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ANSR - II

ANALYSIS OF NONLINEAR STRUCTURAL RESPONSE USER'S MANUAL

by
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and
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Report to Sponsor:
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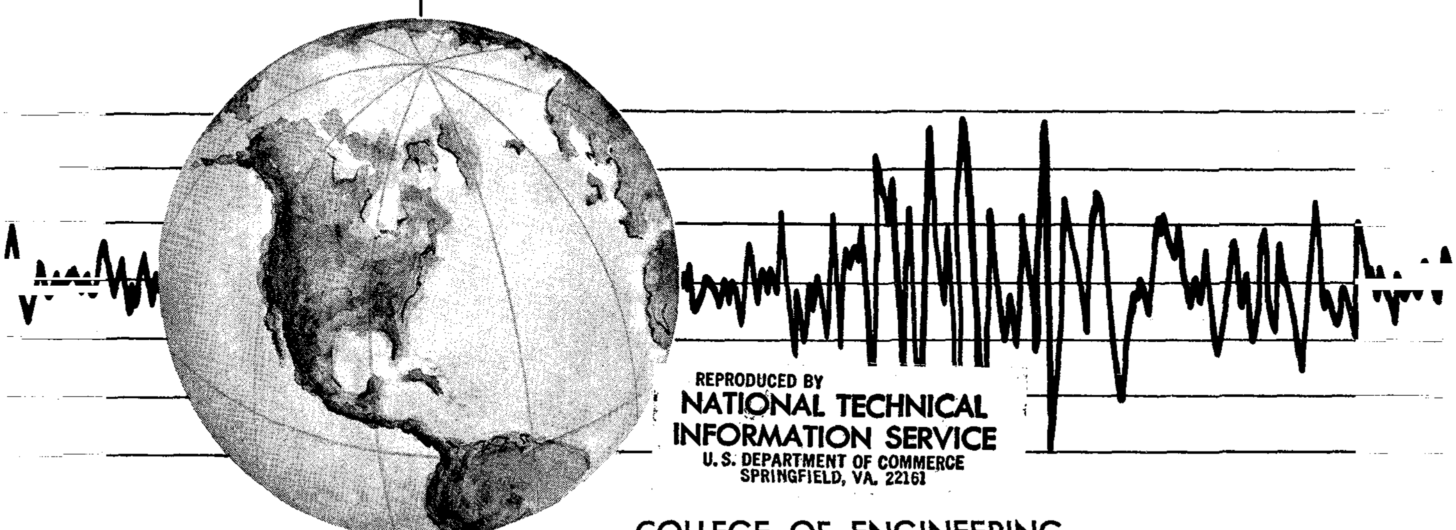

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16. Abstracts

ANSR is a general purpose computer program for the static and dynamic analysis of nonlinear structures, including both large displacements and inelastic effects. In two previously published reports, the theoretical formulations, features and organization of version I (ANSR-I) of the program were documented. This report describes an extended version of the program (ANSR-II).

Several features have been added to the program. The most important of these are: (1) a comprehensive restart option; (2) provision to allow static and dynamic analyses in any sequence; (3) provision for static analysis with prescribed nodal displacements as well as nodal loads; (4) provision for out-of-phase support motions to be specified for earthquake analysis; (5) provision for time delay (travelling wave) effects to be specified for forces and displacements in dynamic analyses; and (6) out-of-core solvers for both symmetrical and unsymmetrical equations.

The procedure for adding new elements to the program are described in this report, and a User's Manual for the main program is given.

The elements in the element library of the program will be described in separate reports.

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ANSR II

ANALYSIS OF NONLINEAR STRUCTURAL RESPONSE

USER'S MANUAL

by

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ABSTRACT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1. ANSR-I and ANSR-II

The computer program ANSR-I was released for general use in 1975. It has proven to be a valuable tool for research in nonlinear structural behavior because of the relative ease with which new nonlinear elements can be developed and added to the program. Theoretical principles, programming considerations, and applications of ANSR-I have been described in References [1] through [4].

ANSR-II is a major improvement over ANSR-I, both in organization and in capabilities, and it is intended that ANSR-II will supersede the earlier program. Although ANSR-II has more capabilities than ANSR-I, and hence is more complex, the two programs are based on closely similar principles. A user with ANSR-I experience will have no difficulty adjusting to ANSR-II. Nonlinear elements which have been developed for ANSR-I must be modified to be acceptable to ANSR-II, but only minor changes are required.

The main improvements incorporated into ANSR-II are as follows :

(1) A restart option has been added. With this option, the structure properties and the results at any number of stages in the analysis may be saved permanently. The properties and the results at any stage may be recalled, and further analyses performed.

(2) Static loadings may include both specified nodal forces and specified nodal displacements. Nodes with specified displacements in one analysis may be released and have specified forces in the next analysis, and vice versa.

(3) Dynamic loadings may include specified forces, specified ground accelerations, and/or specified ground displacements. With the ground displacement option, different support points may be specified to move out-of-phase. A time delay provision is included to allow specification of a train of waves moving past the structure.

(4) Any number of static and dynamic loadings may be specified, in any sequence.

(5) An out-of-core equation solver may be specified for the analysis of large systems.

(6) Both symmetrical and asymmetrical element stiffness matrices can be considered.

1.2. Report Layout

Chapter Two contains the program User's Guide, with explanatory notes. Chapter Three describes the procedures to be followed in adding new elements to the program. In Chapter Four, the theoretical derivations and FORTRAN coding are presented for a simple element, to illustrate the procedures.

Appendices A, B, and C contain, respectively, a summary of the theory for step-by-step dynamic analysis; an explanation of the capacity limits of the program; and discussion of the system control cards needed to use the restart option.

This report does not include discussion of solution strategies for nonlinear analysis. The solution strategies available in ANSR-I have been described and compared in References [2] and [4]. ANSR-II incorporates the same strategies. This report also does not include descriptions of structural elements. Separate reports will be published describing particular elements and presenting examples of their use.

2. PROGRAM USER'S GUIDE

This Chapter describes the input data required for the program. Explanatory notes are at the end of the Chapter.

Consistent units must be used throughout.

The input mode (I, F, or A) is specified for each data item. Mode I = FORTRAN integer format (must be right justified in field). Mode F = FORTRAN F or E format (on CDC machines, the exponent for E format must be right justified). Mode A = FORTRAN alphanumeric format.

A. PROBLEM TITLE

One card.

COLUMNS	NOTE	NAME	DATA
1 - 5(A)		OPER	Execution indicator: (a) START: Execute. (b) CHECK: Data check only. (c) STOP: End of data.
9 - 80(A)		PHED	Problem title.

B. RESTART SPECIFICATION

One card.

COLUMNS	NOTE	NAME	DATA
2 - 5(A)	B.1	DATF	Data file code: (a) OLDF: Use existing file. (b) NEWF: Start new file. (c) NOFL or blank: No file. Leave rest of card blank.
6 - 10(I)	B.1	NRSEQ	Data sequence number for restart (OLDF only). Zero or blank = unstressed state.
15(I)		IPRS	Print code for restart data (OLDF only): (a) 0: No print. (b) 1: Geometry data only. (c) 2: Element states only. (d) 3: Geometry data and element states.
16 - 80(A)	B.2	DFID	Data file identifier (OLDF or NEWF only).

C. STORAGE ALLOCATION AND PROBLEM SIZE

C1. STORAGE ALLOCATION

One card.

COLUMNS	NOTE	NAME	DATA
4 - 5(I)	C.1	KSCHM	Stiffness storage code: (a) −3 : Unsymmetric out-of-core. (b) −2 : Unsymmetric in-core; duplicate out-of-core. (c) −1 : Unsymmetric in-core; duplicate in-core. (d) +1 : Symmetric in-core; duplicate in-core. Defaults to this. (e) +2 : Symmetric in-core; duplicate out-of-core. (f) +3 : Symmetric out-of-core.
6 - 10(I)	C.2	MAXBLK	For KSCHM = ±3 : Maximum number of blocks ($\ngtr$ 20). Default = 1.
15(I)	C.3	IEDBLK	Protection code for element data: (a) 0 or blank : Execute regardless. (b) 1 : Execute only if all element data can be held in core.

C2. PROBLEM SIZE

One card. Omit for OLDF option.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NODES	No. of nodes.
6 - 10(I)		NCNOD	No. of control nodes (coordinates specified directly). (Section D1.)
11 - 15(I)		NODGC	No. of coordinate generation cards (Section D2).
16 - 20(I)		NDCON	No. of cards specifying deleted d.o.f. (Section D3).
21 - 25(I)		NIDDOF	No. of cards specifying equal d.o.f. (Section D4).
26 - 30(I)		NMSGC	No. of cards specifying nodal masses (Section D5).
31 - 35(I)	C.4	NELGR	No. of element groups.

D. NODE DATA

Omit entire Section D for OLDF option.

D1. CONTROL NODE COORDINATES

NCNOD cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	D.1	N	Node number, in any sequence.
6 - 15(F)		X(N)	X coordinate.
16 - 25(F)		Y(N)	Y coordinate.
26 - 35(F)		Z(N)	Z coordinate.

D2. COORDINATE GENERATION

NODGC cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	D.2	NB	Node at beginning of line.
6 - 10(I)		NE	Node at end of line.
11 - 15(I)		NOD	No. of nodes to be generated.
16 - 20(I)		ND	Node number difference. Leave blank if nodes are listed. May be negative.
21 - 30(F)	D.2	SPAC	Spacing between nodes: (a) Zero or blank : Uniform spacing. (b) $<$ 1.0 : Spacing = (length of line) x SPAC. (c) $>$ 1.0 : Spacing = SPAC. (d) $<$ 0.0 : Error.
31 - 80(I)		NLIST	List of nodes. Up to 10 nodes, in 5-column fields. Omit if ND is nonzero.

D3. DELETED DEGREES OF FREEDOM

NDCON cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	D.3	N	Node, or first node in a series.
10(I)			Code for X translation: (a) 1 : Deleted. (b) 0 or blank : Not deleted.
11(I)			Code for Y translation.
12(I)			Code for Z translation.
13(I)			Code for X rotation.
14(I)			Code for Y rotation.
15(I)			Code for Z rotation.
16 - 20(I)	D.4	NE	Last node in series. Blank if a single node or if nodes are listed.
21 - 25(I)	D.4	ND	Node number difference. Default = 1.
26 - 30(I)	D.4	NOD	No. of nodes listed. Max. = 10.
31 - 80(I)	D.4	NLIST	List NOD nodes, in successive 5-column fields.

D4. NODES WITH EQUAL DISPLACEMENTS

NIDDOF cards.

COLUMNS	NOTE	NAME	DATA
1(I)	D.5		Code for X translation: (a) 1 : X displacements identical for all nodes in list (same d.o.f.). (b) 0 or blank : Not identical (different d.o.f.).
2(I)			Code for Y translation.
3(I)			Code for Z translation.
4(I)			Code for X rotation.
5(I)			Code for Y rotation.
6(I)			Code for Z rotation.
11 - 15(I)		NOD	No. of nodes listed. Max = 13.
16 - 80(I)		NLIST	List NOD nodes, in successive 5-column fields.

D5. NODAL MASSES

NMSGC cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	D.6	NF	Node, or first node in a series.
6 - 15(N)		SM(1)	X mass.
16 - 25(N)		SM(2)	Y mass.
26 - 35(N)		SM(3)	Z mass.
36 - 45(N)		SM(4)	X rotational inertia.
46 - 55(N)		SM(5)	Y rotational inertia.
56 - 65(N)		SM(6)	Z rotational inertia.
66 - 70(I)		NL	Last node in series. Blank for a single node.
71 - 75(I)		ND	Node number difference. Default = 1.

E. ELEMENT DATA

Insert cards defining elements. The input requirements are described in separate reports.

Omit Section E for OLDF option.

F. LOAD PATTERNS AND RECORDS

F1. STORAGE ALLOCATION

One card.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	F.1	NSPAT	No. of static force patterns (Section F3).
6 - 10(I)	F.1	NPDP	No. of static displacement patterns (Section F4).
11 - 15(I)	F.2	NGAR	No. of ground acceleration records (Section F5).
16 - 20(I)	F.2	NFHR	No. of dynamic force records (Section F6).
21 - 25(I)	F.2	NSDR	No. of dynamic support motion records (displacement, velocity or acceleration). (Section F7.)
26 - 30(I)	F.3	NFHN	Max. no. of nodes with dynamic forces (not less than total no. of nodes specified in Section J4).
31 - 35(I)	F.3	NSDN	Max. no. of nodes with dynamic support motion (not less than total no. of nodes specified in Section J5).
36 - 40(I)	F.3	MAXIPT	Max. no. of input values for any dynamic record (see NIPT, Sections F5(b), F6(b), F7(b)).
41 - 45(I)	F.3	NSINP	Max. no. of interpolated values for any dynamic record (see NSI, Sections F5(b), F6(b), F7(b)).
46 - 50(I)	F.4	NSDEL	Max. no. of time steps delay (see NS, Sections J3, J4, J5).

F2. CONTROL INFORMATION FOR STEP-BY-STEP INTEGRATION

One card.

COLUMNS	NOTE	NAME	DATA
1 - 10(F)		DT	Integration step size.
11 - 20(F)	F.5	DELTA	Parameter δ in Newmark's method. Default = 0.
21 - 30(F)		BETA	Parameter β in Newmark's method. Default = $0.25(1 + \delta)^2$.
31 - 40(F)	F.6	DAMPM	Mass proportional damping factor, α.

F3. STATIC FORCE PATTERNS

NSPAT sets of cards.

F3(a). CONTROL CARD.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NSLG	No. of load cards for this pattern.
9 - 80(A)			Optional pattern title.

F3(b). LOAD CARDS

NSLG cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NF	Node, or first node in a series.
6 - 15(F)			X force.
16 - 25(F)			Y force.
26 - 35(F)			Z force.
36 - 45(F)			X moment.
46 - 55(F)			Y moment.
56 - 65(F)			Z moment.
66 - 70(I)		NL	Last node in series. Blank for a single node.
71 - 75(I)		ND	Node number difference. Default = 1.

