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2D PLANE/AXISYMMETRIC SOLID ELEMENT (TYPE 3— ELASTIC OR ELASTIC-PERFECTLY-PLASTIC) FOR THE ANSR-II PROGRAM

by
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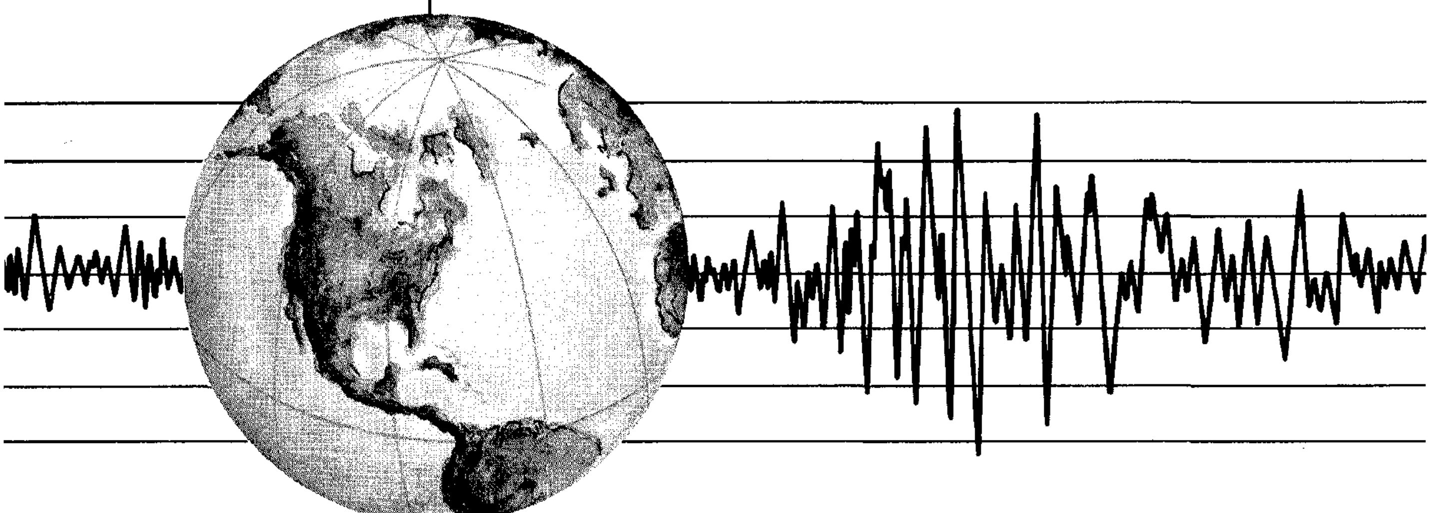

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2D PLANE/AXISYMMETRIC SOLID ELEMENT (TYPE 3 - ELASTIC OR ELASTIC-PERFECTLY PLASTIC) FOR THE ANSR-II PROGRAM

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Earthquake Engineering Research Center
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ABSTRACT

This report describes a two-dimensional nonlinear finite element developed for the ANSR-II program. The report contains a description of the element characteristics, the theoretical formulation, and a computer program user's guide.

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TABLE OF CONTENTS

1. INTRODUCTION

This report describes a two-dimensional nonlinear plane/axisymmetric solid element for the ANSR-II program [1]. The element has the following features:

(1) Two dimensional (X-Y plane) orientation.

(2) Plane stress, plane strain or axisymmetric behavior.

(3) Isoparametric quadrilateral element with variable number of nodes (from 4 to 8).

(4) Large displacement effects may be included or ignored. These effects are based on a total Lagrangian formulation.

(5) Variable Gauss integration order (from 2 to 4 points).

(6) Choice of three material models, namely:
   (a) Linearly elastic isotropic material.
   (b) Linearly elastic orthotropic material.
   (c) Elastic-perfectly plastic material, with von Mises yield criterion.

(7) For dynamic analysis, damping proportional to initial elastic stiffness and/or current tangent stiffness.

(8) Stress and strain output at Gauss integration points plus one other user-specified point.

This report contains a description of the element and the element user's guide.

2. ELEMENT PROPERTIES

The element must lie in the global X-Y plane. For an axisymmetric solid element, the global Y-axis must be the axis of revolution.

