Isoparametric Elements

elements in which the displacements and geometry variation within an element are represented by the same shape functions (q.v.).

Isotropic Hardening

this occurs when, as plastic strains increase after initial yielding, the yield surface in principal stress coordinates expands uniformly about the origin while still maintaining its shape and orientation.

Isotropic Material

Materials where the material properties are independent of the co-ordinate system.

Jacobi Method

A method for finding eigenvalues and eigenvectors of a symmetric matrix.

Jacobian Matrix

A square matrix relating derivatives of a variable in one coordinate system to the derivatives of the same variable in a second coordinate system. It arises when the chain rule for differentiation is written in matrix form.

Jacobians

a mathematical quantity reflecting the distortion of an element from the theoretically perfect shape for that element type. It can be used as an element shape parameter (q.v.).

J-Integral Method

used in fracture mechanics to evaluate fracture parameters at a single crack tip calculated using an expression integrated along a path surrounding the tip.

Kinematic Boundary Conditions

The necessary displacement boundary conditions for a structural analysis. These are the essential boundary conditions in a finite element analysis.

Kinematic Hardening

this occurs when, as plastic strains increase after initial yielding, the yield surface in principal stress coordinates translates as a rigid body while maintaining its initial shape and orientation.

Kinematically Equivalent Forces (Loads)

A method for finding equivalent nodal loads when the actual load is distributed over a surface of a volume. The element shape functions are used so that the virtual work done by the equivalent loads is equal to the virtual work done by the real loads over

Kinematically Equivalent Loads

the point loads that are applied at the nodes of an element to represent a distributed load and that have been derived analytically to give the same work done as the distributed load.

Kinematically Equivalent Mass

if the mass and stiffness are defined by the same displacement assumptions, then a kinetically equivalent mass matrix is produced. This is not a diagonal (lumped) mass matrix.

Kinetic Energy

the energy stored in a system arising from its velocity. In some cases, it can also be a function of the structural displacements.

Kinetic Energy

The energy stored in the system arising from its velocity. In some cases it can also be a function of the structural displacements.

Lagrange Interpolation Lagrange Shape Functions

A method of interpolation over a volume by means of simple polynomials. This is the basis of most of the shape function definitions for elements.

Lagrange Multiplier Technique

A method for introducing constraints into an analysis where the effects of the constraint are represented in terms of the unknown Lagrange multiplying factors.

Lagrangian Formulation

a geometrically non-linear formulation where the equilibrium conditions are satisfied in the fixed reference configuration (q.v. also Eulerian formulation).

Laminar Flow

a state of fluid motion where the fluid moves in layers without turbulence (q.v.).

Laminated Composite

a composite material where each fibre/resin layer is bonded to adjacent layers in the curing process.

Lanczos Method

A method for finding the first few eigenvalues and eigenvectors of a set of equations. It is very well suited to the form of equations generated by the finite element method. It is closely related to the method of conjugate gradients used for solving simu

Large Displacements

displacements that are sufficiently large to render small displacement theory invalid.

Large Rotations

rotations that are sufficiently large to render small rotation theory invalid; relevant to beams, plates and shells.

Large Strains

strains that are sufficiently large to render small strain theory invalid.

Lay-Up

lay up of individual plies or layers to form laminated material. Plies may be arranged in alternating fibre orientations to produce favourable multidirectional strength.

Least Squares Fit

Minimisation of the sum of the squares of the distances between a set of sample points and a smooth surface. The finite element method gives a solution that is a least squares fit to the equilibrium equations.

Limit Points

points at which the tangent to the load-displacement curve becomes either horizontal or vertical and the structural stiffness matrix becomes singular under load or displacement control, respectively.

Line Search

a technique for accelerating incremental-iterative solution procedures.

Line Spring Analysis

a technique for modelling part-through cracks in shell type structures. An equivalent distributed spring replaces the crack with matching compliance, so the curvature is effectively ignored but the modelling is easier.

Linear Dependence

One or more rows (columns) of a matrix are linear combinations of the other rows (columns). This means that the matrix is singular.

Linear Elastic Fracture Mechanics (Lefm)

A given crack inside a loaded structure behaves in conditions of LEFM if the crack fields local to the crack tip are assumed to be elastic, and any plastic behaviour is neglected.

Linear System

When the coefficients of stiffness, mass and damping are all constant then the system is linear. Superposition can be used to solve the response equation.

Load Control

a means of advancing a non-linear solution using a load parameter: this is the conventional method, others being displacement and arc length control.