F4. STATIC DISPLACEMENT PATTERNS

NPDP sets of cards.

F4(a). CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NODPD	No. of imposed displacements.
9 - 80(A)			Optional pattern title.

F4(b). DISPLACEMENT CARDS

As many cards as needed, four displacements per card.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	F.7		Affected node.
10(I)			Displacement code: (a) 1, 2, or 3 = X, Y, or Z translation, respectively. (b) 4, 5, or 6 = X, Y, or Z rotation, respectively.
11 - 20(F)			Displacement magnitude.
21 - 40			Repeat for second node.
41 - 60			Repeat for third node.
61 - 80			Repeat for fourth node.

F5. GROUND ACCELERATION RECORDS

NGAR sets of cards.

F5(a). RECORD TITLE

COLUMNS	NOTE	NAME	DATA
1 - 60(A)			Optional title.
61 - 80(A)	F.8	FORM	Input format. No default.

F5(b). CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NIPT	No. of input acceleration values. Max. = MAXIPT, Section F1.
10(I)		KPR	Print code: (a) 0 : No print. Default = 0. (b) 1 : Print as input and scaled. (c) 2 : Print as interpolated. (d) 3 : Both 1 and 2.
11 - 20(F)	F.8	TINT	Input time interval: (a) Zero or blank : Input time - acceleration pairs. (b) Nonzero : Input accelerations only.
21 - 30(F)	F.9	TO	Time at interpolation step zero.
31 - 35(I)	F.9	NSI	No. of interpolation steps. Max. = NSINP, Section F1.
36 - 45(F)	F.10	SFAC	Scale factor. Default = 1.0.

F5(c). ACCELERATION VALUES

As many cards as needed. If time-acceleration pairs are input, time must immediately precede corresponding acceleration.

F6. DYNAMIC FORCE RECORDS

NFHR sets of cards.

F6(a). RECORD TITLE

COLUMNS	NOTE	NAME	DATA
1 - 60(A)			Optional title.
61 - 80(F)	F.8	FORM	Input format. No default.

F6(b). CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5 (I)		NIPT	No of input force values. Max. = MAXIPT, Section F1.
10 (I)		KPR	Print code: (a) 0 : No print. Default = 0. (b) 1 : Print as input and scaled. (c) 2 : Print as interpolated. (d) 3 : Both 1 and 2.
11 - 20 (F)	F.8	TINT	Input time interval: (a) Zero or blank: Input time - force pairs. (b) Nonzero: Input forces only.
21 - 30 (F)	F.9	TO	Time at interpolation step zero.
31 - 35 (I)	F.9	NSI	No. of interpolation step. Max. = NSINP, Section F1.
36 - 45 (F)		SFAC	Scale factor. Default = 1.0.

F6(c). FORCE VALUES

As many cards as needed. If time-force pairs are input, time must immediately precede corresponding force.

F7. DYNAMIC SUPPORT MOTION RECORDS

NSDR sets of cards.

F7(a). RECORD TITLE

COLUMNS	NOTE	NAME	DATA
1 - 60(A)			Optional title.
61 - 80(A)	F.8	FORM	Input format. No default.

F7(b). CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NIPT	No. of input motion values.
10(I)			Type of motion: (a) 1 : Displacement. Default = 1. (b) 2 : Velocity.. (c) 3 : Acceleration.
15(I)		KPR	Print code: (a) 0 : No print. Default = 0. (b) 1 : Print as input and scaled. (c) 2 : Print as interpolated. (d) 3 : Both 1 and 2.
16 - 25(F)	F.8	TINT	Input time interval: (a) Zero or blank: Input time-motion pairs. (b) Nonzero: Input motion values only.
26 - 35(F)	F.9	TO	Time at interpolation step zero.
36 - 40(I)	F.9	NSI	No. of interpolation steps. Max. = NSINP, Section F1.
41 - 50(F)		SFAC	Scale factor. Default = 1.0.
51 - 60(F)		DO	Displacement at time TO. Required for velocity and acceleration records.
61 - 70(F)	F.11	VO	Velocity at time TO. Required for acceleration records.

F7(c). MOTION VALUES

As many cards as needed. If time-motion pairs are input, time must immediately precede corresponding motion value.

G. OUTPUT SPECIFICATION

G1. CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NODSX	No. of nodes for X-displacement printout. Punch −1 for all nodes. For dynamic analysis, includes velocities and accelerations.
6 - 10(I)		NODSY	No. of nodes for Y-displacement printout Punch −1 for all nodes.
11 - 15(I)		NODSZ	No. of nodes for Z-displacement printout. Punch −1 for all nodes.
16 - 20(I)	G.1	NODXP	No. of nodes for X-displacement punched output. Punch −1 for all nodes.
21 - 25(I)		NODYP	No. of nodes for Y-displacement punched output. Punch −1 for all nodes.
26 - 30(I)		NODZP	No. of nodes for Z-displacement punched output. Punch −1 for all nodes.
31 - 78(A)	G.1	PFORM	Punched output format. No default.

G2. NODE LISTS

Six sets of cards.

(1) As many cards as needed. List NODSX nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODSX = 0 or −1.

(2) As many cards as needed. List NODSY nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODSY = 0, or −1.

(3) As many cards as needed. List NODSZ nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODSZ = 0 or −1.

(4) As many cards as needed. List NODXP nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODXP = 0 or −1.

(5) As many cards as needed. List NODYP nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODYP = 0 or −1.

(6) As many cards as needed. List NODZP nodes in successive 5-column fields (integer format), sixteen nodes to a card. Omit for NODZP = 0 or −1.

H. ANALYSIS TYPE CARD

COLUMNS	NOTE	NAME	DATA
1 - 4(A)	H.1	ANTYP	Analysis type code. (a) STAT : Static analysis. (b) DYNM : Dynamic analysis. (c) NONE : End execution. Default = NONE.
9 - 80(A)		AHED	Analysis heading.

I. STATIC ANALYSIS SPECIFICATION

Omit entire Section I for ANTYP = DYNM or NONE.

I1. CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	I.1	NSLI	No. of static load increments.
9 - 80(A)			Optional additional analysis heading. Not saved on data file.

I2. LOAD INCREMENT SPECIFICATION

NSLI sets of cards.

I2(a). CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)	I.1	NSTEP	No. of equal load steps. (a) Positive : Results envelopes not printed at end of increment. (b) Negative : Envelopes printed.
10(I)	I.1	KSAVE	Results saving code: (a) 0 : Results not saved. (b) 1 : Results at end of load increment saved on data file.
15(I)		ISLOD	Static force patterns application code (Section I2(c)). (a) 0 : Patterns not applied. (b) 1 : Patterns applied.
20(I)		IPDIS	Static displacement patterns application code (Section I2(d)). (a) 0 : Patterns not applied. (b) 1 : Patterns applied.
25(I)		ITYP	Iteration type code: (a) 0 : Newton-Raphson iteration. (b) 1 : Constant stiffness iteration.
30(I)		KPATH	State determination type code for Constant stiffness iteration. (a) 0 : Path independent. (b) 1 : Path dependent. Omit for ITYP = 0.
31 - 35(I)		KRUSE	Stiffness reformation code. (a) 0 : Stiffness not reformed. (b) n : Stiffness reformed every n steps.
40(I)		IQUIT	Solution termination code: (a) 0 : Solution continues if no convergence. (b) 1 : Solution terminated if no convergence.

COLUMNS	NOTE	NAME	DATA
45(I)	I.1	IPRNT	Output print code. (a) 0 : Results not printed. (b) 1 : Results printed at end of load increment. (c) 2 : Results printed every load step. (d) 3 : Results printed every iteration.
46 - 50(I)		MAXC	Max. no. of iteration cycles in any load step.
51 - 55(I)		MAXI	Max. no. of iterations in any cycle.

I2(b). CONVERGENCE TOLERANCES CARD

COLUMNS	NOTE	NAME	DATA
1 - 10(F)		TOLF	Nodal force convergence tolerance in last step of load increment.
11 - 20(F)		TOL	Nodal force convergence tolerance in all except last step.
21 - 30(F)		TOLK	Nodal force convergence tolerance for change of stiffness in Newton-Raphson iteration.
31 - 40(F)		DISL	Max. displacement (translation or rotation) increment permitted in any iteration. Default = 10^{16}.

I2(c). STATIC FORCE PATTERNS APPLICATION

Omit this section for NSPAT = 0 (Section F.1), or ISLOD = 0; otherwise, as many cards as needed to specify NSPAT scale factors. For each pattern (Section F3) in turn, specify a scale factor. 10-column (F10.0) fields, eight to a card.

I2(d). STATIC DISPLACEMENT PATTERNS APPLICATION

Omit this section for NPDP = 0 (Section F.1), or IPDIS = 0; otherwise, as many cards as needed to specify NPDP scale factors. For each pattern (Section F4) in turn, specify a scale factor. 10-column (F10.0) fields, eight to a card.

J. DYNAMIC ANALYSIS SPECIFICATION

Omit entire Section J if ANTYP = STAT or NONE.

J1. CONTROL CARD

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NSTEP	No. of time steps to be considered.
6 - 10(I)	J.1	NICGC	Initial conditions code: (a) −1 : Zero initial velocities and accelerations. (b) 0 : If first analysis in this computer run, conditions of restart data sequence NRSEQ, Section B. If second or subsequent analysis, conditions at end of preceding analysis. (c) >0 : Initial velocities and accelerations input on cards (Section J2).
15(I)	J.2	IGM	Ground acceleration application code. (a) 0 : Ground accelerations not applied. (b) 1 : Ground accelerations applied (Section J3).
16 - 20(I)	J.2	NDLGC	No. of dynamic force application commands. (a) 0 : Forces not applied (b) >0 : Forces applied (Section J4).
21 - 25(I)	J.2	NSDGC	No. of dynamic support motion application commands. (a) 0 : Support motions not applied. (b) >0 : Support motions applied (Section J5).
26 - 30(I)		NITHJ	Time step interval for nodal response printout. Default = no printout.
31 - 35(I)		NITHE	Time step interval for element response printout. Default = no printout.
36 - 40(I)		NIENV	Time step interval for envelope printout. Default = no printout.
41 - 45(I)		NITHJP	Time step interval for nodal response punched output. Default = no output.
46 - 50(I)		KSAVE	Time step interval for saving results on data file. Default = no saving.
51 - 60(F)		TSTART	Time at beginning of this analysis. Needed if envelope times are important; otherwise optional.

J2. INITIAL CONDITIONS SPECIFICATION

NICGC cards. Omit if NICGC = 0 or −1.

COLUMNS	NOTE	NAME	DATA
5(I)		KDOF	D.o.f. code (a) 1, 2, or 3 = X, Y, or Z translation, respectively. (b) 4, 5, or 6 = X, Y, or Z rotation, respectively.
6 - 15(F)			Velocity.
16 - 25(F)			Acceleration.
26 - 80(I)			List nodes with the same initial velocity and acceleration, in successive 5-column fields.

J3. GROUND ACCELERATIONS APPLICATION

Omit if NGAR = 0 or IGM = 0.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NR	Ground acceleration record no. for X direction.
6 - 10(I)	J.3	NS	Step no. in interpolated record. (a) $\geqslant 0$: Step NS in record is step zero for dynamic integration. (b) < 0 : Record applied with NS steps delay. Max = NSDEL, Section F.1.
11 - 20(F)		SFAC	Scale factor. No default.
21 - 40			Repeat for Y direction.
41 - 60			Repeat for Z direction.

J4. DYNAMIC FORCE APPLICATION

Omit if NFHR = 0 or NDLGC = 0; otherwise NDLGC cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NR	Dynamic force record no.
10(I)		KDIR	Direction code. (a) 1, 2, or 3 = X, Y, or Z translation, respectively. (b) 4, 5, or 6 = X, Y, or Z rotation, respectively.
11 - 15(I)	J.3	NS	Step no. in interpolated record. (a) $\geqslant 0$: Step NS in record is step zero for dynamic integration. (b) < 0 : Record applied with NS steps delay. Max. = NSDEL, Section F.1.
16 - 25(F)		SFAC	Scale factor. No default.
26 - 80(I)		NODL	List nodes in successive 5-column fields. Total nodes must not exceed NFHN, Section F.1.

J5. SUPPORT MOTION APPLICATION

Omit if NSDR = 0, or NSDGC = 0; otherwise NSDGC cards.

COLUMNS	NOTE	NAME	DATA
1 - 5(I)		NR	Support motion record no.
10(I)		KDIR	Direction code. (a) 1, 2, or 3 = X, Y, or Z translation, respectively. (b) 4, 5, or 6 = X, Y, or Z rotation, respectively.
11 - 15(I)	J.3	NS	Step no. in interpolated record. (a) $\geqslant 0$: Step NS in record is step zero for dynamic integration. (b) < 0 : Record applied with NS steps delay Max. = NSDEL.
16 - 25(F)		SFAC	Scale factor. No default.
26 - 30(I)		NODL	List nodes in successive 5-column fields. Total nodes must not exceed NSDN, Section F.1.

J6. SOLUTION PROCEDURE CARD

COLUMNS	NOTE	NAME	DATA
5(I)		ITYP	Iteration type code. (a) 0 : Newton-Raphson iteration. (b) 1 : Constant stiffness iteration.
10(I)		KPATH	State determination type code. (a) 0 : Path independent. (b) 1 : Path dependent. Omit for ITYP = 0.
11 - 15(I)		KRUSE	Stiffness reformation code. (a) 0 : Stiffness not reformed. (b) n : Stiffness reformed every n time steps.
20(I)		IQUIT	Solution termination code. (a) 0 : Solution not terminated if no convergence. (b) 1 : Solution terminated if no convergence.
21 - 25(I)		MAXC	Max. no. of iteration cycles in any time step.
26 - 30(I)		MAXI	Max. no. of iterations in any cycle.
31 - 35(I)			Time step interval for "fine" convergence tolerance. "Coarse" tolerance is used in intermediate steps (Section J7).