Each element can have from four to eight nodes. The element maps into a rectangular element in a local r-s coordinate system, such that nodes 1 through 4 are located at the four corners and nodes 5 through 8 are located at the midsides of the rectangle (Fig. 1). The four corner modes must always be specified, and any one or more of the mid-side nodes may be specified.

Three different types of behavior may be specified, namely plane stress, plane strain, and axisymmetric solid behavior. In the plane strain formulation it is assumed that the element has unit thickness, whereas in the axisymmetric formulation a unit radian segment ($\theta = 1$, Fig. 1) is considered. The applied nodal loads for plane strain and axisymmetric structures must be computed accordingly. In the plane stress formulation, each element may be assigned an average thickness.

The element matrices (stiffness, resisting nodal loads, etc.) are computed using Gauss quadrature integration. The integration orders (numbers of integration points) in the local r-direction and s-directions may be specified separately. Any integration order up to 4 may be specified in either direction; however, 2x2 integration is recommended for most cases.

Large displacements effects may be included or ignored. If large displacements are considered, a total Lagrangian formulation is used.

Three different material models are included, as follows:

(a) Isotropic linearly elastic material.

(b) Orthotropic linearly elastic material.

(c) Isotropic elastic-perfectly-plastic material with von Mises yield criterion.

Orthotropic material properties are defined with respect to a set of right-handed coordinate axes A-B-C with the axes A and B lying in the plane of the element (Fig. 1).

For the elastic-perfectly plastic material, the stress increment during plastic loading is obtained by dividing the strain increment into a number of equal subincrements and performing Runge-Kutta integration in each subincrement. For most applications, a single increment and first order (Euler) integration will be sufficient.

For results output, stresses and strains at a user-specified "output" point are printed. In addition, the results at the Gauss integration points may be printed. The local r and s coordinates of the output point may be input by the user, with default at the element center ($r = s = 0$).

3. THEORY

3.1 LARGE DISPLACEMENT FORMULATION

3.1.1 General

The large displacement formulation for a general finite element system in a Lagrangian reference frame has previously been presented [e.g. 2,3]. The strain-displacement relationships and element stiffness matrices are developed as the structure deforms from a known state (configuration 1, time t) to a neighboring state (configuration 2, time $t + \Delta t$). All strain and stress quantities in the deformed configuration are referred to the undeformed state (configuration 0, time = 0).

In this section, the large displacement formulation for the element is presented briefly, following the procedures outlined in detail in [2,3].

3.1.2 Shape Functions

For an 8-node isoparametric element (Fig. 1) the shape functions can be written as follows:

(a) For corner nodes ($m = 1$ to 4; $r_m = \pm 1$ and $s_m = \pm 1$)

$$N^m(r,s) = \frac{1}{4}(1 + rr_m)(1 + ss_m) - \frac{1}{4}(1 + rr_m)(1 - s^2) - \frac{1}{4}(1 - r^2)(1 + ss_m) \quad (1)$$

(b) For midside nodes ($m = 5$ to 8)

$$N^m(r,s) = \frac{1}{2}(1 + rr_m)(1 - s^2), \qquad s_m = 0 \quad (2)$$

$$N^m(r,s) = \frac{1}{2}(1 - r^2)(1 + ss_m), \qquad r_m = 0 \quad (3)$$

For a variable (4 to 8) node element, the shape functions for the mid-side nodes are included only for those nodes which are present. For the corner nodes, terms involving $(1 - s^2)$ and $(1 - r^2)$ in equation (1) are included only if corresponding midside node(s) are present (e.g., if only node 5 is present, the shape functions for nodes 1 and 2 will have only the corresponding terms included).

The X and Y displacements at any point within the element in the current deformed state (state 1) are related to the nodal displacements as follows:

$$\begin{Bmatrix} {}^1u_x \\ {}^1u_y \end{Bmatrix} = \begin{bmatrix} \underline{N} & 0 \\ 0 & \underline{N} \end{bmatrix} \begin{Bmatrix} {}^1\underline{q}_x \\ {}^1\underline{q}_y \end{Bmatrix} \tag{4}$$

or

$$\{{}^1u\} = [N^*]\ \{{}^1q\}$$

Similarly, displacement increments are related to the nodal displacement increments as

$$\begin{Bmatrix} {}^1u_x \\ {}^1u_y \end{Bmatrix} = \begin{bmatrix} \underline{N} & 0 \\ 0 & N \end{bmatrix} \begin{Bmatrix} {}^1\underline{q}_x \\ {}^1\underline{q}_y \end{Bmatrix} \tag{5}$$

or

$$\{u\} = [N^*]\ \{q\}$$

In subsequent relationships, derivatives of shape functions with respect to the global X and Y axes will be needed. These derivatives are obtained by the usual Jacobian transformation [4].