Loading

in the finite element method, the definition of field quantities that impart energy to the structure and are therefore the reason for the analysis.

Loadings

The loads applied to a structure that result in deflections and consequent strains and stresses.

Localisation

for softening materials, a tendency for non-linear behaviour to concentrate into local bands, requiring special treatment.

Logarithmic Strain

see true strain.

Lower Bound Solution Upper Bound Solution

The assumed displacement form of the finite element solution gives a lower bound on the maximum displacements and strain energy (i.e. these are under estimated) for a given set of forces. This is the usual form of the finite element method. The assumed st

Lumped Mass Model

the system mass is represented by a number of point masses or particles. The mass matrix is diagonal.

Mach Number

the ratio of the speed of a flowing fluid to the speed of sound in the fluid.

Mass

the constant(s) of proportionality relating the acceleration(s) to the force(s). For a discrete parameter multi-degree of freedom model, this is usually given as a mass matrix.

Mass Matrix

The matrix relating acceleration to forces in a dynamic analysis. This can often be approximated as a diagonal matrix with no significant loss of accuracy.

Master Freedoms

The freedoms chosen to control the structural response when using a Guyan reduction or substructuring methods.

Material Data

the data required to specify to the finite element process the relevant material properties.

Material Properties

The physical properties required to define the material behaviour for analysis purposes. For stress analysis typical required material properties are Young's modulus, Poisson's ratio, density and coefficient of linear expansion. The material properties mu

Material Stiffness Matrix Material Flexibility Matrix

The material stiffness matrix allows the stresses to be found from a given set of strains at a point. The material flexibility is the inverse of this, allowing the strains to be found from a given set of stresses. Both of these matrices must be symmetric

Matrix Displacement Method

A form (the standard form) of the finite element method where displacements are assumed over the element. This gives a lower bound solution.

Matrix Force Method

A form of the finite element method where stresses (internal forces) are assumed over the element. This gives an upper bound solution.

Matrix Inverse

If matrix A times matrix B gives the unit matrix then A is the inverse of B (B is the inverse of A). A matrix has no inverse if it is singular.

Matrix Notation Matrix Algebra

A form of notation for writing sets of equations in a compact manner. Matrix notation highlights the generality of various classes of problem formulation and solution. Matrix algebra can be easily programmed on a digital computer.

Matrix Products

Two matrices A and B can be multiplied together if A is of size (j*k) and B is of size (k*l). The resulting matrix is of size (j*l).

Matrix Transpose

The process of interchanging rows and columns of a matrix so that the j'th column becomes the j'th row.

Mean Square Convergence

A measure of the rate of convergence of a solution process. A mean square convergence indicates a rapid rate of convergence.

Mesh Adaptivity

the automatic alteration of meshes to provide refinement where the calculated variables vary rapidly and coarsening where they vary slowly.

Mesh Convergence

the progressive refinement of element size and positioning in mesh models (h-convergence) or increase in order of element type (p-convergence) to produce improvements in solution accuracy.

Mesh Density Mesh Refinement

The mesh density indicates the size of the elements in relation to the size of the body being analysed. The mesh density need not be uniform all over the body There can be areas of mesh refinement (more dense meshes) in some parts of the body. Making the

Mesh Design

the creation of a suitable mesh model, to represent the given structure with suitable refinement in regions of high field variation, good representation of boundaries, and incorporating all other required features.

Mesh Generation Element Generation

The process of generating a mesh of elements over the structure. This is normally done automatically or semi-automatically.

Mesh Specification

The process of choosing and specifying a suitable mesh of elements for an analysis.

Mesh Suitability

The appropriate choice of element types and mesh density to give a solution to the required degree of accuracy.

Mindlin Elements

A form of thick shell element.

Mixed Hardening

a combination of isotropic and kinematic hardening.

Modal Damping

The damping associated with the generalised displacements defined by the eigenvectors. Its value has no physical significance since the eigenvector contains an arbitrary normalising factor.

Modal Mass

The mass associated with the generalised displacements defined by the eigenvectors. Its value has no physical significance since the eigenvector contains an arbitrary normalising factor but the ratio of modal stiffness to modal mass is always the eigenva

Modal Stiffness

The stiffness associated with the generalised displacements defined by the eigenvectors. Its value has no physical significance since the eigenvector contains an arbitrary normalising factor but the ratio of modal stiffness to modal mass is always the ei

Modal Testing

The experimental technique for measuring resonant frequencies (eigenvalues) and mode shapes (eigenvectors).

Mode Participation Factor

The generalised force in each modal equation of a dynamic system.