J7. CONVERGENCE TOLERANCES CARD

COLUMNS	NOTE	NAME	DATA
1 - 10(F)		TOLF	"Fine" nodal force convergence tolerance.
11 - 20(F)		TOL	"Coarse" nodal force convergence tolerance.
21 - 30(F)		TOLK	Nodal force convergence tolerance for change of stiffness in Newton-Raphson iteration.
31 - 40(F)		DISL	Max. displacement (translation or rotation) increment permitted in any iteration. Default = 10^{16}.

USER GUIDE NOTES

NOTE B.1

When NEWF is specified, a new data file is created. The structure geometry data is stored, and zero initial conditions (corresponding to the unstressed structure) are automatically set up. During the computer run, analysis results may be saved at any stage in the analysis (at the end of any static load increment, and at specified time step intervals in dynamic analysis). The saved analysis results sets are numbered sequentially. Set number zero is the zero initial conditions. The computer printout includes a log of the results sets saved on the data file.

For subsequent computer runs, the OLDF option may be used to recall the geometry data and any results set number (NRSEQ). These results are used as initial conditions for continued analysis. Additional results may be saved during the analysis. These results are added to those previously saved, and are numbered in continuing sequence.

NOTE B.2

For the NEWF option, the user must provide a data file identifier. This identifier is stored as the first record on the data file. Subsequent uses of the data file (OLDF) must specify the identical identifier, otherwise execution will be terminated. The two identifiers must match character for character, including blanks.

NOTE C.1

The program includes in-core and out-of-core, symmetric and unsymmetric equation solvers. The structure tangent stiffness matrix is stored column-wise in compacted form omitting most zero elements ("active column" form).

For large structures, the core storage may not be adequate to allow storage of the entire matrix, in which case it may be blocked, with the blocks stored out of core (KSCHM = ± 3).

For other values of KSCHM, either one or two stiffness matrices will be held in core. As the structure becomes nonlinear, the tangent stiffness matrix progressively changes. The stiffness matrix is progressively updated, rather that completely reformed, taking into account only those finite elements which have stiffness changes. Updating of the tangent stiffness requires least computational effort if storage for both the current matrix and a duplicate matrix can be allocated in core (KSCHM = $\pm$ 1). If this is not possible, the duplicate matrix must be stored out-of-core (KSCHM = ± 2).

NOTE C.2

If KSCHM = ± 3, the user may wish to specify a maximum number of stiffness matrix blocks, to avoid a large number of small blocks and possibly high I/O costs. The number of blocks may not exceed 20 (unless the program capacity is changed — see Appendix B).

NOTE C.3

For each finite element, an information block is created and continually updated. If the core storage is not sufficient to hold the information for all elements, this information will be stored out-of-core. I/O costs will be substantially higher for out-of-core storage than for complete in-core storage. For small problems, the program user may intend the program to execute in-core, and may wish to suppress execution if in-core storage is not possible. The default option will usually apply.

NOTE C.4

The finite elements must be divided into "groups." All elements in any group must be of the same type (e.g., truss, 3D-solid), and, typically, all elements of a single type will be included in a single group. However, elements of the same type may be divided into separate groups if desired. There is no limit on the number of element groups. Within any group, elements must be sequentially numbered in increasing order. However, the first element within any group may be given any number, not necessarily 1.

NOTE D.1

The "control node" coordinates must be defined with respect to an orthogonal, right-handed coordinate system X, Y, and Z. The coordinates of the remaining nodes may be generated. Only a straight line generation option is currently available (Section D2).

NOTE D.2

Each generation command can generate the coordinates of one or more nodes. The coordinates of the nodes at the beginning and end of the generation line must have been previously defined, either by direct specification or by a previous straight line generation.

The generated nodes are spaced along the generation line as follows:

(a) SPAC = 0.0: The generated nodes are uniformly spaced between the two end nodes.

(b) SPAC < 1.0: The spacing between generated nodes is this proportion of the length of the generation line. Note that this can allow generated nodes to lie beyond node NE if desired.

(c) SPAC > 1.0: The spacing between generated nodes is this distance. Again, generated nodes may lie beyond node NE.

The program also incorporates a default option for nodes which are not otherwise defined. It is not necessary to provide generation commands for nodes which are (a) sequentially numbered between the beginning and end nodes of any straight line, and (b) equally spaced along that line. After all generation commands have been executed, the coordinates for each group of unspecified nodes are automatically generated, assuming sequential numbering and equal spacing along the line joining the specified nodes immediately preceding and following the group. That is, any generation command with SPAC = 0.0 and a node number difference of one is superfluous.

NOTE D.3

Each node of the structure may have up to six displacement degrees of freedom, namely X, Y, and Z displacement, and X, Y, and Z rotation. However, some displacements may be constrained to be zero, and may be deleted. For each deleted degree of freedom (constraint code = 1), the corresponding equilibrium equation (row and column of stiffness matrix) is deleted. All degrees of freedom at which *nonzero* static or dynamic displacements are to be applied must be "free" (code =0).

If constraint codes are specified more than once for any node, the last specified value is used. Hence, if most but not all nodes have similar constraints, the first command may cover all nodes, and specify "basic" constraint codes. Later commands may then modify the "basic" codes for particular nodes.

For plane analysis, the out-of-plane displacement and in-plane rotations must all be deleted.

NOTE D.4

If nodes are not listed, the affected nodes are nodes N, N + ND, N + 2*ND, etc. up to node NE. If nodes are listed, NE and ND are ignored, and only the listed nodes are affected.

NOTE D.5

It may often be reasonable to assume that certain nodes displace equally in certain directions. The displacements (or rotations) can then be assigned the same degree of freedom number. Each equal displacement command covers at most 13 nodes. If a group of nodes has more than 13 nodes, specify the remaining nodes with additional commands. The smallest numbered node in any group must be the first node in the list for all commands defining that group.

Greater computational efficiency will often be achieved by constraining nodes to have equal displacements. However, the effect may be to increase the effective band width of the structure stiffness matrix, and may increase the required stiffness matrix storage and/or the computational effort. Equal displacements should therefore be specified with caution.

Equal displacement constraints apply only to displacements (and rotations) along the global X,Y,Z axes. Inclined displacements cannot generally be made equal using these constraints.

NOTE D.6

Any node may, if desired, appear in more than one specification command. In such cases, the mass will be the sum of the values specified in the separate commands. If certain nodes are constrained to have equal displacements, the mass associated with the affected degree of freedom will be the sum of the masses specified for the individual nodes. If a mass is specified for any degree of freedom that is deleted, the mass is ignored.

NOTE F.1

A static force pattern defines a vector of nodal loads. A static displacement pattern defines a vector of imposed nodal displacements. Any number of different patterns may be defined. Force patterns and/or displacement patterns may be combined together to produce static load and/or displacement increments. Combination factors are specified in Sections I2(c) and I2(d).

NOTE F.2

Any number of ground acceleration records, dynamic force records, and/or support motion records may be specified. Dynamic force records are applied as nodal loads, and support motion records as nodal displacements. Records can be applied singly or in combination. The combination factors are specified in Sections F5, F6, and F7. The nodes affected by the records are specified in Sections J4 and J5.

Ground accelerations are identified with the X, Y, and Z directions in Section J3. Although any number of ground acceleration records may be defined, a maximum of three may be applied at any time, one each in the X, Y, and/or Z directions.

NOTE F.3

The values of NFHN, NSDN, MAXIPT, and NSINP are required by the program for storage allocation. If unnecessarily large values are specified, some core storage will be wasted.

NOTE F.4

Any one of the dynamic force records, support motion records, and ground acceleration records may be applied with a time delay, specified in terms of a number of time steps (DT, Section F2). A record which is applied with, say, NS steps delay will begin to be applied at step (NS + 1) of the step-by-step dynamic integration. The value of NSDEL is the maximum number of time steps delay which will be specified for any dynamic record. This value is needed for storage allocation and blocking of the records.

Because interpolated dynamic records could require large amounts of core storage if each record were stored in-core, the program blocks each record. To perform the analysis with allowance for time delay, each block must contain at least NSDEL time steps. If NSDEL is less than 200, a block size of 200 is assumed. Hence, NSDEL may be left blank if the maximum delay is less than 200 steps.

NOTE F.5

An implicit, single step, two-parameter (δ, β) family of integration operators has been proposed by Newmark. The stability and accuracy characteristics of the procedure have been extensively documented for linear analysis.

A number of different operators can be obtained by specifying values of the parameters δ and β. The two most commonly used operators are:

(a) "Constant average acceleration" operator ($\delta = 0$, $\beta = 1/4$).

(b) Linear acceleration operator ($\delta = 0$, $\beta = 1/6$).

The constant average acceleration operator is unconditionally stable in linear analysis, and its use is recommended for nonlinear analysis. This is the default option. Use of the linear acceleration operator is not recommended.

NOTE F.6

See Appendix A for the damping assumption. The stiffness proportional damping factors, β_o and β_T, are specified separately for each element group.

NOTE F.7

A static displacement pattern is a vector of nodal displacements. For each pattern, any number of imposed displacements and/or rotations may be specified. If more than one displacement is specified for any node and displacement direction (i.e., if a node number is repeated in a pattern) the last input value of imposed displacement is assumed (i.e., values are not added). If an imposed displacement is input for a deleted degree of freedom, the displacement is ignored.

In any static analysis (Section I), several static displacement patterns may be combined to produce a static displacement. Different combinations may be specified for each new load increment, so that the degrees of freedom at which displacements are imposed may be different from one load increment to next. Static force patterns may also be combined with displacement patterns. If a static force is specified for a degree of freedom which also has a specified displacement, the force is ignored.

NOTE F.8

The input format for reading time-value pairs for any dynamic record (ground acceleration, dynamic force, or support motion) must be specified. No default format is assumed by the program. The format must be enclosed in parentheses, e.g., (8F10.0), without the word "FORMAT." If any record contains record values (accelerations, forces, or support motions) at constant time intervals, only the record values need to be input. The times for this case are automatically generated by the program as 0.0, TINT, 2*TINT, ..., etc.

NOTE F.9

The interpolated record consists of NSI time steps (steps 1, 2, 3 ...., NSI). The interpolation may start at the beginning of the record (TO = 0.0) or at some later time. The use of some later time will most often be used when a dynamic analysis is restarted. The value TO must then be the time at the last step of the preceding analysis (i.e., the analysis which defines the initial conditions). Note that the time step, DT, may be different from that in the preceding analysis. Nonzero values of TO may be used in other situations if desired. However, care must be taken, especially in defining the initial conditions.

NOTE F.10

The scale factor may be used to convert from multiples of g to acceleration units, or to scale the record. A further scale factor may be specified in Section J3.

NOTE F.11

For actual application to the structure, dynamic support motions are converted to displacement records. If a displacement record is specified directly, then the interpolation can be carried out with no additional information. However, if a velocity record is specified, then the displacement at time TO must be given. Similarly, if an acceleration record is specified, then both the displacement and velocity at time TO must be given.

NOTE G.1

Punched output is produced for dynamic analysis only. The following quantities are punched, one card for each affected node at each output time step (NITHJP, Section J1).

Node number (I format).
Direction (X, Y, or Z; A format, minimum A2).
Displacement (F or E format).
Velocity (F or E format).
Acceleration (F or E format).
Time (F or E format).

The card format must be specified, with parentheses but without the word "FORMAT" (e.g., (I5, A5, 3E15.5, 5X, F10.5)). The format length must not exceed 80 columns.

NOTE H.1

Static analysis includes prescribed static loads and/or displacements. Dynamic analysis includes ground accelerations, dynamic forces and/or support motions, applied singly or in combination. Any sequence of static or dynamic analyses may be performed in the same computer run. Execution is terminated with the NONE option (or a blank card).

NOTE I.1

Static loads and imposed displacements can be applied in any number of static load *increments.* Each increment is obtained by combining static load and/or imposed displacement patterns. Each increment can be applied in a number of equal *steps.* For each step, the solution may be found in a number of *iterations* (depending on the solution strategy selected). The results may be printed at each iteration, at each step, or only at the end of the increment. Envelope values may be printed only at the end of the increment. The response results at the end of any increment may be saved on the data file, for use in later restarts.

For each new increment, a different solution strategy may be used, and the combination factors for load and displacement patterns may be different from one increment to the next. Thus, non-proportional loads may be applied, and the degrees of freedom at which displacements are imposed may be different from increment to increment.

A particular degree of freedom may have a specified displacement in one load increment (n) and a specified force in the following increment (n + 1). In such a case, a support force will generally be present at the end of increment n, and this force must be eliminated in increment n + 1. The program determines the support force automatically, and eliminates it by applying the reverse of the force in the *first step* of increment n + 1.

NOTE J.1

For any dynamic analysis, initial velocities and accelerations are required. The default option (NICGC = 0) is as follows:

(a) First analysis in this computer run (no preceding static or dynamic analyses): Conditions of restart data sequence NRSEQ; or, for no restart, zero initial velocity and acceleration.

(b) Second or subsequent analysis in this computer run: Final conditions of immediately preceding analysis. If this was a static analysis, the initial velocities and accelerations will all be zero.

The default option may be over-ridden by specifying NICGC = −1 or >0, as indicated. This over-ride applied to velocities and accelerations only. The nodal displacements and element states of stress are those from the preceding analysis (for restart, data sequence NRSEQ).

NOTE J.2

Ground motions may be specified using either ground acceleration specification or dynamic support motion specification.

In the ground acceleration case, a "conventional" seismic time-history analysis is performed, by integrating the equation

$$M.d\ddot{x}_r + C.d\dot{x}_r + K_T.dx_r = -M.d\ddot{x}_g$$

in which x_r = nodal displacements relative to ground, and x_g = ground displacements. For analyses of this type, all support points must move in phase, and the calculated displacements, velocities, and accelerations are values relative to the ground.

In the dynamic support motion case, the analysis is performed by integrating the equation

$$M.d\ddot{x} + C.d\dot{x} + K_T.dx = K_T.dx_g$$

in which x = total nodal displacements and x_g = ground displacements (at support points). The support points need not move in phase, and the calculated displacements, velocities and accelerations are total values.