3.1.3 Strain-Displacement Transformation

The total strain increment is decomposed into linear and non-linear components. That is

$$\begin{Bmatrix} E_{xx} \\ E_{yy} \\ 2E_{xy} \\ E_{zz} \end{Bmatrix} = \begin{Bmatrix} e_{xx} \\ e_{yy} \\ 2e_{xy} \\ e_{zz} \end{Bmatrix} + \begin{Bmatrix} \eta_{xx} \\ \eta_{yy} \\ 2\eta_{xy} \\ \eta_{zz} \end{Bmatrix} \tag{6}$$

or

$$\{E\} = \{e\} + \{\eta\} \tag{6}$$

For plane stress (strain) behavior, terms involving stress S_{zz} (strain E_{zz}) are neglected, and appropriate modifications are made to the stress-strain relationship.

The linear component is related to the nodal displacements through the following relationship:

$$\{e\} = [{}^{1}F] \ \{u\} \tag{7}$$

and

$$\{u\} = [N] \ \{q\} \tag{8}$$

where

$$[{}^1F] = \begin{bmatrix} (1 + \frac{\partial^1 u_x}{\partial x}) & 0 & \frac{\partial^1 u_y}{\partial x} & 0 & 0 \\ 0 & \frac{\partial^1 u_x}{\partial y} & 0 & (1 + \frac{\partial^1 u_y}{\partial y}) & 0 \\ \frac{\partial^1 u_x}{\partial y} & (1 + \frac{\partial^1 u_x}{\partial x}) & (1 + \frac{\partial^1 u_y}{\partial y}) & \frac{\partial^1 u_y}{\partial x} & 0 \\ 0 & 0 & 0 & 0 & (1 + \frac{\partial^1 u_x}{\partial x}) \end{bmatrix} \quad (9)$$

$$\{u_\partial\}^T = \langle \frac{\partial u_x}{\partial x} \; \frac{\partial u_x}{\partial y} \; \frac{\partial u_y}{\partial x} \; \frac{\partial u_y}{\partial y} \; \frac{u}{x} \rangle \quad (10)$$

and

$$[N_\partial] = \begin{bmatrix} \frac{\partial N}{\partial x} & 0 \\ \frac{\partial N}{\partial y} & 0 \\ 0 & \frac{\partial N}{\partial x} \\ 0 & \frac{\partial N}{\partial y} \\ \frac{N}{x} & 0 \end{bmatrix} \quad (11)$$

From a combination of equations (7) and (8), the following strain-displacement relationship is obtained.

$$\{e\} = [{}^1F]\,[N_\partial]\,\{q\} \quad (12)$$

or

$$\{e\} = [{}^1B]\,\{q\}$$

3.1.4 Element Stiffness Matrix

The element stiffness matrix is given by

$$[K_E] = \int_{V_o} [{}^1B]^T\,[C]\,[{}^1B]\,dV \qquad (13)$$

in which [C] is the constitutive matrix, and integration is carried out over the volume V_o of the element in the undeformed state.

The integration is equation (13) is carried out numerically using Gauss quadrature.

3.1.5 Geometric Stiffness Matrix

The nonlinear component of the strain increment is given by

$$\begin{aligned}
\eta_{xx} &= \frac{1}{2}\left[\left(\frac{\partial u_x}{\partial x}\right)^2 + \left(\frac{\partial u_y}{\partial x}\right)^2\right] \\
\eta_{yy} &= \frac{1}{2}\left[\left(\frac{\partial u_x}{\partial y}\right)^2 + \left(\frac{\partial u_y}{\partial y}\right)^2\right] \\
2\eta_{xy} &= \left[\left(\frac{\partial u_x}{\partial x}\right)\left(\frac{\partial u_x}{\partial y}\right) + \left(\frac{\partial u_y}{\partial x}\right)\left(\frac{\partial u_y}{\partial y}\right)\right] \\
\eta_{zz} &= \frac{1}{2}\,\frac{u_x}{x}^{2}
\end{aligned} \qquad (14)$$