Mode Shape

same as eigenvector (q.v.).

Modelling

The process of idealising a system and its loading to produce a numerical (finite element) model.

Modes Of Fracture

Three separate deformation modes exist at any point along a crack profile, representing the basic effects of crack opening, shearing and tearing, commonly known as modes I, II and III. In practice, combinations of these modes are usually present.

Modified Newton-Raphson Method

a Newton-Raphson solution in which the tangent stiffness matrix is updated only at the beginning of every increment.

Mohr-Coulomb Friction

frictional behaviour between surfaces in contact when relative slippage is governed by the coefficient of friction.

Mohr-Coulomb Yield Criterion

a generalisation of the Coulomb friction failure law; used for concrete, rock and soils, where the hydrostatic stress does not influence yielding. The criterion is an inverted hexagonal pyramid in principal stress space.

Mooney-Rivlin Strain Energy Function

is used in large strain elasticity (hyperelastic) problems, and is expressed in terms of the three strain invariants.

Multi Degree Of Freedom

The system is defined by more than one force/displacement equation.

Multigrid Methods

used in CFD to accelerate the convergence of iterative solution techniques based on the solution of a set of simultaneous correction equations, and allowing a reduction in the number of equations to be solved.

Multi-Point Constraints

Where the constraint is defined by a relationship between more than one displacement at different node points.

Natural Frequency (Also Called Resonant Frequency)

the frequency at which resonance occurs, that is when the stiffness and the inertia forces cancel.

Natural Mode

same as eigenvector (q.v.).

Natural Strain

see true strain.

Newmark Method Newmark Beta Method

An implicit solution method for integrating second order equations of motion. It can be made unconditionally stable.

Newmark'S Time Stepping Schemes

a family of time integration methods for the solution of transient dynamic problems.

Newton Cotes Formulae

A family of methods for numerically integrating a function.

Newton-Raphson Method

an incremental-iterative non-linear procedure to solve the equilibrium equations: the tangential stiffness matrix is updated during every iteration of every increment.

Newton-Raphson Non-Linear Solution

A general technique for solving non-linear equations. If the function and its derivative are known at any point then the Newton-Raphson method is second order convergent.

Nodal Values

The value of variables at the node points. For a structure typical possible nodal values are force, displacement, temperature, velocity, x, y, and z.

Node Nodes Nodal

The element behaviour is defined by the response at the nodes of the elements. Nodes are always at the corners of the element, higher order elements have nodes at mid-edge or other edge positions and some elements have nodes on faces or within the element

Non-Associative Plasticity

a form of plasticity in which the yield function is not identical to the plastic potential.

Non-Conforming Elements

Elements that do not satisfy compatibility either within the element or across element boundaries or both. Such elements are not generally reliable although they might give very good solutions in some circumstances.

Non-Linear System Non-Linear Analysis

When at least one of the coefficients of stiffness, mass or damping vary with displacement or time then the system is non-linear. Superposition cannot be used to solve the problem.

Non-Stationary Random

a force or response that is random and its statistical properties vary with time.

Non-Structural Mass

Mass that is present in the system and will affect the dynamic response but it is not a part of the structural mass (e.g. the payload).

Norm

A scalar measure of the magnitude of a vector or a matrix.

Normality Rule

a particular plastic flow rule to ensure that the plastic strain components are in a ratio such that their resultant is in a direction normal to the yield surface (q.v. also flow rule).

Norton Law/Norton-Bailey Law

a law for steady state creep with strain rate proportional to a power of stress.

Numerical Integration

the process of integrating the element stiffness matrix based on numerical algorithms such as Gaussian quadrature. Evaluations are made at strategic points within each element, known as Gauss points (q.v.).

Optimal Points

strategic locations within elements where stress evaluations are especially accurate, often at the Gauss point (q.v.) locations.

Optimal Sampling Points

The minimum number of Gauss points required to integrate an element matrix. Also the Gauss points at which the stresses are most accurate (see reduced Gauss points).

Over Damped System

a system that has an equation of motion where the damping is greater than critical. It has an exponentially decaying, non-oscillatory impulse response.

Overstiff Solutions

Lower bound solutions. These are associated with the assumed displacement method.

Parametric Studies Pilot Studies

Initial studies conducted on small simplified models to determine the important parameters in the solution of a problem. These are often used to determine the basic mesh density required.

Participation Factor

the fraction of the mass that is active for a given mode with a given distribution of dynamic loads. Often this is only defined for a specific load case of inertia (seismic) loads.

