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3D TRUSS BAR ELEMENT (TYPE 1) FOR THE ANSR-II PROGRAM

by

DIGAMBAR P. MONDKAR
GRAHAM H. POWELL

Report to Sponsor:
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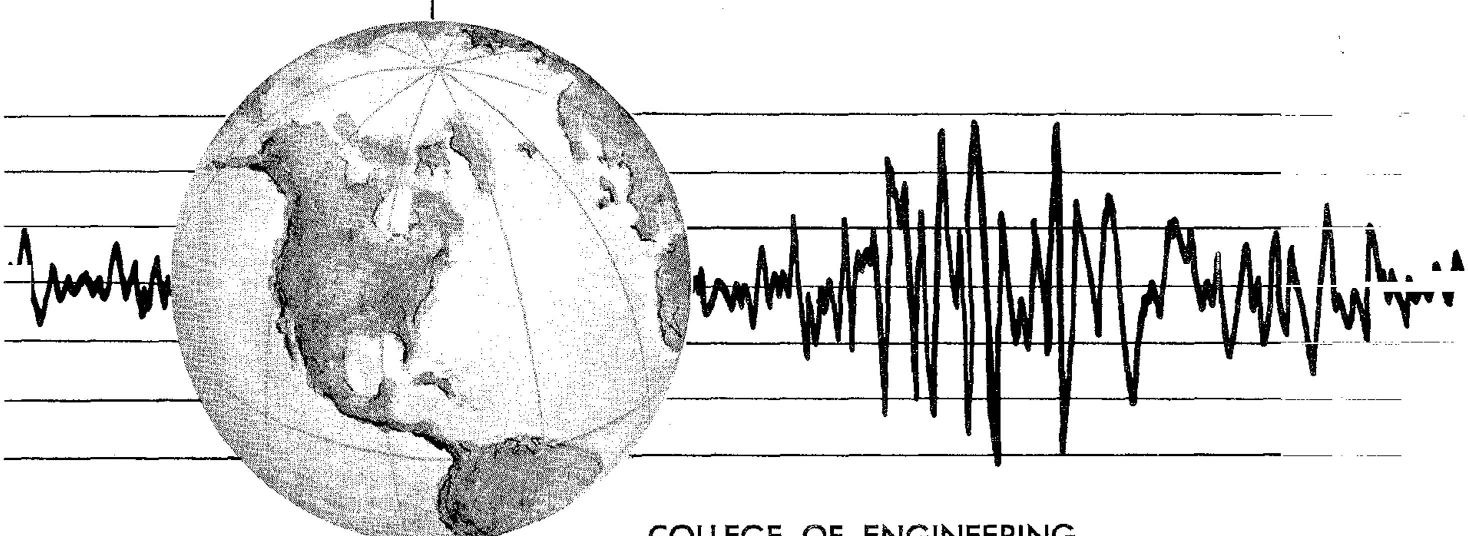

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by

Digambar P. Mondkar
Assistant Research Engineer

and

Graham H. Powell
Professor of Civil Engineering

Report to
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Report No. UCB/EERC - 79/29
Earthquake Engineering Research Center
College of Engineering
University of California
Berkeley, California

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ABSTRACT

This report describes a three dimensional, inelastic, large displacement truss element developed for the ANSR-II program. The report contains a description of the element characteristics and a computer program user's guide.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

1. INTRODUCTION

This report describes a truss element for the ANSR-II program [1]. The element has the following features.

(1) Arbitrary orientation in space.
(2) Only axial deformation and only axial load.
(3) Large displacement effects may be included or ignored.
(4) Large displacement effect is based on a continuum mechanics formulation.
(5) Yield in tension. Either yield or elastic buckling in compression.
(6) Linear strain hardening.
(7) Initial axial force can be specified.
(8) For dynamic analysis, damping proportional to initial elastic stiffness and/or current tangent stiffness.

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

2. TRUSS ELEMENT FEATURES

2.1 ELEMENT FEATURES

Truss elements may be arbitrarily oriented in space, and are assumed to transmit axial load only. Each element is defined by two nodes, one at each end of the element (Fig. 2.1). There are three translational degrees of freedom (X, Y, Z translations) at each node. Large displacement effects may or may not be included.