The element geometric stiffness $[K_G]$ is obtained from the following virtual work equation.

$$\{\delta q\}^T [K_G] \{q\} = \int_{V_o} ({}^1S_{xx}\ \delta\eta_{xx} + {}^1S_{yy}\ \delta\eta_{yy} + 2\,{}^1S_{xy}\ \delta\eta_{xy} + {}^1S_{zz}\ \delta\eta_{zz})dV \quad \text{........(15)}$$

in which $\delta(\cdot)$ is a variation on the undesignated variable, and ${}^1S_{xx}$, ${}^1S_{yy}$, ${}^1S_{xy}$, and ${}^1S_{zz}$ are stresses in the deformed state at time t. By combining equations (14) and (15) and simplifying it can be shown that

$$[K_G] = \int_{V_o} [N_\partial]^T [\hat{S}] [N_\partial]\ dV \qquad (16)$$

in which the matrix $[N\partial]$ is given in equation (11) and the matrix $[\hat{S}]$ is as follows.

$$[\hat{S}] = \begin{bmatrix} {}^1S_{xx} & {}^1S_{xy} & 0 & 0 & 0 \\ {}^1S_{xy} & {}^1S_{yy} & 0 & 0 & 0 \\ 0 & 0 & {}^1S_{xx} & {}^1S_{xy} & 0 \\ 0 & 0 & {}^1S_{xy} & {}^1S_{yy} & 0 \\ 0 & 0 & 0 & 0 & {}^1S_{zz} \end{bmatrix} \qquad (17)$$

As for the element stiffness matrix, the integral in equation (16) is evaluated numerically using Gauss quadrature.

3.1.6 Equilibrium Nodal Loads

Nodal loads in equilibrium with the state of stress in the deformed state at time t are given by

$$\{{}^1R\} = \int_{V_o} [{}^1B]^T \{{}^1S\}\, dV \tag{18}$$

in which $\{{}^1S\}^T = \langle\ {}^1S_{xx}\ \ {}^1S_{yy}\ \ {}^1S_{xy}\ \ {}^1S_{zz}\ \rangle$; and the strain-displacement matrix $[{}^1B]$ is given in equation (12). Again, the integral in equation (18) is evaluated numerically.

3.2 MATERIAL MODELS

3.2.1 General

Three different material models are included, as follows:

(a) Isotropic linearly elastic material model.

(b) Orthotropic linearly elastic material model.

(c) Elastic-perfectly plastic material model, with von Mises yield criterion.

These models can be used with either the plane stress, plane strain, or axisymmetric behavior.

The constitutive relationship between stress and strain can be written as

$$\begin{Bmatrix} S_{xx} \\ S_{yy} \\ S_{xy} \\ S_{zz} \end{Bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} \\ & C_{22} & C_{23} & C_{24} \\ & & C_{33} & C_{34} \\ \text{Symmetric} & & & C_{44} \end{bmatrix} \begin{Bmatrix} E_{xx} \\ E_{yy} \\ 2E_{xy} \\ E_{zz} \end{Bmatrix} \tag{19}$$

That is, $\{S\} = [C]\{E\}$

It should be noted that for large displacements the above relationship is assumed to be between the (second) Piola-Kirchhoff stress and Green-Lagrange strain. The (4 x 4) matrix given in equation (19) is for axisymmetric behavior. To obtain the constitutive matrix for plane stress the matrix is condensed to a (3 x 3) matrix using the condition that stress $S_{zz} = 0$. For plane strain, $E_{zz} = 0$, and the last row and column are ignored.

3.2.2 Isotropic Linearly Elastic Material

For this material, the matrix coefficients (Equation 19) are as follows:

$$
\begin{aligned}
C_{11} &= C_{22} = C_{44} = 2\mu + \lambda \\
C_{12} &= C_{14} = C_{24} = \lambda \\
C_{33} &= \mu \\
C_{13} &= C_{23} = C_{34} = 0
\end{aligned}
\qquad (20)
$$

in which

$$\mu = \frac{E}{2(1+\nu)} \quad \text{and} \quad \lambda = \frac{\nu E}{(1+\nu)(1-2\nu)} \qquad (21)$$

E = Young's modulus of elasticity.