Patch Test

a simple element type test using a patch of several elements, one of which is arbitrarily orientated with respect to the global co-ordinates. If the patch is loaded by displacements consistent with a state of constant strain and the strain inside the sel

Penalty Function (Also Called Penalty Stiffness)

in the context of contact algorithms, a constraint on stiffness behaviour usually applied via large numbers in the equations, e.g. by introducing stiff springs.

Perfect Plasticity

plastic behaviour where the yield stress remains constant for all values of plastic strain.

Periodic Response (Force)

a response (force) that regularly repeats itself exactly.

Phase Angle

the ratio of the in-phase component of a signal to its out-of-phase component gives the tangent of the phase angle of the signal relative to some reference.

Plane Strain Plane Stress

A two dimensional analysis is plane stress if the stress in the third direction is assumed zero. This is valid if the dimension of the body in this direction is very small, e.g. a thin plate. A two dimensional analysis is plane strain if the strain in the

Plastic Strain

irrecoverable permanent strain due to time independent plasticity.

Plastic Zones

regions in a body where a stress measure (usually the equivalent stress) lies on the yield surface and plastic strains are accruing.

Plate Bending Elements

Two dimensional shell elements where the in plane behaviour of the element is ignored. Only the out of plane bending is considered.

Ply Lay-Up

see lay-up.

Poissons Ratio

The material property in Hookes law relating strain in one direction arising from a stress in a perpendicular direction to this.

Post Analysis Checks

Checks that can be made on the results after the analysis. For a stress analysis these could include how well stress free boundary conditions have been satisfied or how continuous stresses are across elements.

Post Yield Fracture Mechanics (Pyfm, Also Called Elastic-Plastic Fracture Mechanics, Epfm)

A given crack inside a loaded structure behaves in conditions of PYFM when the crack fields local to the crack tip exhibit considerable plastic behaviour.

Post-Processing

The interrogation of the results after the analysis phase. This is usually done graphically.

Potential Energy Release Rate

For a hypothetically small increase in crack length or area, this is the amount of potential energy released divided by that length or area. It equals the negative of the strain energy release rate (q.v.) when elastic conditions predominate. It provides

Potential Flow

Fluid flow problems where the flow can be represented by a scalar potential function.

Power Method

A method for finding the lowest or the highest eigenvalue of a system.

Prandtl Number

a fluid flow measure of the ratio of momentum diffusivity to thermal diffusivity.

Prandtl-Reuss Equations

The equations relating an increment of stress to an increment of plastic strain for a metal undergoing plastic flow.

Prandtl-Reuss Flow Rule

in plasticity theory, the special form of the normality rule corresponding to von Mises yield criterion (q.v.).

Predictor-Corrector Schemes

the two-phase format of a time or load stepping scheme where the predicted solution is corrected prior to advancing to the next step.

Primary Component

Those parts of the structure that are of direct interest for the analysis. Other parts are secondary components.

Primary Creep

the initial part of a creep test where the strain rate is decreasing.

Principal Planes

the planes on which the shear stresses are zero. Three such planes exist at every point in a stressed body.

Principal Stresses

stresses normal to the principal planes.

Profile

The profile of a symmetric matrix is the sum of the number of terms in the lower (or upper) triangle of the matrix ignoring the leading zeros in each row. Embedded zeros are included in the count. It gives a measure of the work required to factorise the m

Proportional Damping

a damping matrix that is a linear combination of the mass and stiffness matrices. The eigenvectors of a proportionally damped system are identical to those of the undamped system.

Proportional Loading

occurs when all the external loads are applied simultaneously, and increase in proportion to one another throughout the loading history. This clearly does not occur when one component of load is applied and then another.

Qr Method

A technique for finding eigenvalues. This is currently the most stable method for finding eigenvalues but it is restricted in the size of problem that it can solve.

Radiation

a mode of heat transfer due to electromagnetic waves. Thus, the heat energy can be transferred in a vacuum. It is characterised by the Stefan-Boltzmann law.

Radiation Damping

Damping that arises from energy being carried away from a vibrating body by expanding pressure waves. Sound radiation is an example of this. Such radiating energy, both to the surrounding fluid and through the supports, often forms the main damping in a v

Ramberg-Osgood Power Law

a stress-strain relationship where the strain is proportional to a power of stress.

Random Vibrations

The applied loading is only known in terms of its statistical properties. The loading is non-deterministic in that its value is not known exactly at any time but its mean, mean square, variance and other statistical quantities are known.

Rank Deficiency

A measure of how singular a matrix is.