Two alternative modes of inelastic behavior may be specified, namely, (1) yielding in both tension and compression (Fig. 2.2a) and (2) yielding in tension with elastic buckling in compression (Fig. 2.2b). Linear strain hardening effects may be considered. It should be noted that the inelastic behavior is specified in terms of stress and strain, rather than axial force and axial deformation. The stress-strain relationship is decomposed into two components, one linearly elastic and the other elastic-perfectly plastic. Linearly elastic behavior can be obtained by specifying a very high value of the yield stress. Elastic-perfectly-plastic behavior can be obtained by specfying a very small strain hardening ratio.

Initial axial forces in the truss elements can be specified. These initial forces will typically be the forces in the elements under static loading, as calculated by a separate analysis. For consistency, these forces should be in equilibrium with the static load producing them, but this is not essential as the computer program makes corrections for any equilibrium imbalance resulting from the initial forces.

For dynamic analysis, damping proportional to the initial elastic stiffness and/or the current tangent stiffness may be specified. There is no mass contribution from the truss element, as the ANSR-II program permits specification of masses only at the structure level.

2.2 THEORY

The detailed descriptions of the large displacement formulation for a finite element system, following continum mechanics principles, have been presented in two previous reports [2,3]. Following this approach, the large displacements formulation for the truss element is briefly described in Table 2.1.

For a given axial strain, a new state of axial force in the element (state determination) is computed for each of the two components (elastic-perfectly plastic). The total axial force for the element is the sum of these two forces.

2.3 RESULTS OUTPUT

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

(1) Element number.
(2) Node numbers at ends I and J.
(3) Yield code: Zero indicates that the element is elastic, and one indicates that it is yielding or buckling.
(4) Axial force, tension positive.
(5) Total axial deformation, elongation positive.
(6) Accumulated positive and negative plastic deformations (elongation positive) up to the current load or time. These deformations are computed by accumulating the plastic extensions during all positive and negative plastic excursions. For an element which buckles in compression (Fig. 2.2b), the accumulated negative plastic deformations are printed as zero.

The results envelopes consist of the following:

(1) Element number.
(2) Node numbers at ends I and J.
(3) Maximum positive and negative values of axial force, and the corresponding times at which these values occur.
(4) Maximum positive and negative values of total deformation, and the corresponding times.
(5) Accumulated plastic deformations.

3. TRUSS ELEMENT USER'S GUIDE

A group of elements consisting of three-dimensional truss elements requires following <u>three</u> sets of data cards.

3.1 CONTROL INFORMATION

One card.

COLUMNS	NOTE	NAME	DATA
5(I)		NGR	Element group indicator. Punch 1.
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_o .
26 - 35(F)		DKT	Current tangent stiffness damping factor, β_T .
41 - 80(A)		GRHED	Optional group heading.

3.2 MATERIAL PROPERTY INFORMATION

3.2(a) Control Card

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NMAT	Number of different material types. Default = 1.

3.2(b) Subsequent Cards

NMAT cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)			Material number, in sequence starting with 1.
6 - 15(F)	(2)		Young's modulus of elasticity.
16 - 25(F)			Strain hardening modulus, as a <u>proportion</u> of Young's modulus.

3.2(b) Subsequent Cards (Continued)

COLUMNS	NOTE	NAME	DATA
26 - 35(F)			Yield stress in tension.
36 - 45(F)			Yield stress in compression, or elastic buckling stress in compression.

3.3 ELEMENT DATA GENERATION

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

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	(3)	MEL	Element number, or number of first element in a sequentially numbered series of elements to be generated by this card.
6 - 10(I)		NODI	Node number I.
11 - 15(I)		NODJ	Node number J.
16 - 20(I)		MAT	Material number. Default = 1.
21 - 30(F)		AO	Cross section area.
31 - 40(F)	(4)	FO	Initial axial force. Tension positive.
41 - 45(I)		INC	Node number increment for element generation. Default = 1.
50(I)		KGEOM	Code for large displacement effects. (a) Blank or zero = small displacements. (b) 1 = large displacements.
55(I)		KTHO	Response output code. (a) Blank or zero = no response printout. (b) 1 = response output required.
60(I)		KBU	Buckling code. (a) Blank or zero = yield in compression without buckling. (b) 1 = buckles elastically in compression.