ν = Poisson's ratio.

3.2.3 Orthotropic Linearly Elastic Material

For this material model, orthogonal axes a-b-c are defined as the orthotropic material axes, and material constants are defined with respect to these axes. Axes a and b lie in the global x-y plane. Axis c is parallel to axis z.

The constitutive relationship in a-b-c is:

$$\{E\}_{abc} = [C]^{-1}_{abc} \{S\}_{abc} \tag{22}$$

in which

$$[C]^{-1}_{abc} = \begin{bmatrix} 1/E_a & & & \text{symmetric} \\ -\nu_{ab}/E_a & 1/E_b & & \\ 0 & 0 & 1/G_{ab} & \\ -\nu_{ac}/E_a & -\nu_{bc}/E_b & 0 & 1/E_c \end{bmatrix} \tag{23}$$

The seven independent constants (E_a, E_b, E_c, G_{ab}, ν_{ab}, ν_{ac}, ν_{bc}) define the orthotropic material.

The constitutive matrix in the global axes is obtained as

$$[C] = [Q]^T [C]_{abc} [Q] \tag{24}$$

in which the transformation matrix [Q] relates strains in the local (a-b-c) axes to the strains in the global (x-y-z) axes, and is given by

$$[Q] = \begin{bmatrix} \ell_1^2 & m_1^2 & \ell_1 m_1 & 0 \\ \ell_2^2 & m_2^2 & \ell_2 m_2 & 0 \\ 2\ell_1\ell_2 & 2m_1 m_2 & \ell_1 m_2 + \ell_2 m_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{25}$$

in which ℓ_1, ℓ_2 and m_1, m_2 are direction cosines of axes a and b, respectively, with respect to the global axes X and Y.

3.2.4 Elastic-Perfectly Plastic Material

The flow theory of plasticity and the von Mises yield criterion are used to derive the constitutive relationship.

The von Mises yield criterion is given by

$$f \equiv 3J_2 - \sigma_0^2 = 0 \tag{26}$$

in which σ_0 is the yield stress in pure tension or compression, and

$$J_2 = \frac{1}{2} [(\bar{S}_{xx})^2 + (\bar{S}_{yy})^2 + (\bar{S}_{zz})^2 + 2(\bar{S}_{xy})^2] \tag{27}$$

in which

$$\begin{aligned} \bar{S}_{xx} &= \frac{1}{3} (2 S_{xx} - S_{yy} - S_{zz}) \\ \bar{S}_{yy} &= \frac{1}{3} (2 S_{yy} - S_{zz} - S_{xx}) \\ \bar{S}_{zz} &= \frac{1}{3} (2 S_{zz} - S_{xx} - S_{yy}) \\ \bar{S}_{xy} &= S_{xy} \end{aligned} \tag{28}$$

For an associated flow rule it can be shown that the constitutive matrix for an elastic-perfectly plastic material is as follows:

$$[C] = [C^e] - [C^p] \tag{29}$$

in which $[C^e]$ is equal to the matrix [C] for an isotropic linearly elastic material (Equation (20)), and the matrix $[C^p]$ is as follows:

$$[C^P] = \frac{3\mu}{\sigma_0^2} \begin{bmatrix} (\bar{S}_{xx})^2 & \bar{S}_{xx}\,\bar{S}_{yy} & \bar{S}_{xx}\,\bar{S}_{xy} & \bar{S}_{xx}\,\bar{S}_{zz} \\ & (\bar{S}_{yy})^2 & \bar{S}_{yy}\,\bar{S}_{xy} & \bar{S}_{yy}\,\bar{S}_{zz} \\ & & (\bar{S}_{xy})^2 & \bar{S}_{xy}\,\bar{S}_{zz} \\ \text{Symmetric} & & & (\bar{S}_{zz})^2 \end{bmatrix} \quad (30)$$

The constant μ is given in equation (21).

3.3 STATE DETERMINATION CALCULATION

"State determination" involves computation of the stress increments for given strain increments. For linearly elastic isotropic and orthotropic materials, the stress increments are obtained by applying equation (19). For an elastic-perfectly plastic material, the state of stress, computed assuming elastic behavior during any load step, may lie outside the yield surface. This is not admissible and must be corrected.