The program allows both ground accelerations and dynamic support displacements to be applied simultaneously. However, the calculated results will be inconsistent because relative and total values will be combined. Because total values are calculated for dynamic force application, it will also be inconsistent to combine ground accelerations with dynamic forces. A similar inconsistency will arise if a ground acceleration analysis is *followed* by a dynamic force or dynamic support motion analysis, because the final conditions from the first analysis will not be consistent with the required initial conditions for the second.

If only static plus "conventional" seismic analyses are being performed, either the ground acceleration option or the dynamic support motion option may be used. If both dynamic forces and seismic motions are to be considered, only the dynamic support motion option should be used. If out-of-phase seismic motions are to be considered, use of the dynamic support motion option is essential.

The damping matrix, C, is given (see Appendix A) by :

$$C = \alpha M + \beta_o K_o + \beta_T K_T$$

Because rigid body motion of a structure will be unrestrained, it follows that :

$$K.dx_r = K.dx$$

in which $K = K_o \; or \; K_T$. Hence, if $\alpha = 0$, the damping forces in any analysis will be the same for both the ground acceleration and support motion options. If $\alpha \neq 0$, however, the damping forces will differ. Physically, "αM" damping implies the presence of mass-proportional damping links as follows :

(a) Ground acceleration option: links connecting nodes to points which move with the ground.

(b) Support motion option: links connecting nodes to points which are fixed in space.

NOTE J.3

Any dynamic record (e.g., ground acceleration record, force record, or support motion record) may be applied with or without a time delay. When a record is applied without delay (NS $\geqslant$ 0), the record is applied with step number NS+1 of the interpolated record as step 1 in the step-by-step integration. When a record is applied with delay (NS $<$ 0, e.g., NS = -10), step 1 of the interpolated record becomes step NS+1, (e.g., 11) in the step-by-step integration. Up to this step, the value of the record is assumed to be zero.

A typical application will be seismic excitation of structures which are long in plan. Assume that the ground motion is a train of waves travelling from left to right (note that this is not correct for a true earthquake, but may be a reasonable assumption). The delay for the first (leftmost) support will be zero; the delay for the second support will be the wave travel time from the first support to the second; the delay for the third support will be the wave travel time from the first support to the third; etc.

Time delays can also be considered when an analysis is restarted, by using the option NS $>$ 0. For the above typical application, the time step at interpolation step zero (TO, Section F7(b)) will be the time in the record at the last (rightmost) support at the *end* of the preceding analysis. The number of time steps delay (NS, Section J5) will then be zero for the *rightmost* support and positive values corresponding to the wave travel time for successive supports to the left.

In any restart, the time step (DT, Section F2) may be changed if desired. For analyses with delay, however, the time step should be such that the delay between any pair of supports is always an exact number of steps. If this is done, the ground motions at all supports will continue, in the restart analysis, exactly where they ended in the preceding analysis. If not, the continuation will not be from exactly the same times, and errors may result.

Provision is made for delays to be specified for "conventional" seismic analyses using acceleration records (Section J3). It is important to note, however, that out-of-phase excitations involve relative support displacements ("pseudostatic" effect) as well as accelerations ("inertia" effect). This type of analysis considers the inertia effect only, ignoring the pseudostatic effect, and should normally be used only for in-phase motions (no delay).

3. ADDITION OF ELEMENTS TO PROGRAM

3.1. INTRODUCTION

The computer program is organized to simplify, as much as possible, the procedures for adding new elements to the element library. For this purpose, the program is divided into two parts, as follows:

(a) the *base program*, which consists of a series of subroutines performing tasks which are common to all elements; and

(b) a set of *auxiliary programs*, which consists of a package of subroutines for each type of element, performing tasks which are not common to all elements.

A user/programmer adding a new type of element to the library must follow the auxiliary program rules described in this chapter.

3.2. ELEMENT INFORMATION BLOCKS

For data input, the elements must be arranged in groups, such that all elements in any group are of the same type. For each type of element, the base program calls the subroutines of the auxiliary program at various times during the computation.

Information is transmitted to and from the subroutines of the auxiliary program in the following three ways:

(a) through formal parameters (argument lists) of the subroutines;

(b) through labelled common blocks; and

(c) through an element "information block."

The formal parameters are described in Section 3.4, and the labelled COMMON blocks in Section 3.3. The information block is described in this section.

For each element, an information block must be created and continually updated. This information is defined by COMMON block /INFEL/. All information to be retained for the element must be contained in this block, and this information must be sufficient to allow complete monitoring of the element behavior. Rules for setting up the block are presented subsequently.

Because the core storage will rarely be adequate to hold the information for all elements, this information will usually be held in secondary storage, typically a disc file, and retrieved from time to time. If each element information block were to be individually transmitted to or from the disc file each time it is required during computation, the number of input-output operations would be large, possibly resulting in large input-output costs. To reduce this cost, the base program automatically assembles "super" blocks of element information. Each super-block consists of as many element information blocks as can be fitted into the available core storage, and is transmitted to secondary storage with a single I/O command. If the problem is small enough that the information blocks for all elements can be held in core, secondary storage is not used.

The base program transfers the element information for any element to subroutines in the auxiliary program through the array COMS in the formal parameter list. The address assigned to the array COMS by the base program corresponds to the first word of information for the corresponding element in the super-block. To transfer the data from this super-block to the element information block, the following FORTRAN statements must appear at the beginning of the major auxiliary subroutines:

```
          COMMON /INFEL /IMEM, ......
          DIMENSION COMS (1), COM(1)
          EQUIVALENCE (IMEM, COM(1))
          DO  100  J = 1, NINFC
      100 COM (J) = COMS(J)
```

in which NINFC = number of words in the element information block /INFEL/.

If the data within /INFEL/ is updated during computations in the subroutine, it may be necessary to transmit the updated data back to the super-block at the end of the subroutine. This is achieved with the following FORTRAN statements:

```
          DO   200    J = 1, NINFC
      200 COMS (J) = COM (J)
```

In some cases, only a part of the data may be updated. Hence, it may be more efficient to transfer the modified data selectively. However, the computer time required to transfer data between COMS and /INFEL/ should be a small proportion of the total execution time, and it will usually be safer for the program to transfer the entire block.

3.3. LABELLED COMMON BLOCKS

3.3.1. List of Blocks

The labelled COMMON blocks used in subroutines of the auxiliary program are as follows:

(a) COMMON /TAPES/ NIU, NOU, NPU, NT1, ... , NT11

(b) COMMON /INFGR/ NGR, NELS, MFST, DKO, DKT, GRHED (10), NINFC, NDOF, EPROP (1000)

(c) COMMON /INFEL/IMEM, KST, LM(.), ...

(d) COMMON /WORK / WORK (2000)

3.3.2. Input-Output Units (/TAPES/)

COMMON block /TAPES/ contains file numbers assigned by the base program. The variables in this block must not be changed in any subroutines of the auxiliary program. NIU is the input unit for reading data, NOU is the output unit for printing data, and NPU is the punch unit for punching data. Units NT1 through NT11 are used by the base program as scratch files for manipulation of data. The subroutines of the auxiliary program may use units NIU and NOU to read element data and print response results, and unit NPU may be used for punching data. Units NT1 through NT11 must *not* be used.

3.3.3. Element Group Information Block (/INFGR/)

COMMON block /INFGR/ contains data which is common to all elements in a group. This avoids storing repeated information in the /INFEL/ blocks. The variables in the block have the following meanings:

NGR : Element type number (the type of element in the group).

NELS : Number of elements in the group.

MFST : Element number of the first element in the group.

DKO : Initial stiffness damping factor, β_0 (see Appendix A).

DKT : Current tangent stiffness damping factor, β_T (see Appendix A).

GRHED : An array of dimension 10, containing the group heading in alphanumeric format (10A4).

NINFC : Number of words of information stored for each element in the group. This is the length of the labelled COMMON block /INFEL/.

NDOF : Number of displacement degrees of freedom for elements in the group (dimension of element stiffness matrix).

EPROP : An array of 1000-word length in which the programmer may store any data (for example, group control parameters, material properties, etc.).

The length of the array EPROP can be increased beyond 1000 words if desired, by modifying the FORTRAN statement, COMMON/INFGR/ .... , in the main subroutine of the base program.

The values of variables NGR, NELS, MFST, DKO, DKT, and GRHED are set by the base program when it reads the first data card of each element group, using a (3I5, 2F10.0, 5X, 10A4) format. The values of the variables NINFC, NDOF, and EPROP must be set in the auxiliary program, as described in Section 3.4.

3.3.4. Element Information Block (/INFEL/)

COMMON block /INFEL/ contains all data to be retained for an element. The data can be arranged by the programmer in any desired order, except for the following restrictions:

(a) The first word of the block must be the element number. Variable name IMEM is suggested.

(b) The second word must be the stiffness update code. Variable name KST is suggested.

(c) The third word must be the first word of the element location matrix. The suggested variable name is LM. The length of LM is the number of degrees of freedom for the element (NDOF).

The remaining data in the block will typically consist of node coordinates, strain-displacement transformation matrices, tangent stiffness matrix, stresses and strains, plastic strains, peak values of stresses and strains, etc.

A maximum length of 1000 words is currently allocated to this block by the FORTRAN statement COMMON/INFEL/ ..... in the main subroutine of the base program.

3.3.5. Temporary Storage Block (/WORK/)

COMMON block /WORK/ provides a work area for use by the programmer, avoiding the need to reserve new core for temporary variables. The area can be used for temporary storage of data in any subroutine of the auxiliary program. Because the area is used for temporary data storage by both the base program and other auxiliary programs, data stored in any subroutine will not generally be retained after control is returned from that subroutine to the base program. Hence, the area must be used only as a scratch storage area within a subroutine.

The block may be broken up in any way, provided the total length specified in the main subroutine of the base program (currently 2000 words) is not exceeded.

3.4. AUXILIARY PROGRAM

3.4.1. General

Each auxiliary program consists of subroutines required for a specific type of element. Each program must consist of four main subroutines, as follows:

(a) INEL : Input and initialization of element data.

(b) STIF : Computation of element tangent stiffness.

(c) RESP : Element state determination. This will generally be the lengthiest and most critical subroutine.

(d) EOUT: Print envelope values of element response.

Each of these four subroutines must be identified by a number designating the element type, suffixed to the subroutine name. For example, the names of subroutines for the element type 1 must be

INEL1, STIF1, RESP1, EOUT1

The programmer can also write, if needed, secondary subroutines which are referenced by any of the four main subroutines of the auxiliary program. At the end of a secondary subroutine, control will be returned to the main subroutine, and at the end of a main subroutine, control will be returned to the base program. Information may be transferred to and from a secondary subroutine through formal parameters (argument list), through any of the labelled common blocks described in Section 3.3, or through other labelled COMMON blocks created specifically for such information transfer.

Explanations of the tasks to be performed by each of the four main subroutines, and the meanings of the formal parameters are given in the following sections.

3.4.2. Subroutine INEL

Subroutine INEL is called by the base program once for each group of elements of the corresponding element type (for example, subroutine INEL1 will be called once for each group of elements containing elements of type 1). The purpose of the subroutine is to read the input data for all elements in the group, and to initialize the variables in the /INFEL/ block.

The subroutine will use COMMON blocks /TAPES/, /INFGR/, and /INFEL/. The COMMON block /WORK/ may be used if desired. The formal parameter list is:

(NJT, NDKOD, X, Y, Z, KEXEC).

The variables in this list have the following meanings:

NJT : Total number of nodes in the structure. This value is set by the base program.

NDKOD : An array of dimension (NJT,6) which contains the numbers of the structure degrees of freedom. That is, NDKOD(I,1) through NDKOD(I,6) contain the numbers of the structure degrees of freedom corresponding to the X, Y, and Z displacements and X, Y, and Z rotations, respectively, at node I. These values are set by the base program, and must not be changed in the auxiliary program.

X,Y,Z : Arrays of dimensions NJT each, which contain nodal coordinates. That is, X(I), Y(I), and Z(I) contain the X, Y, and Z coordinates, respectively, of node I. These values are set by the base program, and must not be changed in the auxiliary program.

KEXEC : Data check parameter. This must be set to one if there are errors in the element data; otherwise should not be changed. The base program will continue execution only if KEXEC is not one.

As explained previously, the values of variables NGR through GRHED in the block /INFGR/ are set in the base program by reading the first data card of the element group. All subsequent data for the elements must be read within the subroutine INEL (or any secondary subroutines called by INEL). The data sequence and input formats can be chosen by the programmer.

The following steps must be performed in the subroutine:

(a) Set the variables NDOF and NINFC in the block /INFGR/.

(b) Establish additional group control parameters in block /INFGR/, if needed.

(c) If desired, establish reference tables of material properties, initial stresses, etc. for use in specifying the properties for each element. The /WORK/ block may be used to store these tables temporarily, or block /INFGR/ may be used to store them permanently.

(d) Specify properties for each element in the group. The property data will typically consist of node numbers, material properties, the initial state of stress, an indicator for inclusion of large displacement effects, etc. Any reference tables established in (c) may be used. Generation options may be incorporated, provided the elements are generated in element number sequence and information for only one element at a time is stored in the /INFEL/ block.

(e) For each element, the following initialization operations must be performed:

(1) Set up the element location matrix, LM, within /INFEL/. This can be done with reference to the numbers of the structure degrees of freedom contained in the array NDKOD, and the element node numbers.

(2) Set IMEM to the element number within the group. Set the stiffness update code KST to one (KST = 1).

(3) Set any status indicators established within /INFEL/ to appropriate values. Such indicators will typically be used to indicate whether or not large displacement effects are to be considered, to monitor yield status, to control printing of stress and strain time histories, etc.

(4) Compute and store, in /INFEL/, strain-displacement transformation matrices for use in forming the element stiffness and for state determination calculations. Note that the nodal coordinates X, Y, and Z are not transferred by the base program to the auxiliary routines STIF and RESP. However, the programmer may retain the nodal coordinates for the nodes to which the element connects, as part of the /INFEL/ block, if desired.

(5) Call subroutine BAND with the statement:

```
CALL BAND (LM, NDOF).
```

This permits the base program to establish information on the profile of the structure stiffness matrix. This call must be made after the element location matrix, LM, has been set up.