3.4 USER'S GUIDE NOTES

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

NOTE (2) Each material type requires four material constants. The strain hardening ratio must be less than 1.0. For an elastic material, specify very high yield stress and a zero strain hardening ratio.

NOTE (3) Cards must be input in order of increasing element number. Cards for the first and last elements must be included (that is, 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, 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), cross section area (AO), initial force (FO), and codes for large displacement effect, response output and buckling (KGEOM, KTHO, and KBU), as for the element preceding the missing series of elements.

(b) The node numbers I and J for each missing element are obtained by adding the increment (INC) to the node numbers of the preceding element. That is,

$$NODI(N) = NODI(N - 1) + INC$$
$$NODJ(N) = NODJ(N - 1) + INC$$

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

NOTE (4) The initial forces in the elements allow for prestressing. These forces should generally be self-equilibrating. If they are not, the program will compute an equilibrium unbalance at the beginning of the analysis, and will apply this unbalance as a load on the structure in the first load step.

REFERENCES

1. Mondkar, D. P. and Powell, G. H., "ANSR-II, Analysis of Nonlinear Structural Response, User's Manual," Report No. UCB/EERC - 79/17, Earthquake Engineering Research Center, University of California, Berkeley (July 1979).

2. Mondkar, D. P. and Powell, G. H., "ANSR - I , General Purpose Program for Analysis of Nonlinear Structural Response," Report No. EERC 75-37, Earthquake Engineering Research Center, University of California, Berkeley (December 1975).

3. Mondkar, D. P. and Powell, G. H., "Static and Dynamic Analysis of Nonlinear Structures," Report No. EERC 75-10, Earthquake Engineering Research Center, University of California, Berkeley (March 1975).

TABLE 2.1

LARGE DISPLACEMENT FORMULATION FOR TRUSS BAR

Any point on the truss bar axis is defined with respect to orthogonal local axes x-y-z, in the original bar configuration. Axis x is directed from element end I to end J. The point has displacements u, v, w in x, y, z.

Let ${}^{t}u = \left[{}^{t}u \; {}^{t}v \; {}^{t}w\right]$ and $u = [u \; v \; w]$ be the total displacements in the current configuration (time t) and the increments in displacements (from t to t + Δt), respectively.

The increment in axial strain is given by:

$$\epsilon = e + \eta$$

where

e = linear part of strain increment;

η = nonlinear part of strain increment;

$$e = \left(1 + \frac{\partial {}^{t}u}{\partial x}\right)\frac{\partial u}{\partial x} + \frac{\partial {}^{t}v}{\partial x}\frac{\partial v}{\partial x} + \frac{\partial {}^{t}w}{\partial x}\frac{\partial w}{\partial x} \tag{1}$$

and

$$\eta = \frac{1}{2}\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial x}\right)^2\right] \tag{2}$$

Let ${}^{t}r = \left[{}^{t}r_1 \; {}^{t}r_2 \; {}^{t}r_3 \; {}^{t}r_4 \; {}^{t}r_5 \; {}^{t}r_6\right]$ be a vector of the x - y - z displacements (time t) at nodes I and J. The interpolation relationship for internal element displacements is :

$$\begin{Bmatrix} {}^{t}u \\ {}^{t}v \\ {}^{t}w \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & 0 & N_2 & 0 & 0 \\ 0 & N_1 & 0 & 0 & N_2 & 0 \\ 0 & 0 & N_1 & 0 & 0 & N_2 \end{bmatrix} \begin{Bmatrix} {}^{t}r_1 \\ {}^{t}r_2 \\ {}^{t}r_3 \\ {}^{t}r_4 \\ {}^{t}r_5 \\ {}^{t}r_6 \end{Bmatrix} \tag{3}$$

where $N_1 = \left(1 - \frac{x}{L_o}\right)$; $N_2 = \frac{x}{L_o}$; *and* L_o = length of the element at time t = o.