As an example, let point A (Fig. 2) define the state of stress at the beginning of a load step. Assuming linear behavior within the step, let the new state of stress be at point D, which is outside the yield surface and is, therefore not admissible. Assuming that strains vary proportionately within the step, a stress state (point B) is computed where the stress path intersects the yield surface. For the remainder of the strain increment, the stress increment from point B to point C is computed as follows:

(a) The increment is divided into a number of equal subincrements. This number is specified by the user.

(b) The stress increment for each strain subincrement is computed using Runge-Kutta integration of up to fourth order. The order of integration is specified by the user.

If large plastic strain increments can occur within a load or time step, it may be desirable to specify several subincrements. For most applications, however, it is recommended that the number of subincrements be at most 2, and that Euler integration (order = 1) be used.

4. USER'S GUIDE

2D PLANE/AXISYMMETRIC SOLID ELEMENT (TYPE 3)

4.1 CONTROL INFORMATION

Two cards.

4.1(a) First Card

COLUMNS	NOTE	NAME	DATA
5(I)		NGR	Element group indicator. Punch 3.
6 - 10(I)		NELS	Number of elements in group.
11 - 15(I)	(1)	MFST	Element number of first element in group. Default = 1.
16 - 25(F)		DKO	Initial stiffness damping factor, β_0.
26 - 35(F)		DKT	Tangent stiffness damping factor, β_T.
41 - 80(A)		GRHED	Optional group heading.

4.1(b) Second Card

COLUMNS	NOTE	NAME	DATA
5(I)	(2)	NODES	Number of nodes describing each element (Min. = 4, Max. = 8). Default = 4.
6 - 10(I)		NMAT	Number of different material types. Default = 1.
15(I)		MODEL	Material model number. No default. (a) 1: Isotropic linearly elastic. (b) 2: Orthotropic linearly elastic. (c) 3: Elastic-perfectly plastic, with von Mises yield criterion.
20(I)	(3)	IORDR	Gauss integration order in r-direction (Min. = 1, Max. = 4). Default = 2.
25(I)	(3)	IORDS	Gauss integration order in s-direction (Min. = 1, Max. = 4). Default = 2.
30(I)	(4)	IPLN	Behavior code. No default. (a) 1: Plane stress. (b) 2: Plane strain. (c) 3: Axisymmetric.

4.2 MATERIAL PROPERTIES

4.2(a) ISOTROPIC LINEARLY ELASTIC MATERIAL

NMAT cards. Omit this section if MODEL is not 1.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)			Material type number.
6 - 15(I)			Young's modulus, E.
16 - 25(F)			Poisson's ratio, ν.

4.2(b) ORTHOTROPIC LINEARLY ELASTIC MATERIAL

NMAT cards. Omit this section if MODEL is not 2.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)			Material type number.
6 - 15(F)	(5)		Young's modulus along A-axis, E_A.
16 - 25(F)			Young's modulus along B-axis, E_B.
26 - 35(F)			Young's modulus along C-axis, E_C.
36 - 45(F)			Poisson's ratio, ν_{AB}.
46 - 55(F)			Poisson's ratio, ν_{AC}.
56 - 65(F)			Poisson's ratio, ν_{BC}.
66 - 75(F)			Shear modulus, G_{AB}.
76 - 80(F)			Angle from global X-axis to material A-axis (degrees; positive = right hand screw rule about Z axis).

4.2(c) ELASTIC-PERFECTLY PLASTIC MATERIAL

NMAT cards. Omit this section if MODEL is not 3.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)			Material type number.
6 - 15(F)			Young's modulus, E.
16 - 25(F)			Poisson's ratio, ν.

4.2(c) ELASTIC-PERFECTLY PLASTIC MATERIAL (Continued)

COLUMNS	NOTE	NAME	DATA
26 - 35(F)			Yield stress, σ_Y
36 - 45(F)	(6)		Number of equal subincrements of strain for plastic loading. No default.
46 - 55(F)	(6)		Order of Runge-Kutta integration (Min. = 1, Max. = 4). No default.