Ratchetting

occurs in cyclic loading (q.v.) when plastic strains keep on accumulating incrementally with each cycle, leading to eventual failure via incremental collapse.

Rayleigh Damping

a model for representing the variation of damping with frequency.

Raylelgh Quotient

The ratio of stiffness times displacement squared (2*strain energy) to mass times displacement squared. The minimum values of the Rayleigh quotient are the eigenvalues.

Reaction Forces

The forces generated at support points when a structure is loaded.

Receptance

the ratio of the steady state displacement response to the value of the forcing function for a sinusoidal excitation. It is the same as the dynamic flexibility.

Reduced Integration

the process of intentionally under-integrating the element stiffness matrix to prevent problems such as shear locking or to improve the element's performance.

Residual Forces

the forces which are equal to the applied load minus the internal resisting forces which occur during non-linear solutions: used to measure the state of equilibrium by comparison to the convergence tolerance.

Response Spectrum Method

A method for characterising a dynamic transient forcing function and the associated solution technique. It is used for seismic and shock type loads.

Restarts Checkpoints

The process whereby an analysis can be stopped part way through and the analysis restarted at a later time.

Reynolds Number

a fluid flow measure of the ratio of momentum forces to viscous forces.

Rigid Body Deformations

A non-zero displacement pattern that has zero strain energy associate with it.

Rigid Body Displacement

A non-zero displacement pattern that has zero strain energy associate with it.

Rigid Body Modes

If a displaced shape does not give rise to any strain energy in the structure then this a rigid body mode. A general three dimensional unsupported structure has 6 rigid body modes, 3 translation and 3 rotation.

Rigid Links Rigid Offsets

This is a connection between two non-coincident nodes assuming that the connection is infinitely stiff. This allows the degrees of freedom at one of the nodes (the slave node) to be deleted from the system. It is a form of multi-point constraint.

Roundoff Error

Computers have a fixed wordlength and hence only hold numbers to a certain number of significant figures. If two close numbers are subtracted one from another then the result loses the first set of significant figures and hence loses accuracy. This is rou

Row Vector Row Matrix

A 1xn matrix written as a horizontal string of numbers. It is the transpose of a column vector.

Safe Life

a design philosophy in which products are designed to survive a specific operational life with a chosen reserve.

Sandwich Structure

a composite structure composed of lightweight core material (usually honeycomb or foam) to which two relatively thin, dense, high-strength, functional or decorative skins are adhered.

Scalars Vectors

Quantities that have no direction associated with them, e.g. temperatures. Scalar problems only have one degree of freedom at a node. Vector quantities have a direction associated with them, e.g. displacements. Vector problems have more than one degree of

Secant Stiffness

The stiffness defined by the slope of the line from the origin to the current point of interest on a load/deflection curve.

Second Piola-Kirchhoff Stress

the work conjugate stress measure to the Green strain.

Secondary Components

Components of a structure not of direct interest but they may have some influence of the behaviour of the part of the structure that is of interest (the primary component) and have to be included in the analysis in some approximate form.

Secondary Creep

that part of a creep test where the strain rate is constant.

Seepage Flow

Flows in porous materials

Seismic Analysis

The calculation of the dynamic displacement and stress response arising from earthquake exicitations.

Self Adjoint Equations

A form of matrix products that preserves symmetry of equations. The product A*B*A(transpose) is self-adjoint if the matrix B is symmetric. The result of the product will be symmetric for any form of A that is of a size compatible with B. This form of equa

Self Equilibrating Loads

A load set is self equilibrating if all of its resultants are zero. Both translation and moment resultants are zero.

Semi-Loof Element

A form of thick shell element.

Shakedown

occurs in cyclic loading where the plastic strain in each cycle stabilises so that the total strain within a cycle is less than twice the yield strain (the strain when the stress reaches the yield stress).

Shape Functions

equations which are used to define the variation of the geometry and main degrees of freedom (typically displacement) within an element: the equations vary over different element types.

Shape Parameters

ways of defining an element's shape, with particular reference to how the shape differs from the theoretically perfect shape for that element type. Parameters include aspect ratio (q.v.), taper, skew, curvature, warpage and variation of the Jacobian (q.v

Shear Locking

the phenomena which occurs when thick elements give overstiff results when modelling thin beams/plates/shells, due to an excess of shear energy being present. It can also affect 2D and 3D continuum elements.

Simpsons Rule

A method for numerically integrating a function.

Simultaneous Vector Iteration

A method for finding the first few eigenvalues and eigenvectors of a finite element system. This is also known as subspace vector iteration.

