LIST OF NOTATIONS

\{ \} = Column vector

\langle \rangle = Row vector

\[ \] = Matrix

\frac{d(\cdot)}{d(\cdot)} = Denotes a differentiation of the numerator with respect to the denominator

\frac{\partial(\cdot)}{\partial(\cdot)} = Denotes a partial differentiation of the numerator with respect to the denominator

\alpha = Material constant

a_o = Coefficient in Alexander's Stress Strain Curve

a_o, a_1, a_2 = Coefficients relating to minor radius of ultimate strength surface

a_o, a_1, ... a_6 = Coefficients in Newmark's method

A = Area or area per unit length or area per unit width

b_o, b_1, b_2 = Coefficients relating to major radius of ultimate strength surface

[B] = Strain displacement matrix

B_{ij} = Coefficients of matrix in Eq. 3.7
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>(c)</td>
<td>Material constant</td>
</tr>
<tr>
<td>([C])</td>
<td>Constitutive matrix or damping matrix in dynamic analysis</td>
</tr>
<tr>
<td>(d)</td>
<td>Differential element</td>
</tr>
<tr>
<td>(dA)</td>
<td>Elemental area</td>
</tr>
<tr>
<td>(db_1, db_2)</td>
<td>Elements of vector forming sides of element area</td>
</tr>
<tr>
<td>(dr_1, dr_2)</td>
<td>radial and horizontal components of the vectors (db_1, db_2)</td>
</tr>
<tr>
<td>(dV)</td>
<td>Elemental volume</td>
</tr>
<tr>
<td>([D])</td>
<td>Constitutive matrix</td>
</tr>
<tr>
<td>([D_{ep}])</td>
<td>Elasto-plastic matrix</td>
</tr>
<tr>
<td>(E)</td>
<td>Modulus of elasticity</td>
</tr>
<tr>
<td>(E_i)</td>
<td>Effective Young's modulus in direction 'i'</td>
</tr>
<tr>
<td>(E_{oi})</td>
<td>Initial Young's modulus</td>
</tr>
<tr>
<td>(E_{si})</td>
<td>Secant modulus</td>
</tr>
<tr>
<td>(f_{1,2,3,4})</td>
<td>Functions</td>
</tr>
<tr>
<td>(f_{cb})</td>
<td>Biaxial compressive strength</td>
</tr>
<tr>
<td>(f'_c)</td>
<td>Uniaxial compressive strength</td>
</tr>
</tbody>
</table>
\[ f_i \quad = \quad \text{uniaxial tensile strength} \]
\[ F_i \quad = \quad \text{Body force} \]
\[ F_s \quad = \quad \text{Spring force in boundary element} \]
\[ g \quad = \quad \text{Coefficient in Alexander's stress strain curve} \]
\[ G \quad = \quad \text{Shear modulus} \]
\[ G^c \quad = \quad \text{Cracked shear modulus} \]
\[ I_1 \quad = \quad \text{First invariant of stress tensor} \]
\[ J'_1 \quad = \quad \text{First invariant of strain tensor} \]
\[ [J] \quad = \quad \text{Jacobian matrix} \]
\[ ||J|| \quad = \quad \text{Jacobian determinant} \]
\[ J_2 \quad = \quad \text{Second invariant of deviatoric stress tensor} \]
\[ J'_2 \quad = \quad \text{Second invariant of deviatoric strain tensor} \]
\[ K \quad = \quad \text{Bulk modulus or number of elements in a body} \]
\[ h_k \quad = \quad \text{Shell thickness at node 'k'} \]
\[ [K] \quad = \quad \text{Tangent stiffness matrix} \]
\[ l \quad = \quad \text{Length} \]
\[ [M] \quad = \quad \text{Mass matrix} \]
\[ M_x, M_y, M_{xy} \quad = \quad \text{Bending moments} \]

\[ m \quad = \quad \text{Material constant} \]

\[ [N] \quad = \quad \text{Shape function matrix} \]

\[ N \quad = \quad \text{Number of subin increments} \]

\[ N_x \quad = \quad \text{Normal force} \]

\[ \{P\} \quad = \quad \text{Equilibrating force resulting from integration of stresses over volume} \]

\[ q_i \quad = \quad \text{Displacement} \]

\[ \dot{q}_i \quad = \quad \text{Velocity} \]

\[ \ddot{q}_i \quad = \quad \text{Acceleration} \]

\[ Q \quad = \quad \text{Equilibrating force resulting from integration of stresses over volume} \]

\[ \Delta Q^i \quad = \quad \text{Unbalanced loads at load step 'i'} \]

\[ r \quad = \quad \text{Radius of deviatoric trace of the ultimate strength surface or horizontal co-ordinate or radius} \]

\[ r_c, r_t \quad = \quad \text{Compressive and tensile radii of the deviatoric trace of the ultimate strength surface} \]

\[ R \quad = \quad \text{Loads} \]