Therefore:

$$\begin{Bmatrix} \dfrac{\partial^1 u}{\partial x} \\ \dfrac{\partial^1 v}{\partial x} \\ \dfrac{\partial^1 w}{\partial x} \end{Bmatrix} = \frac{1}{L_o} [-I_3 \quad I_3] \{^1 r\} \tag{4}$$

or:

$$\{^1 u_\partial\} = \frac{1}{L_o} [-I_3 \quad I_3] \{^1 r\}$$

in which $I_3 = 3 x 3$ unit matrix.
Similarly:

$$\begin{Bmatrix} \dfrac{\partial u}{\partial x} \\ \dfrac{\partial v}{\partial x} \\ \dfrac{\partial w}{\partial x} \end{Bmatrix} = \frac{1}{L_o} [-I_3 \quad I_3] \{r\} \tag{5}$$

or:

$$\{u_\partial\} = \frac{1}{L_o} [-I_3 \quad I_3] \{r\}$$

in which {r} = vector of displacement increments at nodes I and J.

Substituting equations (4) and (5) into equations (1) and (2), we have:

$$e = \frac{1}{L_o} \left[B_L\right] \{r\} \tag{6}$$

$$\eta = \tfrac{1}{2} \{u_\partial\}^T \{u_\partial\} \tag{7}$$

where:

$$\left[B_L\right] = \left[-\left(1 + \frac{\partial^1 u}{\partial x}\right) \; -\frac{\partial^1 v}{\partial x} \; -\frac{\partial^1 w}{\partial x} \quad \left(1 + \frac{\partial^1 u}{\partial x}\right) \quad \frac{\partial^1 v}{\partial x} \quad \frac{\partial^1 w}{\partial x} \right] \tag{8}$$

The linear and nonlinear parts of the local tangent stiffness are obtained as follows (see, for example, Reference 3, Chapter 2).

(1) Linear Part of Local Tangent Stiffness:

$$\left[K_L\right] = \frac{E_T A_o}{L_o} \left(B_L\right)^T \left[B_L\right] \tag{9}$$

where:

E_T = tangent modulus

A_o = area of truss bar at time t = o.

(2) Nonlinear Part of Local Tangent Stiffness :

$$\left[K_{NL}\right] = \frac{{}^{1}\sigma\ A_o}{L_o} \begin{bmatrix} I_3 & -I_3 \\ -I_3 & I_3 \end{bmatrix} \tag{10}$$

where:

${}^{1}\sigma$ = axial stress in truss bar in current configuration (time t)

The local tangent stiffnesses in equations (9) and (10) are transformed to the global axes using the direction cosine matrix, T, relating local and global axes. That is

$$\left[K_{LG}\right] = \begin{bmatrix} T^T & 0 \\ 0 & T^T \end{bmatrix} \left[K_L\right] \begin{bmatrix} T & 0 \\ 0 & T \end{bmatrix} \tag{11}$$

and:

$$\left[K_{NLG}\right] = \begin{bmatrix} T^T & 0 \\ 0 & T^T \end{bmatrix} \left[K_{NL}\right] \begin{bmatrix} T & 0 \\ 0 & T \end{bmatrix} \tag{12}$$

After the matrix operations in equation (12), the global nonlinear tangent stiffness matrix is simply