(6) Call subroutine COMPACT with the statement

CALL COMPACT

This transfers data from the /INFEL/ block to a scratch file assigned by the base program. This call must be made after the element information in the block INFEL has been fully initialized. The call transfers NINFC words to the scratch file, and the data is later recalled by the base program and arranged in "super" blocks, as explained previously.

3.4.3. Subroutine STIF

Subroutine STIF is called by the base program whenever a total structure stiffness matrix or a change in this matrix is to be computed. If the total stiffness is to be formed, the subroutine is called once for each element. If a change in stiffness is being formed, the subroutine is called only for those elements which have undergone stiffness changes.

The purpose of the subroutine is to compute either a change in element stiffness or the total element stiffness, and return this stiffness to the base program for assembly into the structure stiffness matrix. The element stiffness matrix will be either the static tangent stiffness (static analysis), or the effective dynamic tangent stiffness (dynamic analysis). Because the structure stiffness matrix is not necessarily updated at every load step, time step, or iteration, the change in any element stiffness must be the change since the STIF subroutine was last called for that element.

As for subroutine INEL1, subroutine STIF1 will be called for elements of type 1. The subroutine will use COMMON blocks /INFGR/ and /INFEL/. The COMMON block /WORK/ may be used if desired. The formal parameter list is:

(ISTEP, NDF, LINF, CDKO, CDKT, COMS, FK, INDFK, ISTFC)

The variables in this list have the following meanings:

ISTEP : Load step number, or time step number. This value is set by the base program.

NDF : Equal to NDOF, for use in dimensioning array FK.

LINF : Equal to NINFC, for use in dimensioning array COMS.

CDKO : Value of constant $a_4\beta_o$ (see Appendix A) to be used in computing the damping contribution to the effective stiffness matrix in dynamic analysis. This value is set by the base program.

CDKT : Value of constant $a_4\beta_T$ (see Appendix A) to be used in computing the damping contribution to the effective stiffness matrix in dynamic analysis. This value is set by the base program.

COMS : A vector of dimension LINF, which contains the element information. The address assigned to COMS by the base program corresponds to the first word of information for the element.

FK : An array of dimension (NDF x NDF), into which is to be placed either the change in the element stiffness matrix since the last update, or the total element stiffness matrix. See explanation below.

INDFK: Indicator to specify the storage arrangement of the element stiffness matrix in the array FK. The programmer is required to assign a value of zero or one to INDFK, as explained later.

ISTFC : An indicator set by the base program. A value of zero means that array FK must contain the change in the element stiffness; whereas a value of one means that FK must contain the total element stiffness.

The element stiffness matrix can be stored in the array FK either (1) as a square symmetric matrix of dimension (NDF X NDF) or (2) as a vector in which the columns of the *lower half* of the symmetric stiffness matrix are stacked together compactly. The number of words for this latter form will be NDF X (NDF + 1)/2. The programmer must set INDFK to zero if the element stiffness is stored as in (1), and to one if the element stiffness is stored as in (2). The base program uses INDFK in the assembly of the element stiffnesses into the structure stiffness.

The following steps must be performed in the subroutine.

(a) Transfer the data from array COMS to the element information block /INFEL/, using the procedure explained in Section 3.2.

(b) Set INDFK to zero or one, as appropriate.

(c) Depending on the value of ISTFC, compute the change in the element stiffness, or the total element stiffness. If ISTEP $\leqslant 0$ (static analysis), the stiffness is the tangent stiffness; if ISTEP $\geqslant 1$ (dynamic analysis), the stiffness is the effective tangent stiffness.

(d) Set the stiffness update code, KST, to zero.

(e) Update any data in /INFEL/ which has changed.

(f) Transfer the information in /INFEL/ to COMS, using the procedure explained in Section 3.2.

3.4.4. Subroutine RESP

Subroutine RESP is called by the base program once for each element at each iteration in a static or dynamic analysis. As for subroutine INEL1, subroutine RESP1 will be called for elements of type 1.

The purpose of the subroutine is to perform the following tasks:

(T1) Compute the element deformations (strains) and actions (stresses).

(T2) Determine the change of yield status for the element, if any.

(T3) Compute nodal loads which are in equilibrium with the new state of stress.

(T4) Compute effective dynamic damping loads, using the element nodal velocities.

(T5) Accumulate envelope (peak) values of the element deformations (strains), actions (stresses), and any other element response quantities. This task is optional, depending on whether or not the programmer decides to store envelope values in the /INFEL/ block.

(T6) Update the element data in the /INFEL/ block.

(T7) Print the current element response results, such as status code(s), stresses and strains, etc.

Not all tasks are performed in any given call to the subroutine. As explained subsequently, the base program specifies, through the value of the indicator KUPD, which of the above tasks must be performed.

The subroutine will use COMMON blocks /TAPES/, /INFGR/, and /INFEL/. The COMMON block /WORK/ may be used if desired. The formal parameter list is:

(NDF, LINF, KPR, COMS, Q, VEL, ACC, FE, FD, TIME, C7, C8, KUPD, KITRN)

The variables in this list have the following meanings:

NDF : Equal to NDOF, for use in dimensioning (see below).

LINF : Equal to NINFC, for use in dimensioning COMS.

KPR : Print indicator for element stress and strain results. This value is set by the base program. KPR is set to zero if the results are not to be printed; otherwise it is set to the element group number.

COMS : A vector of dimension LINF, which contains the element information. The address assigned to COMS by the base program corresponds to the first word of information for the element.

Q : A vector of dimension NDF, which contains *increments* of element nodal displacements.

VEL : A vector of dimension NDF, which contains the element nodal velocities.

ACC : A vector of dimension NDF, which contains the element nodal accelerations.

FE : A vector of dimension NDF, in which the nodal loads in equilibrium with the current state of stress must be returned.

FD : A vector of dimension NDF, in which the effective dynamic loads must be returned. See Appendix A for definition of these loads.

TIME : Time, in seconds, at the current time step. This value is set by the base program. In static analysis, TIME = 0.0.

C7 : Value of constant C_7 (see Appendix A) to be used in computing the damping contribution to the effective dynamic load vector. This value is set by the base program.

C8 : Value of a second constant to be used in computing the damping contribution to the effective dynamic load vector. This value is set by the base program.

KUPD : An indicator controlling which task or combination of tasks is to be performed, as explained later. The base program sets KUPD to a value of 1, 2, 3, or 4.

KITRN : An indicator specifying the form of the effective load vector in dynamic analysis. This value is assigned by the base program. The calculation procedures are described later.

The values of MFST (in block /INFGR/) and KPR can be used by the programmer to print the element numbers and an appropriate heading when element response results are printed. The element group heading (in block /INFGR/) may also be printed.

The value of KUPD is used as follows in performing tasks (T1) through (T7).

(1) KUPD = 1: Perform all tasks (T1) through (T7).

(2) KUPD = 1: Perform tasks (T1) through (T4), and (T7).

(3) KUPD = 3: Perform task (T7) only.

(4) KUPD = 4: Perform tasks (T3), (T4), and (T7).

The steps in the subroutine will be as follows:

(a) Transfer the data from array COMS to the element information block /INFEL/ using the procedure explained in Section 3.2.

(b) Perform tasks (T1) through (T7), depending on the value of the indicator KUPD.

(c) If the element changes its status because of material yielding or unloading, set the stiffness update code, KST, to one. If large displacement effects are included for the element, KST must always be set to 1, because there will be a continuous change in the element geometry and hence in its stiffness. KST must be set prior to updating the element information in /INFEL/ (i.e., prior to performing task (T6)).

(d) Transfer the information in /INFEL/ to the array COMS, using the procedure explained in Section 3.2. This transfer must be carried out *only if* KUPD = 1. For all other values of KUPD, omit this step.

3.4.5. Subroutine EOUT

Subroutine EOUT is called by the base program for each element at certain load and time step intervals. As for subroutine INEL1, subroutine EOUT1 will be called for elements of type 1.

The purpose of the subroutine is to print envelope (maximum and minimum) values of stresses, strains, etc., and the corresponding times at which these values have occurred. The format for printing these results is chosen by the programmer. If the programmer decides not to store envelope values and corresponding times in the block /INFEL/, a dummy EOUT subroutine must be supplied.

The subroutine will use COMMON blocks /TAPES/, /INFGR/, and /INFEL/. The COMMON block /WORK/ may be used if desired. The formal parameter list is:

(LINF, COMS)

The variables in this list have the following meanings:

LINF : Equal to NINFC, for use in dimensioning COMS.

COMS: A vector of dimension LINF, which contains the element information. The address assigned to COMS by the base program corresponds to the first word of information for the element.

The following steps must be performed in the subroutine.

(a) Transfer the data from array COMS to the element information block /INFEL/, using the procedure explained in Section 3.2.

(b) Print an appropriate heading for the envelope results.

(c) Print the results for the element.

4. EXAMPLE ELEMENT

4.1. Truss Element

Elements added to the ANSR program may be elastic or inelastic, and may consider small or large displacements. The theory for an element may be developed rigorously, using finite element and continuum mechanics principles, or less formally, using physical ("engineering") approaches. The use of rigorous continuum mechanics formulations becomes particularly important for elements undergoing large displacements.

The simplest of all elements is the truss bar, transmitting only axial load. A large displacements theory for this element can be formulated using either an engineering approach or a rigorous mechanics approach. In this chapter, FORTRAN coding is presented for a truss bar element with simple inelastic behavior and with a rigorous mechanics formulation for large displacements effects. This element is identical to the truss bar element in ANSR-I [2].

The features of the element and the ANSR-II input data are presented in the following sections. The theory for the element is shown in Table 4.1, and the INEL1, STIF1, RESP1, and EOUT1 subroutines are listed in Tables 4.2 through 4.5, respectively. These tables, in conjunction with Chapter Three, illustrate the procedure to be used in developing elements for the program.

4.2. Truss Element Features

Truss elements may be arbitrarily oriented in space, but can transmit axial load only (Fig. 4.1). Large displacement effects may or may not be included. When this effect is specified, it is included in both static and dynamic analyses.

Two alternative modes of inelastic behavior may be specified, namely, (1) yielding in both tension and compression (Fig. 4.2a) and (2) yielding in tension with elastic buckling in compression (Fig. 4.2b). 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 specifying 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.

4.3. 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. 4.2b), 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.

4.4. Input Data

4.4.1. CONTROL INFORMATION

COLUMNS	DATA
5(I)	Element group indicator. Punch 1 (to indicate that group consists of three-dimensional truss elements).
6 - 10(I)	Number of elements in group.
11 - 15(I)	Element number of first element in group (MFST). Default = 1.
16 - 25(F)	Initial stiffness damping factor, β_o.
26 - 35(F)	Current tangent stiffness damping factor, β_T.
41 - 80(A)	Optional group heading.

4.4.2. MATERIAL PROPERTY INFORMATION

4.4.2(a) CONTROL CARD

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

4.4.2(b) SUBSEQUENT CARDS

NMAT cards.

COLUMNS	DATA
1 - 5(I)	Material number in sequence, starting with 1.
6 - 15(F)	Young's modulus of elasticity, E.
16 - 25(F)	Strain hardening modulus as a proportion of Young's modulus.
26 - 35(F)	Yield stress in tension.
36 - 45(F)	Yield stress in compression, or elastic buckling stress in compression.

4.4.3. ELEMENT DATA GENERATION

As many cards as needed to generate all elements in group. The cards for the first and the last elements in the group must be input. If cards for intermediate elements are omitted, the data is generated. Elements within the group are sequentially numbered, starting with MFST.

COLUMNS	DATA
1 - 5(I)	Element number, or number of first element in a sequentially numbered series of elements to be generated by this card.
6 - 10(I)	Node number at end i.
11 - 15(I)	Node number at end j.
16 - 20(I)	Material number. Default = 1.
21 - 30(F)	Cross sectional area.
31 - 40(F)	Initial axial force.
41 - 45(F)	Node number increment for element generation. Default = 1.
50(I)	Code for large displacement effects. Blank or punch zero = small displacements. 1 = large displacements.
55(I)	Time history code. Blank or punch zero = no time history printout. 1 = time history output required.
60(I)	Buckling code. Blank or punch zero = element yields in compression without buckling. 1 = element buckles elastically in compression.