Single Element Tests

any test of an element's performance using only one element (q.v. also patch test and continuum region element (CRE) method).

Single Point Constraint

Where the constraint is unique to a single node point.

Singular Matrix

A square matrix that cannot be inverted.

Skew Distortion (Angular Distortion)

A measure of the angular distortion arising between two vectors that are at right angles in the basis space when these are mapped to the real coordinate space. If this angle approaches zero the element becomes ill- conditioned.

Sliding

in contact analysis, when adjacent surfaces move tangentially to one another.

Smeared Crack Model

in the non-linear analysis of concrete structures, a model which does not follow discrete cracks, but assumes damage is caused by closely spaced cracks associated with an integration point.

Snap Back (Also Called Snap Through)

a situation that occurs when a vertical line in the load-displacement curve is encountered, and two or more equilibrium states are possible for the same applied load.

Softening

in plastic flow, this is a contraction of the yield surface that leads to localisation phenomena.

Solid Elements

Three dimensional continuum elements.

Solution Diagnostics

Messages that are generated as the finite element solution progresses. These should always be checked for relevance but the are often only provided for information purposes

Solution Efficiency

an indication of the efficiency of the solution of the equations used in the finite element method, usually referring to the main stiffness equations. Minimising the number of such equations without compromising solution accuracy is a common challenge.

Sparse Matrix Methods

Solution methods that exploit the sparse nature of finite element equations. Such methods include the frontal solution and Cholesky (skyline) factorisation for direct solutions, conjugate gradient methods for iterative solutions and the Lanczos method and

Spectral Density

The Fourier transform of the correlation function. In random vibrations it gives a measure of the significant frequency content in a system. White noise has a constant spectral density for all frequencies.

Spline Curves

A curve fitting technique that preserves zero, first and second derivative continuity across segment boundaries.

Spurious Cracks

Cracks that appear in a mesh when the elements are not correctly connected together. This is usually an error in the mesh generation process.

Statically Determinate Structure

A structure where all of the unknowns can be found from equilibrium considerations alone.

Statically Equivalent Loads

Equivalent nodal loads that have the same equilibrium resultants as the applied loads but do not necessarily do the same work as the applied loads.

Statically Indeterminate Structure Redundant

A structure where all of the unknowns can not be found from equilibrium considerations alone. The compatibility equations must also be used. In this case the structure is said to be redundant.

Steady State Creep Law

a creep model in which there are no hardening or softening effects.

Steady State Response

The response of the system to a periodic forcing function when all of the transient components of the response have become insignificant.

Step

a series of computer readable data models which form an international standard for exchange of product definition data, relevant to finite elements as a medium for data transfer to and from CAD packages. It is planned to eventually replace the existing s

Step-By-Step Integration

Methods of numerically integrating time varying equations of motion. These methods can be either explicit or implicit.

Stiffness Matrix

The parameter(s) that relate the displacement(s) to the force(s). For a discrete parameter multi degree of freedom model this is usually given as a stiffness matrix.

Strain Energy

The energy stored in the system by the stiffness when it is displaced from its equilibrium position.

Strain Energy Release Rate

For a hypothetically small increase in crack length or area, this is the amount of strain energy released divided by that length or area. It equals the negative of the potential energy release rate (q.v.) when elastic conditions predominate.

Strain Hardening Law

used in analysing creep behaviour under variable load where the creep strain rate is assumed to depend on the current stress and accumulated creep strain, or in plasticity where the current yield stress is a function of the plastic strain.

Strain-Life Approach

in fatigue, a method whereby the predicted life of a product is based on calculated strain values, typically used in low cycle fatigue.

Stress Concentration

A local area of the structure where the stresses are significantly higher than the general stress level. A fine mesh of elements is required in such regions if accurate estimates of the stress concentration values are required.

Stress Discontinuities Stress Error Estimates

Lines along which the stresses are discontinous. If the geometry or loading changes abruptly along a line then the true stress can be discontinous. In a finite element solution the element assumptions means that the stresses will generally be discontinuou

Stress Extrapolation

The process of taking the stress results at the optimum sampling points for an element and extrapolating these to the element node points.

Stress Intensity Factor

a fracture parameter at a crack tip when under conditions of LEFM. It is a function of applied load and crack length, suitably dimensioned to have a finite value at the tip even though the stresses are singular there, and may be used to characterise the

Stress Relaxation

occurs in creep problems when the structure is loaded up to a certain stress level and then held at constant strain.