$$\left[K_{NLG}\right] = \left[K_{NL}\right] \tag{13}$$

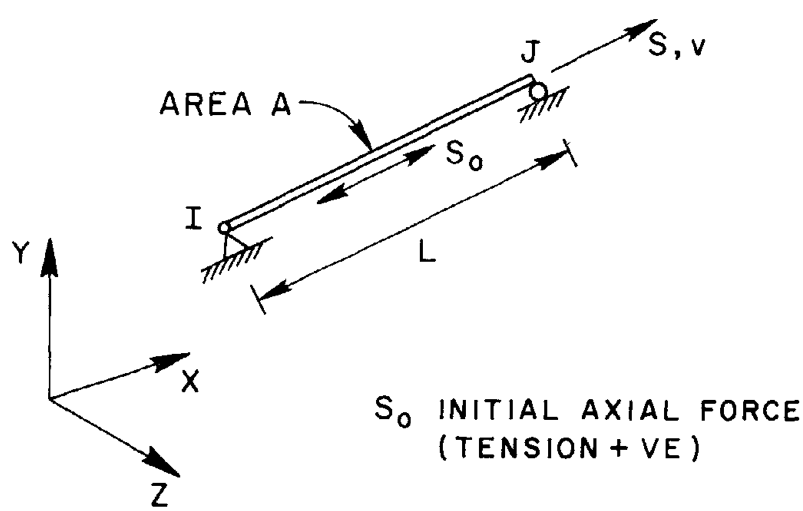
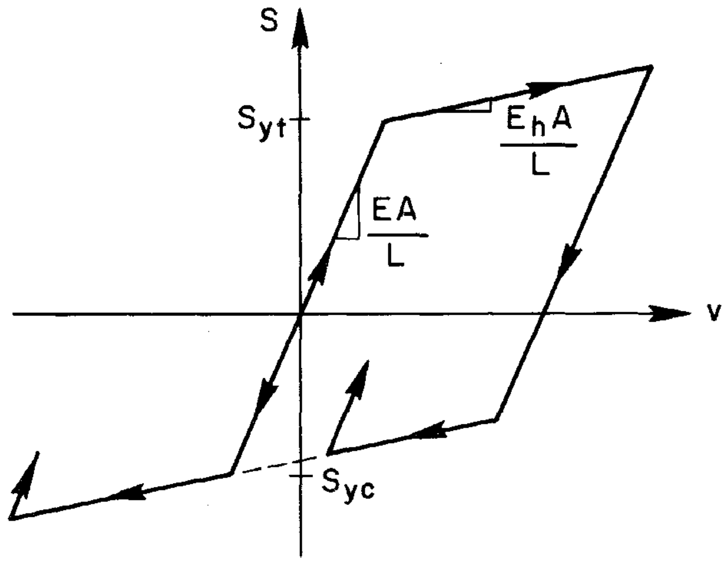
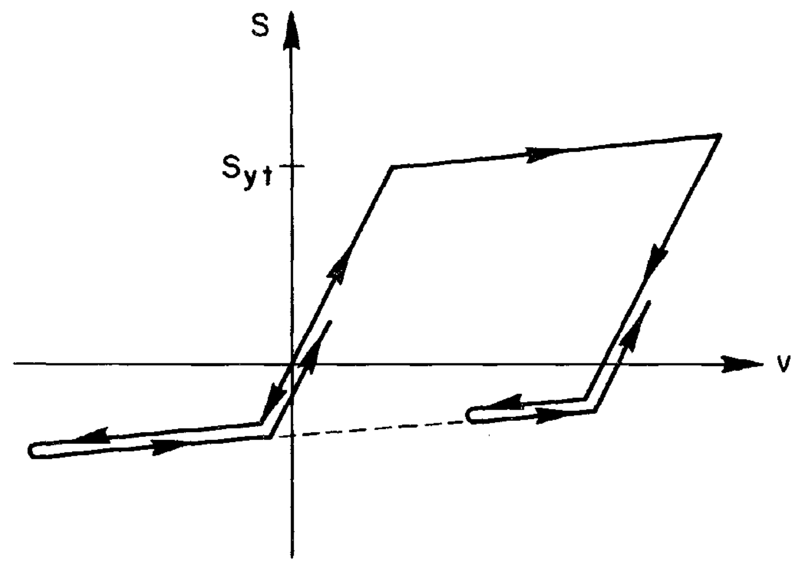


FIG. 2.1 TRUSS ELEMENT



(a) YIELD IN TENSION AND COMPRESSION



(b) YIELD IN TENSION, BUCKLING IN COMPRESSION

FIG. 2.2 INELASTIC BEHAVIOR FOR TRUSS ELEMENT

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