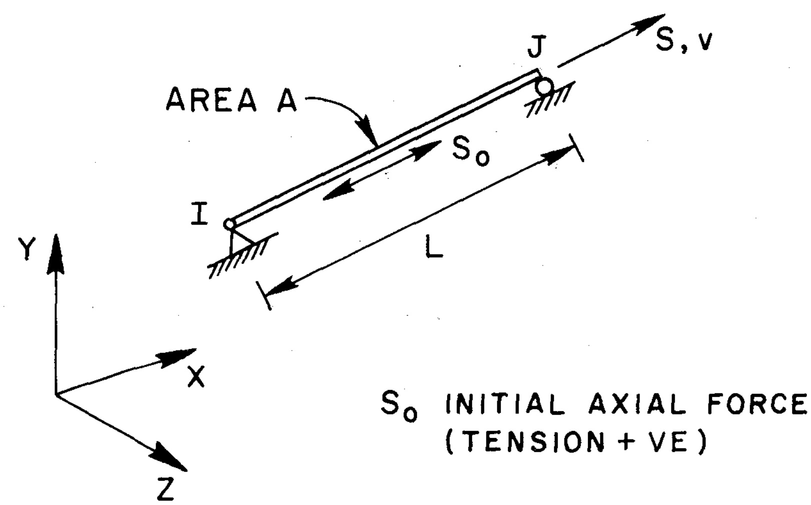
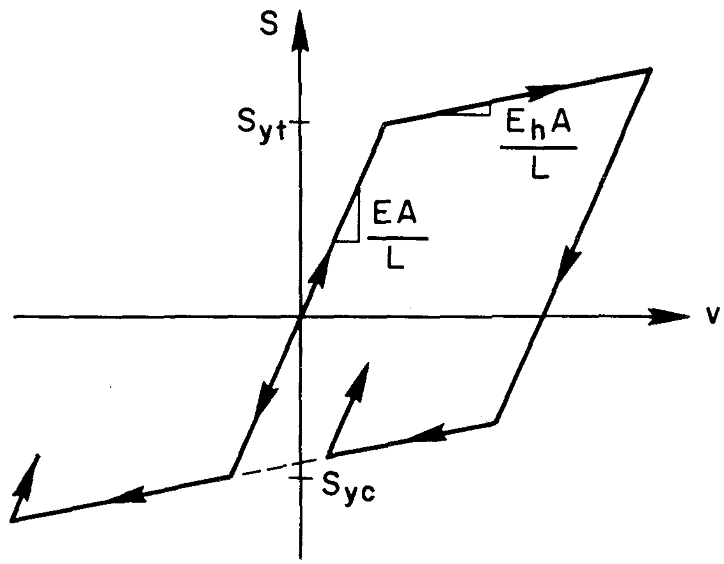
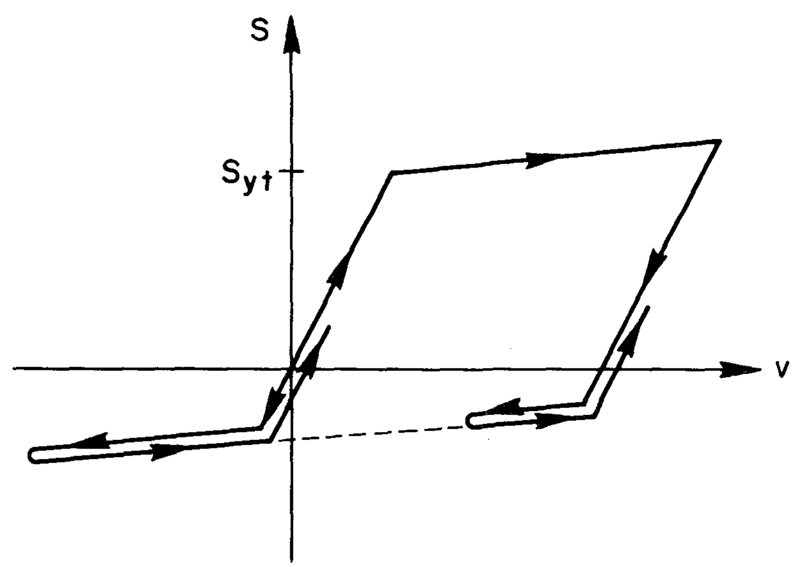


FIG. 4.1 TRUSS ELEMENT



(a) YIELD IN TENSION AND COMPRESSION



(b) YIELD IN TENSION, BUCKLING IN COMPRESSION

FIG. 4.2 INELASTIC BEHAVIOR FOR TRUSS ELEMENT

TABLE 4.1

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 ${}^1u = \left[{}^1u \; {}^1v \; {}^1w\right]$ 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;

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

and

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

Let ${}^1r = \left[{}^1r_1 \; {}^1r_2 \; {}^1r_3 \; {}^1r_4 \; {}^1r_5 \; {}^1r_6\right]$ be a vector of the x - y - z displacements (time t) at nodes I and J. The interpolation relationship for internal element displacements is :

$$\begin{Bmatrix} {}^1u \\ {}^1v \\ {}^1w \end{Bmatrix} = \begin{bmatrix} N_1 & 0 & 0 & N_2 & 0 & 0 \\ 0 & N_1 & 0 & 0 & N_2 & 0 \\ 0 & 0 & N_1 & 0 & 0 & N_2 \end{bmatrix} \begin{Bmatrix} {}^1r_1 \\ {}^1r_2 \\ {}^1r_3 \\ {}^1r_4 \\ {}^1r_5 \\ {}^1r_6 \end{Bmatrix} \qquad (3)$$

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:

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

The linear and nonlinear parts of the local tangent stiffness are obtained as follows (see, for example, Reference 1, 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

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

TABLE 4.2. SUBROUTINE INEL FOR TRUSS BAR

```
      SUBROUTINE INEL1 (NJT,NDKOD,X,Y,Z,KEXEC)
C
C     ***********************************************************************
C     SUBROUTINE TO READ, GENERATE AND PRINT ELEMENT DATA.
C     ELEMENT TYPE = 1.  THREE DIMENSIONAL TRUSS ELEMENTS.
C     ***********************************************************************
C
      DIMENSION NDKOD(NJT,6),X(NJT),Y(NJT),Z(NJT),COM(74)
      COMMON /TAPES / NIU,NOU,NPU,NT1,NT2,NT3,NT4,NT5,NT6,NT7,NT8,NT9,
     *                NT10,NT11
      COMMON /INFGR / NGR,NELS,MFST,DKO,DKT,GRHED(10),NINFC,NOCF,
     *                EPROP(4,250)
      COMMON /INFEL / IMEM,KST,LM(6),NODE(2),PROP(4),AREA,KGEOM,KTHO,
     *                KBUCK,SL,T(3,3),DU1X,DU1Y,DU1Z,Q1(6),SKP(21),
     *                KOD,KODP,VTOT,SEP,SEL,VENP,VENN,VPACP,VPACN,
     *                VBUCK,SENP,SENN,TVENP,TVENN,TSENP,TSENN
      COMMON /WORK  / NODC(2),XYZ(3,2)
      EQUIVALENCE (IMEM,COM(1))
C
      DIMENSION AST(3),YNO(2)
      DATA AST /2H  ,2H *,2H**/, YNO /3H NO,3HYES/
C
C     -----------------------------------------------------------------------
C     MEANINGS OF VARIABLES IN COMMON BLOCK /INFEL/
C
C     IMEM    - ELEMENT NUMBER.
C     KST     - STIFFNESS UPDATE CODE.
C     LM(6)   - LOCATION MATRIX.
C     NODE(2)- NODE NUMBERS AT END I AND J.
C     PROP(4)- MATERIAL PROPERTIES.
C     AREA    - CROSS SECTIONAL AREA.
C     KGEOM   - LARGE DISPLACEMENT CODE.
C     KTHO    - RESPONSE OUTPUT CODE.
C     KBUCK   - BUCKLING BEHAVIOR CODE.
C     SL      - ELEMENT LENGTH.
C     T(3,3) - GLOBAL TO LOCAL TRANSFORMATION MATRIX.
C     DU1X, DU1Y, DU1Z
C             - DISPLACEMENT GRADIENTS.
C     Q1(6)   - CURRENT NODAL DISPLACEMENTS.
C     SKP(21)- CURRENT TANGENT OR EFFECTIVE STIFFNESS MATRIX.
C     KOD     - CURRENT YIELD CODE.
C     KODP    - PREVIOUS YIELD CODE.
C     VTOT    - TOTAL AXIAL DEFORMATION.
C     SEP     - AXIAL FORCE IN ELASTO-PLASTIC COMPONENT.
C     SEL     - AXIAL FORCE IN ELASTIC COMPONENT.
C     VENP, VENN
C             - POS. AND NEG. ENVELOPE VALUES OF AXIAL DEFORMATION.
C     VPACP, VPACN
C             - ACCUMULATED POS. AND NEG. PLASTIC DEFORMATIONS.
C     VBUCK   - BUCKLING DEFORMATION.
C     SENP, SENN
C             - POS. AND NEG. ENVELOPE VALUES OF AXIAL FORCE.
C     TVENP, TVENN
C             - TIMES AT POS. AND NEG. ENVELOPE VALUES OF DEFORMATION.
C     TSENP, TSENN
C             - TIMES AT POS. AND NEG. ENVELOPE VALUES OF AXIAL FORCE.
```

```
C     ------------------------------------------------------------------
C
C     ELEMENT GROUP PARAMETERS
C
      IF (MFST.LE.0) MFST = 1
C
      NDOF  = 6
      NINFC = 74
      KST   = 1
      DO 100 I=3,NINFC
100   COM(I) = 0.0
C
C     PRINT ELEMENT GROUP INFORMATION
C
      WRITE(NOU,2000) NGR,GRHED,NELS,MFST,NDOF,NINFC,DKO,DKT
C
C     READ AND PRINT MATERIAL PROPERTIES
C
      READ (NIU,1000) NMAT
      IF (NMAT.LE.0) NMAT = 1
C
      WRITE(NOU,2010) NMAT
      DO 110 I=1,NMAT
110   READ (NIU,1005) M,(EPROP(J,M),J=1,4)
      WRITE(NOU,2020) (M,(EPROP(J,M),J=1,4),M=1,NMAT)
C
C     READ, GENERATE AND PRINT ELEMENT DATA
C
      IMEM  = MFST
      NLAST = MFST + NELS - 1
      WRITE(NOU,2030)
C
140   READ (NIU,1010) N,NODC,MT,AO,FO,ND,KG,KTH,KBU
C
      IF (MT.LE.0) MT = 1
      IF (ND.EQ.0) ND = 1
C
150   IF (N - IMEM) 155,160,210
C
155   FAST  = AST(3)
      KEROR = 1
      WRITE(NOU,2040) FAST,N,NODC,MT,AO,FO,KG,KTH,KBU
      GO TO 290
C
160   DO 170 I=1,2
170   NODE(I) = NODC(I)
C
      KEROR = 0
      NDIF  = ND
      MTYP  = MT
      KGEOM = KG
      KTHO  = KTH
      KBUCK = KBU
      AREA  = AO
      FORCE = FO
      PSH   = EPROP(2,MT)
```

```
      PPSH  = 1.0 - PSH
      PPSHA = PPSH*AC
      PROP1    = EPROP(1,MT)*PPSHA
      PROP2    = PROP1*PSH/PPSH
      PROP(3)  = EPROP(3,MT)*PPSHA
      PROP(4)  = -ABS(EPROP(4,MT)*PPSHA)
      SEP  = PPSH*FC
      SEL  =  PSH*FO
      FAST = AST(1)
C
      IF (N.NE.NLAST) 190,210
C
190   DO 200 I=1,2
200   NODE(I) = NODE(I) + NDIF
      FAST = AST(2)
C
210   WRITE(NOU,2050) FAST,IMEM,NODE,MTYP,AREA,FORCE,YNO(KGEOM+1),
     *                 YNO(KTHO+1),YNO(KBUCK+1)
C
C     ELEMENT CONNECTIVITY AND DIRECTION
C
      DO 220 I=1,2
      NOD = NODE(I)
      II = 3*I
      LM(II-2) = NDKCD(NOD,1)
      LM(II-1) = NDKCD(NOD,2)
      LM(II)   = NDKCD(NOD,3)
      XYZ(1,I) = X(NOD)
      XYZ(2,I) = Y(NOD)
220   XYZ(3,I) = Z(NOD)
C
      DX1 = XYZ(1,2) - XYZ(1,1)
      DX2 = XYZ(2,2) - XYZ(2,1)
      DX3 = XYZ(3,2) - XYZ(3,1)
      SL  = SQRT(DX1**2 + DX2**2 + DX3**2)
      AL  = SQRT(DX1**2 + DX3**2)
      IF (AL.LE.0.) GO TO 230
      T(2,2) =  AL/SL
      EXP    = -DX2/(AL*SL)
      T(2,3) =  DX3*EXP
      T(2,1) =  DX1*EXP
      GO TO 240
230   T(2,1) = 1.0
      T(2,2) = 0.0
      T(2,3) = 0.0
240   T(1,1) = DX1/SL
      T(1,2) = DX2/SL
      T(1,3) = DX3/SL
      T(3,1) = T(1,2)*T(2,3) - T(1,3)*T(2,2)
      T(3,2) = T(1,3)*T(2,1) - T(1,1)*T(2,3)
      T(3,3) = T(1,1)*T(2,2) - T(1,2)*T(2,1)
C
      PROP(1) = PROP1/SL
      PROP(2) = PROP2/SL
C
C     COMPUTE STIFFNESS MATRIX PROFILE AND TRANSFER ELEMENT DATA TO TAPE
```

```
C
      CALL BAND (LM,NDOF)
      CALL COMPACT
C
C     CHECK LAST ELEMENT
C
      IF (IMEM.EQ.NLAST) GO TO 290
      IMEM = IMEM + 1
      IF (IMEM.EQ.N) 160,190
C
C     ERROR AND ELEMENT DATA GENERATION MESSAGES
C
290   IF (KERCR.EQ.0) GO TO 300
C
      WRITE(NOU,2060)
      CALL EXIT
C
1000  FORMAT (16I5)
1005  FORMAT (I5,4F10.0)
1010  FORMAT (4I5,2F10.0,4I5)
2000  FORMAT (26H ELEMENT GROUP INDICATOR = I3,
     *          35H (THREE DIMENSIONAL TRUSS ELEMENTS)//5X,10A4//
     *          5X,43HNUMBER OF ELEMENTS IN THIS GROUP ........ = I5/
     *          5X,43HNUMBER OF FIRST ELEMENT IN THIS GROUP ... = I5//
     *          5X,43HNUMBER OF DEGREES OF FREEDOM PER ELEMENT  = I5/
     *          5X,43HLENGTH OF ELEMENT INFORMATION ARRAY ..... = I5//
     *          5X,43HDAMPING COEFFICIENT, BETA-C ............. = F11.5/
     *          5X,43HDAMPING COEFFICIENT, BETA-T ............. = F11.5)
2010  FORMAT (//20H MATERIAL PROPERTIES//
     *          5X,36HNUMBER OF DIFFERENT MATERIAL TYPES = I5//
     *          5X,4HMAT.,8X,4HEMOD,7X,5HRATIO,5X,12HYIELD STRESS,
     *          5X,12HYIELD STRESS/5X,4H NO.,19X,5H EH/E,
     *          5X,12H   TENSION   ,5X,12H COMPRESSION/)
2020  FORMAT (I9,E12.5,F12.4,2E17.5)
2030  FORMAT (///20H ELEMENT INFORMATION//
     *          5X,4HELEM,5X,4HNODE,5X,4HNODE,5X,4HMAT.,8X,4HAREA,
     *          5X,7HINITIAL,5X,4HGEOM,5X,4HHIST,5X,4HBUCK/
     *          5X,4H NO.,5X,4H    I,5X,4H    J,5X,4H NO.,17X,7H FORCE ,
     *          5X,4HCODE,5X,4HCODE,5X,4HCODE/)
2040  FORMAT (1X,A2,I6,3I9,2F12.4,3I9)
2050  FORMAT (1X,A2,I6,3I9,2F12.4,3(6X,A3))
2060  FORMAT (///15H ERROR MESSAGES//
     * 5X,3HKEY,5X,34H------------ MESSAGE ------------,5X,5HERROR//
     * 5X,3H   ,5X,34HELEMENT DATA INPUT DIRECTLY       ,5X,5HNONE /
     * 5X,3H  *,5X,34HELEMENT DATA GENERATED            ,5X,5HNONE /
     * 5X,3H **,5X,34HELEMENT CARD OUT OF SEQUENCE      ,5X,5HFATAL/)
C
300   RETURN
      END
```