Stress Substitution Method

a method of calculating the stress intensity factor at a given crack tip using the local stresses from FE analysis and known crack tip equations.

Stress Vector Stress Tensor Strain Vector Strain Tensor

The stress (strain) vector is the components os stress (strain) written as a colunn vector. For a general three dimensional body this is a (6x1) matrix. The components of stress (strain) written in tensor form. For a general three dimensional body this f

Stress Waves

elastic stresses that propagate through materials at high speeds due to impact loads.

Stress-Life Approach

in fatigue, a method whereby the predicted life of a product is based on calculated stress values, typically at stress concentrations and for high cycle fatigue.

Structured Grid (Or Mesh)

a grid (in CFD) or mesh where the elements form a regular pattern.

Subspace Vector Iteration

A method for finding the first few eigenvalues and eigenvectors of a finite element system. This is also known as simultaneous vector iteration.

Substructure (Also Called Superelement)

a mesh modelling technique whereby a part of a structure, containing a number of elements, can be stored by the software as a single element. It can then be used for a variety of different purposes, just as if it were a new element type with its own stif

Substructuring Super Element Method

Substructuring is a form of equation solution method where the structure is split into a series of smaller structures - the substructures. These are solved to eliminate the internal freedoms and the complete problem solved by only assembling the freedoms

Superposition

For a linear system the response is the same if it is found by adding together two or more separate forcing functions and then solving the equations or by solving for the separate forcing functions and then adding the responses together. The second method

Supports

Degrees of freedom where the variable is known before the solution is found. Typically the zero displacements at fixed points in a structural analysis or the points of known temperature in a heat conduction analysis. Generally there must be some points of

Surface Element

Special elements that are used to model surface boundary conditions. Typically surface heat transfer elements used to model surface heat transfer coefficients in heat conduction problems.

Symmetrical Matrix Skew Symmetric Matrix Hermitian

A matrix is symmetric if it is square and if the ij term is equal to the ji term. A matrix is SKEW symmetric if it is square and if the ij term is equal to minus the ji term. All of the diagonal terms are zero. A matrix is Hermitian if it is square, the r

Symmetry

A structural problem is symmetric if one half of the structure and the loading is the mirror image of the other half. Symmetry can be used to half the problem size.

Tangent Stiffness

For non-linear problems this is the slope of the load/deflection curve for the current solution position.

Tangent Stiffness Matrix

the matrix of coefficients corresponding to the derivatives of the residual forces with respect to the displacement degrees of freedom: this matrix is evaluated and factorised during the incremental-iterative solution procedure.

Tertiary Creep

that part of a creep test where the strain rate is increasing.

Tetrahedron Tetrahedral Element

A three dimensional four sided solid element.

Thermal Capacity

The material property defining the thermal inertia of a material. It relates the rate of change of temperature with time to heat flux.

Thermal Conductivity

The material property relating temperature gradient to heat flux.

Thermal Contact

the analysis of contacting surfaces when thermal effects are significant.

Thermal Loads

The equivalent loads on a structure arising from thermal strains. These in turn arise from a temperature change.

Thermal Strains

The components of strain arising from a change in temperature.

Time Domain

The structures forcing function and the consequent response is defined in terms of time histories. The Fourier transform of the time domain gives the corresponding quantity in the frequency domain.

Time Hardening Law

used in analysing creep behaviour under variable load where the creep strain rate is assumed to depend on the current stress and time from the start of the test.

Time Stepping Schemes

methods for integrating the governing equations of time dependent non-linear problems. Examples include Newmark's family of methods for solving the transient dynamic equilibrium equations and time marching procedures for creep analysis.

Total Lagrangian Formulation

in geometrically non-linear analysis, a formulation in which all static and kinematic variables are referred to the initial undeformed configuration (see also updated Lagrangian formulation).

Trace Of The Matrix

The sum of the leading diagonal terms of the matrix.

Transfinite Mapping

A systematic method for generating element shape functions for irregular node distributions on an element.

Transformation Method

Solution techniques that transform coordinate and force systems to generate a simpler form of solution. The eigenvectors can be used to transform coupled dynamic equations to a series of single degree of freedom equations.

Transient Analysis

an analysis is transient when at least one of the parameters involved in the boundary conditions, material properties or loading conditions is time dependent.

Transient Force

A forcing function that varies for a short period of time and then settles to a constant value.

Transition Element

Special elements that have sides with different numbers of nodes. They are used to couple elements with different orders of interpolation, typically a transition element with two nodes on one edge and three on another is used to couple a 4-node quad to an

Tresca Yield Criterion

is used for metals and assumes that yielding starts when the maximum value of the shear stress reaches a given value. It gives a hexagonal cylindrical shape in principal stress space.