4.3 ELEMENT DATA GENERATION

As many cards as needed to generate all elements in group.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	(7)	MEL	Element number, or number of first element in a sequentially numbered series of elements to be generated by this card.
6 - 10(I)		NODE1	Node number 1.
11 - 15(I)		NODE2	Node number 2.
16 - 20(I)		NODE3	Node number 3.
21 - 25(I)		NODE4	Node number 4.
26 - 30(I)		NODE5	Node number 5. May be zero.
31 - 35(I)		NODE6	Node number 6. May be zero.
36 - 40(I)		NODE7	Node number 7. May be zero.
41 - 45(I)		NODE8	Node number 8. May be zero.
46 - 50(I)		MAT	Material type number. Default = 1.
51 - 55(F)		THIC	Element thickness (for IPLN = 1 only). Default = 1.0 for IPLN = 2 or 3.
56 - 60(I)		INC	Node number increment for element generation. Default = 1.
62(I)		KGEOM	Large displacements code. (a) Zero or blank: Small displacements. (b) 1: Large displacements.

4.3 ELEMENT DATA GENERATION (Continued)

COLUMNS	NOTE	NAME	DATA
64(I)		KTHO	Response output code. (a) Blank or zero: No print output. (b) 1: Results at "output" point only. (c) 2: Results at Gauss points in addition to "output" point.
66 - 70(F)		ROUT	Local r-coordinate of "output" point. Default = 0.0.
71 - 75(F)		SOUT	Local s-coordinate of "output" point. Default = 0.0.

4.4 USER'S GUIDE NOTES

NOTE (1) The elements in group are numbered sequentially, starting with MFST (i.e. MFST, MFST + 1, MFST + 2,...., MFST + NELS - 1).

NOTE (2) Each element can have from four to eight nodes (Fig. 1). All elements in any group must have the same number of nodes. The four corner nodes (1 through 4) must always be specified. Any one or more of the midside nodes (5 through 8) may be specified.

NOTE (3) The Gauss integration order (from 1 to 4) may be specified separately, in each of the local (r and s) directions e.g. IORDR = 2, IORDS = 3. All elements in any group must have the same integration order.

NOTE (4) All elements must lie in the global X-Y plane. For axisymmetric elements, the global Y-axis must be the axis of revolution.

NOTE (5) The orthotropic material properties are defined with respect to a set of right handed coordinate axes A-B-C, with the axes A and B lying in the plane of the element i.e. the global X-Y plane, and the C-axis parallel to the global Z-axis.

NOTE (6) Refer to Section 3.3 for explanation of the number of strain subincrements and the order of Runge-Kutta integration. For most applications a single increment and first order integration will be sufficient.

4.4 USER'S GUIDE NOTES (Continued)

NOTE (7) Cards must be input in order of increasing element number. Cards for the first and the last elements must be included (that is, the data for these two elements cannot be generated).

Cards may be provided for all elements, in which case each card specifies the data for one element and the generation option is not used. Alternatively, the cards for a series of elements may be omitted, in which case data for the missing elements is generated as follows:

(a) All missing elements are assigned the same material number (MAT), thickness (THIC), codes for large displacements and response output (KGEOM and KTHO), and the "output" point coordinates as for the element preceding the missing series of elements.

(b) The node numbers, NODE1 through NODE8, for each missing element are obtained by adding the increment (INC) to the node numbers of the preceding element. For example

$$\text{NODE1}\ (N) = \text{NODE1}\ (N-1) + \text{INC}$$

The node number increment (INC) is the value specified with the element preceding the missing series of elements.

5. RESULTS OUTPUT

The following results are printed at the specified output intervals in static and dynamic analyses, for those elements for which results are requested.

(a) Element number.

(b) Yield code at "output" point: zero indicates that the material is elastic, and one indicates that it is plastic.

(c) Stress components (SIG11, SIG22, SIG12, and SIG33) at "output" point.

(d) Strain components (STR11, STR22, STR12, and STR33) at "output" point.