\[ \Delta R^i \quad = \quad \text{Load increment in load step 'i'} \]

\[ S_{ij} \quad = \quad \text{Deviatoric stress tensor} \]

xxxiv
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$S$</td>
<td>Surface</td>
</tr>
<tr>
<td>$S_q$</td>
<td>Surface on which the displacement is specified</td>
</tr>
<tr>
<td>$S_\sigma$</td>
<td>Surface on which tractions are prescribed</td>
</tr>
<tr>
<td>$t$</td>
<td>Time</td>
</tr>
<tr>
<td>$T$</td>
<td>Surface force</td>
</tr>
<tr>
<td>$u$</td>
<td>Displacement in the horizontal direction</td>
</tr>
<tr>
<td>$v$</td>
<td>Displacement in vertical direction</td>
</tr>
<tr>
<td>$V_{ik}$</td>
<td>nodal co-ordinate set</td>
</tr>
<tr>
<td>$W$</td>
<td>Gaussian integration weights</td>
</tr>
<tr>
<td>$u,v,w$</td>
<td>Displacements in co-ordinate directions</td>
</tr>
<tr>
<td>$x,y,z$</td>
<td>Co-ordinate set</td>
</tr>
<tr>
<td>$X,Y,Z$</td>
<td>Co-ordinate axes</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Principal stress ratio or a factor or Newmark's integration parameter or tension stiffening parameter</td>
</tr>
<tr>
<td>$\alpha_1, \alpha_2, \alpha_3$</td>
<td>Parameters of descending branch of stress strain curve</td>
</tr>
<tr>
<td>$\alpha_c, \alpha_t$</td>
<td>Ratios of biaxial compressive and uniaxial tensile strengths to uniaxial compressive strength</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Coefficient</td>
</tr>
</tbody>
</table>
$\beta_1, \beta_2$ = Parameters of the descending branch of stress strain curve

$\gamma$ = Specific weight or shear strain or coefficient in Alexander's stress strain curve

$\gamma_{oct}$ = Octahedral shear strain

$\gamma_{12}$ = Shear strain associated with plane 1 & 2

$\gamma_{c12}$ = Shear strain corresponding to ultimate shear strength on plane 1 & 2

$\delta$ = Variation or Newmark's integration parameter

$\Delta$ = Increment

$\nu$ = Poisson's ratio

$\varepsilon$ = Strain

$\varepsilon_i$ = Strain in direction 'i'

$\varepsilon_c$ = Equivalent uniaxial strain corresponding to ultimate strength

$\varepsilon_{cu}$ = Strain corresponding to uniaxial compressive strength

$\varepsilon_o$ = Normal octahedral strain

$\varepsilon_{iu}$ = Equivalent uniaxial strain

$\varepsilon_u$ = Ultimate strain

$d\varepsilon^e, d\varepsilon^p$ = Elastic and plastic strain increments
\( \eta \) = Equivalent Poisson's ratio
\( \theta \) = Angle of similarity or angle of inclination of a reinforcing layer to the horizontal axis
\( \theta_\xi, \theta_\eta \) = Angle of the plane \( \xi \) and \( \eta \) described with respect to the vertical axis
\( d\lambda \) = Proportionality constant in flow rule
\( \lambda \) = Parameter in Willam and Warnke's surface
\( \lambda_q, \lambda_Q \) = Convergence tolerance for displacements and loads respectively
\( \xi, \eta, \zeta \) = Nondimensional co-ordinates
\( \xi_1, \xi_2 \) = Normalised mean normal stresses in compression
\( \xi_o \) = Nondimensional mean normal stress in tension denoting the apex of the ultimate strength surface
\( \mu \) = Coefficient in spiral surface
\( \Gamma \) = Configuration
\( \rho \) = Mass density
\( \rho_1, \rho_2 \) = Nondimensionalised mean shear stresses at nondimensionalised mean normal stresses \( \xi_1 \) and \( \xi_2 \) respectively
\( \omega \) = Natural frequency
\( \sigma \) = Normal stress

\( \sigma_a \) = Mean normal stress

\( \sigma_m \) = Normal stress in ultimate strength surface

\( \sigma_c \) = Ultimate strength

\( \sigma_i \) = Normal stress in direction 'i'

\( \sigma_o \) = Effective stress

\( \tau \) = Shear stress

\( \tau_{oct} \) = Octahedral shear stress

\( \tau_m \) = Shear stress in ultimate strength surface

\( \phi \) = Function of Poisson's ratios

\( (\_e) \) = Element

\( (\_m) \) = Order of Gaussian integration

\( (\_o), (\_o) \) = Initial quantities

\( [ ]^T \) = Transpose

\( (\_\xi), (\_\eta) \) = Quantities in directions \( \xi \) and \( \eta \) respectively

\( (\_\_\_\_\_\_) \) = Prescribed quantities

\( (\_) \) = Nodal quantities