TABLE 4.3 SUBROUTINE STIF FOR TRUSS BAR

```
      SUBROUTINE STIF1 (ISTEP,NDF,LINF,CDKO,CDKT,COMS,FK,INDFK,ISTFC)
C
C     ******************************************************************
C     SUBROUTINE TO COMPUTE ELEMENT TANGENT STIFFNESS MATRIX.
C     ELEMENT TYPE = 1. THREE DIMENSIONAL TRUSS ELEMENTS.
C     ******************************************************************
C
      DIMENSION COMS(LINF),FK(NDF,NDF),COM(74)
      COMMON /INFGR / NGR,NELS,MFST,CKO,DKT,GRHED(10),NINFC,NOOF,
     *                EPROP(4,250)
      COMMON /INFEL / IMEM,KST,LM(6),NODE(2),PROP(4),AREA,KGEOM,KTHO,
     *                KBUCK,SL,T(3,3),DU1X,DU1Y,DU1Z,G1(6),SKP(21),
     *                KOD,KODP,VTOT,SEP,SEL,VENP,VENN,VPACP,VPACN,
     *                VBUCK,SENP,SENN,TVENP,TVENN,TSENP,TSENN
      COMMON /WORK  / UD(3),B(6),SK(6,6)
      EQUIVALENCE (IMEM,COM(1))
C
C     TRANSFER ELEMENT DATA TO ELEMENT INFORMATION ARRAY
C
      JMEM = IMEM
      DO 100 J=1,NINFC
100   COM(J) = COMS(J)
C
C     LINEAR PART OF EFFECTIVE STIFFNESS
C
      CE = PROP(1) + PROP(2)
      CT = PROP(2)
      IF (KOD.EQ.0) CT = CE
      IF (ISTEP.LE.0) GO TO 105
      CT = CT*(1.0 + CDKT) + CE*CDKO
C
105   UD(1) = 1.0 + DU1X
      UD(2) = DU1Y
      UD(3) = DU1Z
C
      DO 120 I=1,3
      SUM = 0.0
      DO 110 J=1,3
110   SUM = SUM + UD(J)*T(J,I)
      B(I+3) = SUM
120   B(I) = - SUM
C
      DO 130 I=1,NOOF
      CC = CT*B(I)
      DO 130 J=I,NOOF
130   SK(I,J) = CC*B(J)
C
C     ADD NONLINEAR PART OF STIFFNESS
C
      IF (KGEOM.EQ.0) GO TO 135
      PL = (SEP + SEL)/SL
      SK(1,1) = SK(1,1) + PL
      SK(1,4) = SK(1,4) - PL
      SK(2,2) = SK(2,2) + PL
      SK(2,5) = SK(2,5) - PL
      SK(3,3) = SK(3,3) + PL
```

```
      SK(3,6) = SK(3,6) - PL
      SK(4,4) = SK(4,4) + PL
      SK(5,5) = SK(5,5) + PL
      SK(6,6) = SK(6,6) + PL
C
C     COMPUTE CHANGE IN STIFFNESS AND RETAIN CURRENT STIFFNESS
C
135   IF (ISTFC.EQ.0) GO TO 145
C
      IJ = 0
      DO 140 I=1,NDOF
      DO 140 J=I,NDOF
      IJ       = IJ + 1
      STIF     = SK(I,J)
      FK (I,J) = STIF
      FK (J,I) = STIF
140   SKP(IJ)  = STIF
      GO TO 155
C
145   IJ = 0
      DO 150 I=1,NDOF
      DO 150 J=I,NDOF
      IJ       = IJ + 1
      STIF     = SK(I,J)
      STIFD    = STIF - SKP(IJ)
      FK (I,J) = STIFD
      FK (J,I) = STIFD
150   SKP(IJ)  = STIF
C
C     UPDATE ELEMENT INFORMATION
C
155   KST  = 0
      KODP = KOD
      DO 160 J=1,NINFC
160   COMS(J) = COM(J)
C
      RETURN
      END
```

TABLE 4.4 SUBROUTINE RESP FOR TRUSS BAR

```
      SUBROUTINE RESP1 (NDF,LINF,KPR,COMS,Q,VEL,ACC,FE,FD,TIME,C7,C8,
     *                  KUPD,KITRN)
C
C     ******************************************************************
C     SUBROUTINE FOR STATE DETERMINATION CALCULATIONS.
C     ELEMENT TYPE = 1. THREE DIMENSIONAL TRUSS ELEMENTS.
C     ******************************************************************
C
      DIMENSION COMS(LINF),COM(74)
      DIMENSION Q(NDF),VEL(NDF),ACC(NDF),FE(NDF),FD(NDF)
      COMMON /TAPES / NIU,NOU,NPU,NT1,NT2,NT3,NT4,NT5,NT6,NT7,NT8,NT9,
     *                NT10,NT11
      COMMON /INFGR / NGR,NELS,MFST,DKO,DKT,GRHED(10),NINFC,NDOF,
     *                EPROP(4,250)
      COMMON /INFEL / IMEM,KST,LM(6),NODE(2),PROP(4),AREA,KGEOM,KTHO,
     *                KBUCK,SL,T(3,3),DU1X,DU1Y,DU1Z,Q1(6),SKP(21),
     *                KOD,KODP,VTOT,SEP,SEL,VENP,VENN,VPACP,VPACN,
     *                VBUCK,SENP,SENN,TVENP,TVENN,TSENP,TSENN
      COMMON /WORK  / UD(3),B(6)
      EQUIVALENCE (IMEM,COM(1))
C
C     TRANSFER ELEMENT DATA TO ELEMENT INFORMATION ARRAY
C
      DO 100 J=1,NINFC
100   COM(J) = COMS(J)
C
C     INITIALIZE
C
      IF (IMEM.EQ.MFST) KHED = 0
      STOT = SEL + SEP
      IF (KUPD.EQ.3) GO TO 390
      KODE = KOD
C
      UD(1) = 1.0 + DU1X
      UD(2) = DU1Y
      UD(3) = DU1Z
      DO 120 I=1,3
      SUM = 0.0
      DO 110 J=1,3
110   SUM = SUM + UD(J)*T(J,I)
      B(I+3) = SUM
120   B(I) = - SUM
C
      GO TO (125,125,390,345), KUPD
C
C     INCREMENT ELEMENT NODAL DISPLACEMENTS
C
125   DO 130 I=1,NDOF
130   Q1(I) = Q1(I) + Q(I)
C
C     COMPUTE LINEAR STRAIN INCREMENT
C
      DV = 0.0
      DO 135 I=1,NDOF
135   DV = DV + B(I)*Q(I)
C
```

```
C      ADD NONLINEAR STRAIN INCREMENT
C
       IF (KGEOM.EQ.0) GO TO 140
C
       Q41 = Q(4) - Q(1)
       Q52 = Q(5) - Q(2)
       Q63 = Q(6) - Q(3)
       DUX = (T(1,1)*Q41 + T(1,2)*Q52 + T(1,3)*Q63)/SL
       DUY = (T(2,1)*Q41 + T(2,2)*Q52 + T(2,3)*Q63)/SL
       DUZ = (T(3,1)*Q41 + T(3,2)*Q52 + T(3,3)*Q63)/SL
       DV  = DV + 0.5*SL*(DUX**2 + DUY**2 + DUZ**2)
C
C      COMPUTE INCREMENT IN STRESS
C
140    SEL = SEL + DV*PROP(2)
       FACAC = 0.0
C
150    FACTOR= 1.0 - FACAC
C
C      ELASTIC AND YIELDING
C
       IF (KODE.NE.0) GO TO 190
       DSEP = DV*PROP(1)
       IF (DSEP) 160,240,170
160    FAC = (PROP(4) - SEP)/DSEP
       IF (FAC.GE.FACTOR) GO TO 180
       FACTOR = FAC
       SEP = PROP(4)
       KODE = 1
       VBUCK = 0.0
       GO TO 240
170    FAC = (PROP(3) - SEP)/DSEP
       IF (FAC.GE.FACTOR) GO TO 180
       FACTOR = FAC
       SEP  = PROP(3)
       KODE  = 1
       GO TO 240
180    SEP = SEP + FACTOR*DSEP
       GO TO 240
C
C      YIELDED OR BUCKLING AND CONTINUING
C
190    IF (SEP*DV.LT.0.) GO TO 210
       IF (KBUCK.NE.0.AND.SEP.LT.0.) GO TO 200
       DVP = FACTOR*DV
       IF (DVP.GT.0.) VPACP = VPACP + DVP
       IF (DVP.LT.0.) VPACN = VPACN + DVP
200    VBUCK = VBUCK - FACTOR*DV
       GO TO 250
C
C      YIELDED BUT UNLOADING
C
210    IF (KBUCK.NE.0.AND.SEP.LT.0.) GO TO 220
       KODE = 0
       GO TO 150
C
```

```
C     BUCKLING AND REVERSING
C
220   FAC = VBUCK/DV
      IF (FAC.GE.FACTOR) GO TO 230
      FACTOR = FAC
      KODE = 0
230   VBUCK = VBUCK - FACTOR*DV
C
C     CHECK FOR COMPLETION OF CYCLE
C
240   FACAC = FACAC + FACTOR
      IF (FACAC.LT.0.9999999) GO TO 150
C
250   VTOT = VTOT + DV
      STOT = SEL + SEP
      KOD  = KODE
C
C     COMPUTE CURRENT DISPLACEMENT TRANSFORMATION
C
      IF (KGEOM.EQ.0) GO TO 290
C
      DU1X = DU1X + DUX
      DU1Y = DU1Y + DUY
      DU1Z = DU1Z + DUZ
      UD(1) = 1.0 + DU1X
      UD(2) = DU1Y
      UD(3) = DU1Z
      DO 270 I=1,3
      SUM = 0.0
      DO 260 J=1,3
260   SUM = SUM + UD(J)*T(J,I)
      B(I+3) = SUM
270   B(I) = - SUM
C
C     ACCUMULATE ENVELOPES AND UPDATE ELEMENT INFORMATION
C
290   IF (KUPD.NE.1) GO TO 345
C
      IF (SENP.GE.STOT) GO TO 300
      SENP  = STOT
      TSENP = TIME
      GO TO 310
300   IF (SENN.LE.STOT) GO TO 310
      SENN  = STOT
      TSENN = TIME
310   IF (VENP.GE.VTOT) GO TO 320
      VENP  = VTOT
      TVENP = TIME
      GO TO 330
320   IF (VENN.LE.VTOT) GO TO 330
      VENN  = VTOT
      TVENN = TIME
330   CONTINUE
C
      KST = 0
      IF (KOD.NE.KODP.OR.KGEOM.NE.0) KST = 1
```

```
      DO 340 J=1,NINFC
340   COMS(J) = COM(J)
C
C     COMPUTE EQUIVALENT ELASTIC NODAL LOADS
C
345   DO 350 I=1,NDOF
350   FE(I) = STCT*B(I)
C
C     COMPUTE EQUIVALENT NODAL LOADS DUE TO DAMPING
C
      IF (TIME.EQ.0.) GO TO 390
C
      DVD = 0.0
      DO 355 I=1,NDOF
355   DVD = DVD + B(I)*VEL(I)
      DVD = -DVD
C
      CE = PROP(1) + PROP(2)
      CT = PROP(2)
      IF (KODE.EQ.0) CT = CE
C
      IF (KITRN.EQ.1) GO TO 365
C
      CC7 = 1.0 + C7
      DO 360 I=1,NDOF
360   DVD = DVD + B(I)*(CC7*VEL(I) + C8*ACC(I))
C
365   SD = (DKO*CE + DKT*CT)*DVD
C
370   DO 380 I=1,NDOF
380   FD(I) = SD*B(I)
C
C     PRINT TIME HISTORY OF RESPONSE
C
390   IF (KPR.EQ.0.OR.KTHO.EQ.0) GO TO 400
C
      IF (KHED.NE.0) GO TO 395
C
      KHED = 1
      KKPR = IABS(KPR)
      WRITE(NOU,2000) KKPR,TIME,GRHED
C
395   WRITE(NOU,2010) IMEM,NODE,KOD,STCT,VTCT,VPACP,VPACN
C
2000  FORMAT (///18H RESULTS FOR GROUP,I3,
     *         43H (THREE DIMENSIONAL TRUSS ELEMENTS), TIME = E11.4//
     *         5X,10A4//
     *         5X,4HELEM,5X,4HNODE,5X,4HNODE,4X,5HYIELD,8X,5HAXIAL,
     *         4X,9H  TOTAL   ,3X,25HACCUM. PLASTIC EXTENSIONS/
     *         5X,4H NO.,5X,4H   I,5X,4H   J,4X,5H CODE,8X,5HFORCE,
     *         4X,9HEXTENSION,5X,8HPOSITIVE,5X,8HNEGATIVE/)
2010  FORMAT (4I9,E13.4,3E13.5)
C
400   RETURN
      END
```