(e) Von Mises effective stress (EFFSIG) at "output" point. EFFSIG is defined as

$$\text{EFFSIG} = \sqrt{1.5\ \text{YSS}}$$

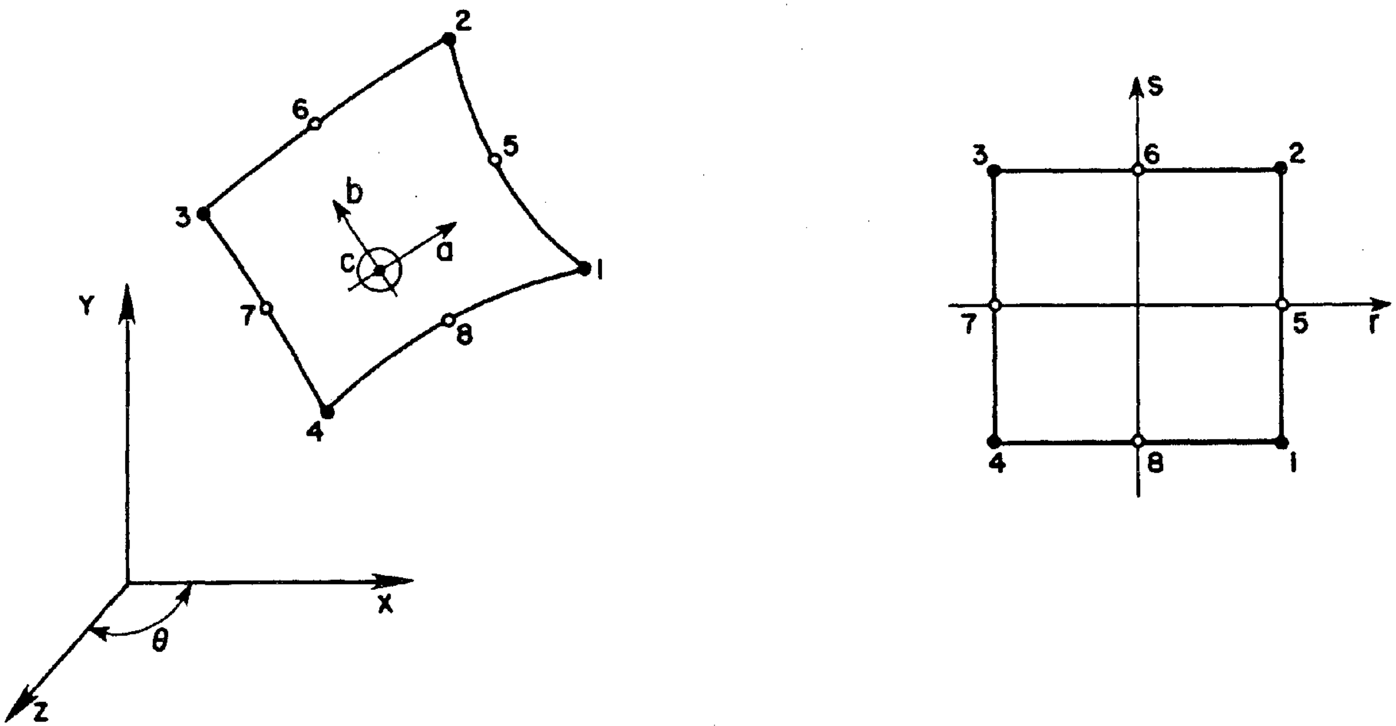
where $\text{YSS} = (\text{SIG11})^2 + (\text{SIG22})^2 + 2\ (\text{SIG12})^2 + (\text{SIG33})^2$

(f) Output at Gauss integration points if requested (response output code KTHO = 2, Section 4.3). These results consist of the yield code, stress components, strain components and effective stress at each Gauss point.

The results envelopes consist of the following:

(a) Element number.

(b) Maximum positive and negative values of stresses and strains at the "output" point and or each of the Gauss points, and the times at which these maxima occur.



(a) 2D ELEMENT IN GLOBAL
X-Y-Z SYSTEM

(b) 2D ELEMENT IN LOCAL
r-s SYSTEM

FIG. 1 TWO-DIMENSIONAL FINITE ELEMENT

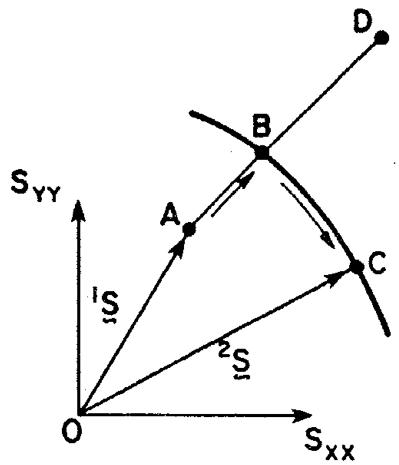


FIG. 2 STATE DETERMINATION

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