Triangular Elements

Two dimensional or surface elements that have three edges.

True Strain (Also Called Logarithmic Strain Or Natural Strain)

a particular strain measure used in large strain elasto-plasticity; the log of one plus the engineering strain, or the integral of the incremental change of length over the current length.

True Stress (Also Called Cauchy Stress)

the force divided by the current (instantaneous) area.

Turbulence

a chaotic state of fluid motion where the velocity and pressure at a point change continuously with time.

Ultimate Stress

The failure stress (or equivalent stress) for the material.

Undamped Natural Frequency

the square root of the ratio of the stiffness to the mass (the square root of the eigenvalue). It is the frequency at which an undamped system vibrates naturally. A system with n degrees of freedom has n natural frequencies.

Under damped system

a system that has an equation of motion where the damping is less than critical. It has an oscillatory impulse response.

Unstructured Grid (Or Mesh)

a grid (in CFD) or mesh where the elements form no regular pattern.

Updated Lagrangian Formulation

in geometrically non-linear analysis, a formulation in which all static and kinematic variables are referred to the last calculated configuration (see also total Lagrangian formulation).

Upwinding In Fluids

A special form of weighting function used in viscous flow problems (solution to the Navier-Stokes equations) used in the weighted residual method to bias the results in the direction of the flow.

Variable Bandwidth (Skyline)

A sparse matrix where the bandwidth is not constant. Some times called a skyline matrix.

Velocity

The first time derivative of the displacement.

Virtual Crack Extension Method

a method for calculating fracture criteria at a crack tip using the potential energy change with crack growth and utilising in an efficient manner certain characteristics of the stiffness equations.

Virtual Displacements

An arbitrary imaginary change of the system configuration consistent with its constraints.

Virtual Work Virtual Displacements Virtual Forces

Techniques for using work arguments to establish equilibrium equations from compatibility equations (virtual displacements) and to establish compatibility equations from equilibrium (virtual forces).

Visco-Elasticity

a non-linear material behaviour in which both the effects of elasticity and creep are exhibited, so that the stress is dependent on the strain rate.

Viscous Damping

the damping is viscous when the damping force is proportional to the velocity.

Viscous Damping Matrix

The matrix relating a set of velocities to their corresponding velocities

Volume Distortion Volumetric Distortion

The distortion measured by the determinant of the Jacobian matrix, det j.

Volumetric Strain

see hydrostatic strain.

Volumetric Stress

see hydrostatic stress.

Von Mises Equivalent Stress Tresca Equivalent Stress

Equivalent stress measures to represent the maximum shear stress in a material. These are used to characterise flow failures (e.g. plasticity and creep). From test results the Von-Mises form seems more accurate but the Tresca form is easier to handle.

Von Mises Stress

the second invariant of the deviatoric stress tensor. This is a scalar value and is used to relate a 3D stress field to a 1D tensile test. Thus, it is often called an effective or equivalent stress (q.v.).

Von Mises Yield Criterion

is used to describe the yield of metals and assumes that yielding commences when the von Mises stress (q.v.) reaches a critical value.

Wave Propagation

The dynamic calculation involving the prediction of the history of stress and pressure waves in solids and fluids.

Weighted Residuals

A technique for transforming a set of partial differential equations to a set of simultaneous equations so that the solution to the simultaneous equations satisfy the partial differential equations in a mean sense.The form used in the finite element metho

Whirling Stability

The stability of rotating systems where centrifugal and Coriolis are also present.

White Noise

White noise has a constant spectral density for all frequencies.

Wilson Theta Method

An implicit solution method for integrating second order equations of motion. It can be made unconditionally stable.

Word Length

Within a digital computer a number is only held to a finite number of significant figures. A 32bit (single precision) word has about 7 significant figures. A 64bit (double precision) word has about 13 significant figures. All finite element calculations s

Yield Criterion

in the theory of plasticity, a law defining the limit of elastic behaviour under any possible combination of the stress components at any point: the criteria of Tresca and von Mises (q.v.) are common for metals.

Yield Stress

the stress level at which yielding commences in a uniaxial stress-strain state.

Yielding

the transition of material behaviour from elastic to plastic.

Youngs Modulus

The material property relating a uniaxial stress to the corresponding strain.

Zero Energy Modes Zero Stiffness Modes

Non-zero patterns of displacements that have no energy associated with them. No forces are required to generate such modes.