TABLE 4.5   SUBROUTINE EOUT FOR TRUSS BAR

```
      SUBROUTINE EOUT1 (LINF,COMS)
C
C     ******************************************************************
C     SUBROUTINE TO PRINT PEAK VALUES OF RESPONSE.
C     ELEMENT TYPE = 1. THREE DIMENSIONAL TRUSS ELEMENTS.
C     ******************************************************************
C
      DIMENSION COMS(LINF),COM(74)
      COMMON /TAPES / NIU,NOU,NPU,NT1,NT2,NT3,NT4,NT5,NT6,NT7,NT8,NT9,
     *                NT10,NT11
      COMMON /INFGR / NGR,NELS,MFST,DKO,DKT,GRHED(10),NINFC,NDOF,
     *                EPROP(4,250)
      COMMON /INFEL / IMEM,KST,LM(6),NODE(2),PROP(4),AREA,KGEOM,KTHO,
     *                KBUCK,SL,T(3,3),DU1X,DU1Y,DU1Z,Q1(6),SKP(21),
     *                KOD,KODP,VTOT,SEP,SEL,VENP,VENN,VPACP,VPACN,
     *                VBUCK,SENP,SENN,TVENP,TVENN,TSENP,TSENN
      EQUIVALENCE (IMEM,COM(1))
C
C     TRANSFER ELEMENT DATA TO ELEMENT INFORMATION ARRAY
C
      DO 100 J=1,NINFC
100   COM(J) = COMS(J)
C
      IF (IMEM.EQ.MFST) WRITE(NOU,2000) GRHED
C
      WRITE(NOU,2010) IMEM,NODE,SENP,TSENP,SENN,TSENN,VENP,TVENP,
     *                VENN,TVENN,VPACP,VPACN
C
2000  FORMAT (33H THREE DIMENSIONAL TRUSS ELEMENTS//5X,10A4//
     *        5X,4HELEM,3X,4HNODE,3X,4HNODE,11X,20HMAXIMUM AXIAL FORCES,
     *        19X,18HMAXIMUM EXTENSIONS,12X,25HACCUM. PLASTIC EXTENSIONS
     *        /5X,4H NO.,3X,4H  I ,3X,4H  J ,5X,7HTENSION,3X,4HTIME,
     *        6X,5HCOMPN,3X,4HTIME,5X,8HPOSITIVE,3X,4HTIME,3X,
     *        8HNEGATIVE,3X,4HTIME,7X,8HPOSITIVE,5X,8HNEGATIVE/)
2010  FORMAT (I8,2I7,2X,2(F11.2,F7.2),2X,2(F11.5,F7.2),2X,2F13.5)
C
      RETURN
      END
```

REFERENCES

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3. Mondkar, D. P. and Powell, G. H., "Finite Element Analysis of Nonlinear Static and Dynamic Response," *International Journal for Numerical Methods in Engineering,* Vol. 11, pp. 499 – 520 (1977).

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APPENDIX A

EFFECTIVE STIFFNESS MATRIX AND EFFECTIVE LOAD VECTOR FOR DYNAMIC ANALYSIS

A.1. Theory

In dynamic analysis, the solution is advanced from time t to time t + Δt by solving the equation

$$\left[K_t^*\right]\{q\} = \left\{f_t^*\right\} \tag{1}$$

where $\left[K_t^*\right]$ = effective stiffness matrix;

$\{q\}$ = displacement increment from t to t + Δt;

and $\{f_t^*\}$ = effective load vector.

The effective stiffness matrix is given by

$$\left[K_t^*\right] = a_1[M] + a_4[D] + \left[K_T\right] \tag{2}$$

and the effective load vector by

$$\{f_t^*\} = \{P\} - \left([M]\{\ddot{q}_t\} + [D]\{\dot{q}_t\} + \{R_t\}\right) + [M]\left(a_2\{\dot{q}_t\} + a_3\{\ddot{q}_t\}\right) + [D]\left(a_5\{\dot{q}_t\} + a_6\{\ddot{q}_t\}\right) \tag{3}$$

In equations (2) and (3), [M], [D], and $[K_T]$ are the mass matrix, damping matrix, and tangent stiffness matrix at time t, respectively; {P} is the externally applied load at time $t + \Delta t$; $\{R_t\}$ is the resisting load in equilibrium with the state of stress at time t; $\{\dot{q}_t\}$ and $\{\ddot{q}_t\}$ are the velocity and acceleration, respectively, at time t. Constants a_1 through a_6 are associated with the step-by-step integration scheme. For the Newmark $\beta - \gamma - \delta$ scheme, these constants are as follows:

$$a_1 = \frac{1}{\beta \Delta t^2} \qquad a_2 = \frac{1}{\beta \Delta t} \qquad a_3 = \frac{1}{2\beta}$$

$$a_4 = \frac{\gamma}{\beta \Delta t} \qquad a_5 = \frac{\gamma}{\beta} \qquad a_6 = \Delta t\left(\frac{\gamma}{2\beta} - 1\right)$$

It is assumed that the damping matrix is of the form:

$$[D] = \alpha[M] + \beta_o[K_o] + \beta_T[K_T] \tag{4}$$

where α, β_o, and β_T are scalar multipliers, and $[K_o]$ is the original elastic stiffness matrix.

After substitution of equation (4) into equations (2) and (3), and rearranging of terms, the effective stiffness matrix and effective load vector are given by:

$$\left[K_t^*\right] = \left(a_1 + a_4\alpha\right) [M] + a_4\beta_o \left[K_o\right] + \left(1 + a_4\beta_T\right)\left[K_T\right] \tag{5}$$

and

$$\{f_t^*\} = \{P\} - \{R_t\} + \{f_M^*\} + \{f_D^*\} \tag{6}$$

where

$$\{f_M^*\} = [M]\left(\left[\alpha(a_5 - 1) + a_2\right] \{\dot{q}_t\} + (a_3 - 1 + \alpha\, a_6)\, \{\ddot{q}_t\}\right) \tag{7}$$

$$\{f_D^*\} = \left[\beta_o K_o + \beta_T K_T\right]\left[(a_5 - 1)\{\dot{q}_t\} + a_6\{\ddot{q}_t\}\right] \tag{8}$$

When iterations are performed, the following equation is solved at each iteration:

$$\left[K_t^*\right] \{\Delta q\}_i = \{f_{t+\Delta t}\}_i \qquad i = 1, 2, \ldots, \textit{no. of iterations} \tag{9}$$

where

$\{\Delta_q\}_i$ = displacement increment in this iteration;

and

$$\{f_{t+\Delta t}\}_i = \{P\} - \left[[M]\{\ddot{q}_{t+\Delta t}\}_i + [D]\{\dot{q}_{t+\Delta t}\}_i + \{R_{t+\Delta t}\}_i\right] \tag{10}$$

Substituting for [D] from equation (4) and simplifying gives:

$$\left\{f_{t+\Delta t}\right\}_i = \{P\} - \left\{R_{t+\Delta t}\right\}_i - [M]\left[\alpha\left\{\dot{q}_{t+\Delta t}\right\}_i + \left\{\ddot{q}_{t+\Delta t}\right\}_i\right] - \left[\beta_o K_o + \beta_T K_T\right]\left\{\dot{q}_{t+\Delta t}\right\}_i \tag{11}$$

or

$$\left\{f_{t+\Delta t}\right\}_i = \{P\} - \left\{R_{t+\Delta t}\right\}_i + \{f_M\}_i + \{f_D\}_i \tag{12}$$

where

$$\{f_M\}_i = -[M]\left[\alpha\{\dot{q}_{t+\Delta t}\}_i + \{\ddot{q}_{t+\Delta t}\}_i\right] \tag{13}$$

and

$$\{f_D\}_i = -\left[\beta_o K_o + B_T K_T\right]\left\{\dot{q}_{t+\Delta t}\right\}_i \tag{14}$$

A.2. ANSR Implementation

Following standard finite element methodology, the terms on the right hand side of equations (5), (6), and (12) are obtained by direct assembly of the corresponding terms for individual finite elements.

The present version of the program assumes the following :

(1) The structure mass is lumped at nodes, with no consistent masses and no mass contributions from the element level.

(2) Loads are applied at nodes at the structure level only, with no load contributions from the element level.

Therefore, it is necessary only to compute the following terms at the element level :

(a) Terms $a_4\beta_o \left[K_o\right]$ and $\left(1 + a_4\beta_T\right)\left[K_T\right]$ in equation (5)

(b) Terms $\{R_t\}$ and $\{f_D^*\}$ in equation (6)

or terms $\{R_{t+\Delta t}\}_i$ and $\{f_D\}_i$ in equation (12)

As explained in Chapter 3, these terms are computed in subroutines of each auxiliary program, and returned to the base program. All other terms in equations (5), (6), and (12) are computed in the base program.

Terms such as $a_4\beta_o[K_o]$ *and* $a_4\beta_T[K_T]$ are computed in the STIF subroutines of the auxiliary program. For this purpose, constants $a_4\beta_o$ and $a_4\beta_T$ are supplied as CDKO and CDKT, respectively, in the formal parameter list (i.e., CDKO = $a_4\beta_o$ and CDKT = $a_4\beta_T$).

Terms such as $\{R_t\}$, $\{f_D^*\}$ and $\{f_D\}_i$ are computed in the RESP subroutines of the auxiliary program. For this purpose, some of the quantities are made available to the routine through formal parameters as follows :

(1) Q : Displacement increments for the element for computing increments of stress, updating the state of stress, and computing $\{R_t\}$ *or* $\{R_{t+\Delta t}\}_i$

(2) VEL, ACC : Current velocities and accelerations, respectively, for the element (i.e., $\{\dot{q}_t\}$ *or* $\{\dot{q}_{t+\Delta t}\}_i$ and $\{\ddot{q}_t\}$ *or* $\{\ddot{q}_{t+\Delta t}\}_i$)

(3) C7 : Constant $(a_5 - 1)$

(4) C8 : Constant a_6

(5) KITRN : Iteration indicator, as follows :
(a) If KITRN = 0, compute $\{f_D^*\}$ as in equation (8).
(b) If KITRN $\neq$ 0, compute $\{f_D\}_i$ as in equation (14).

The damping proportionality factors β_o and β_T are made available as DKO and DKT, respectively, in the labelled COMMON block /INFGR/.

APPENDIX B

PROGRAM CAPACITY CHANGES

The ANSR program's capacity is governed by labelled and blank COMMON statements included in the main program:

PROGRAM ANSR (INPUT, OUTPUT, ...)

These statements are as follows:

```
COMMON /INFEL/ ELDAT (1025)
COMMON /WORK / WORK (2000)
COMMON /FKBUF/ FK (300)
COMMON /LIMITS/ NTSTOR,LIMBLK,LIMSD
COMMON A (5000)
NTSTOR = 5000
LIMBLK = 20
LIMSD = 200
```

The capacity of the program can be changed by modifying the above statements as follows:

(a) The length of vector ELDAT must be maximum length of the /INFEL/ array, considering all element types.

(b) The length of vector WORK must be at least 2000, but can be increased if needed. This COMMON block is used as a temporary storage area in both the base program and element subroutines.

(c) The length of vector FK must be at least the length of the largest element stiffness matrix, considering all element types.

(d) The blank COMMON storage, A, can be set to a value N1 (i.e., COMMON A(N1)), depending on the amount of core storage available. The variable NTSTOR must be set equal to N1.

(e) The variable LIMBLK is the maximum permitted number of stiffness matrix blocks for out-of-core solution of equations. This is used to avoid an excessive number of small blocks. The user also has the option of limiting the number of blocks to less that LIMBLK when the input data is prepared (see MAXBLK, Section C1 of User's Guide).

(f) The variable LIMSD is the minimum number of time steps in a block of any dynamic load record (ground accelerations, dynamic forces, and support motions). Any dynamic load record is first interpolated at time step intervals, and then blocked, each block containing LIMSD steps. These blocks are then transferred to scratch storage for subsequent retrieval. The specification of a minimum block size avoids an excessive number of small blocks. The user may specify a larger block size when the input data is prepared (see NSDEL, Section F1 of User's Guide). The block size used in any analysis must be at least equal to the maximum number of time steps by which any record is delayed (see NS, Sections J3, J4, and J5 of User's Guide).

APPENDIX C

PROGRAM RESTART

Nonlinear structural analyses will rarely be completed in a single computer run. Typically, the analyst will wish to examine the results up to a certain load level before applying more static load, or for a certain time period before continuing a dynamic analysis. It may also be necessary to experiment with load increments, time steps and solution strategies to obtain accurate results.

ANSR-II contains a flexible restart option. The results at any stage of any analysis can be saved permanently in any computer run. In a later computer run, any of the saved results sets (not necessarily the most recent) can be recalled and used as initial conditions for further analysis.

(a) First Computer Run: In the first computer run for a new structure, a data file is initialized (NEWF option). The structure geometry is saved, and zero initial conditions, corresponding to the unstressed structure, are automatically set up. This becomes results set zero for future restarts. Additional results sets, for analyses carried out in the first computer run, may also be saved. These results sets are sequentially numbered, starting with one.

(b) Subsequent Computer Runs: For any subsequent computer run, the OLDF option is used. Any results set saved in any previous computer run can be recalled, by referring to its sequence number, and used as initial conditions for additional analyses. Further results sets may also be saved. These are added to the results sets previously saved, and are numbered in continuing sequence.

The program uses storage file TAPE20 as the restart file from which results sets are recalled and to which results sets are added. At the end of the first computer run, the contents of TAPE20 must be transferred to permanent storage (magnetic tape or permanent disc file) using appropriate system control cards. For each subsequent computer run, it is necessary to transfer the contents of the permanent data storage to TAPE20 before execution commences, and to transfer the contents of TAPE20 back to the permanent data storage after execution is complete.

The control cards for the CDC 6400 at the University of California, Berkeley, are as follows for magnetic tape storage:

(a) First Computer Run:

```
Job Card. User Name
REQUEST , TAPE , HI , I. Reel No. , WRITE , User Name
[ Compilation and Execution Related Control Cards
REWIND, TAPE20, TAPE.
COPYBF, TAPE20, TAPE
789
 Data Cards
6789
```

(b) Subsequent Computer Runs:

Job Card. User Name
REQUEST, TAPE, HI, I. Reel No., WRITE, User Name
COPYBF , TAPE , TAPE20.
[Compilation and Execution Related Control Cards
REWIND, TAPE20, TAPE.
COPYBF , TAPE 20 , TAPE.
789
Data Cards
6789

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