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SINGER: A COMPUTER CODE FOR GENERAL ANALYSIS OF
TWO-DIMENSIONAL REINFORCED CONCRETE STRUCTURES.
VOLUME 3.   USER'S GUIDE

R. J. Melosh, et al

Virginia Polytechnic Institute and State University

Prepared for:

Air Force Weapons Laboratory
Defense Nuclear Agency

May 1975

AFWL-TR-74-228, Vol. III

AFWL-TR-
74-228
Vol. III

ADA011585

SINGER: A COMPUTER CODE FOR GENERAL ANALYSIS OF TWO-DIMENSIONAL CONCRETE STRUCTURES

Volume III

User's Guide

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R. M. Barker
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May 1975

Final Report for Period August 1972 - August 1974

Approved for public release; distribution unlimited.

JUN 24 1975

Prepared By

DEPARTMENT OF CIVIL ENGINEERING

Virginia Polytechnic Institute and State University

Blacksburg, Virginia

AIR FORCE WEAPONS LABORATORY

Air Force Systems Command

Kirtland Air Force Base, NM 87117

This final report was prepared by the Department of Civil Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia under Contract F29601-73-C-0022, Program Element 62704H, Project 5710, WDNS 3414, Subtask Y99QAXSC157, with the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Rodney G. Galloway, 2 LT, USAF, was the Laboratory Project Officer-in-Charge. Major Tyler M. Jackson was the former Laboratory Project Officer.

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This technical report has been reviewed and is approved for publication.

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFWL-TR-74-228, Vol 3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* SINGER: A COMPUTER CODE FOR GENERAL ANALYSIS OF TWO-DIMENSIONAL REINFORCED CONCRETE STRUCTURES Volume 3, User's Guide		5. TYPE OF REPORT & PERIOD COVERED Final Report: August 1972 – August 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) R. J. Melosh, R. M. Barker. S. M. Holzer		8. CONTRACT OR GRANT NUMBER(s) F29601-73-C-0022
9. PERFORMING ORGANIZATION NAME AND ADDRESS Department of Civil Engineering Virginia Polytechnic Institute & State University Blacksburg, Virginia		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element: 62704H Project: 5710, WDNS 3414
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE May 1975
		13. NUMBER OF PAGES 89
14. MONITORING AGENCY NAME & ADDRESS*(if different from Controlling Office)* Air Force Weapons Laboratory Kirtland Air Force Base, NM 87117		15. SECURITY CLASS. *(of this report)* UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

Same as block 16.

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Reinforced Concrete Analysis   Energy Minimization
Dynamic Analysis   Structural Failure and Collapse
Nonlinear Structural Response
Air Blast Effects
Finite Element Method

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

This document is a user's guide to the SINGER computer program. The guide defines the form and interpretation of input and output data. SINGER predicts the transient response of two dimensional reinforced concrete frames subjected to time varying loadings, accounting for nonlinear material effects and large geometry changes.

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PREFACE

This Guide represents part of the work performed for the Air Force Weapons Laboratory, Kirtland Air Force Base, N. M. The assistance of Major Tyler Jackson in attaining the level of completeness and usefulness to the user is appreciated. The authors would also like to acknowledge the valuable assistance of Virginia Tech students H. D. Greer and T. T. Baber in assembling guide data and developing SINGER logic.

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SECTION 1

THE SINGER PROGRAM

SINGER is an acronym for Simulation of Inelastic and Nonlinear Geometric Effects in Reinforced Concrete. The SINGER computer program addresses the simulation of a plane framework assembled of straight elements, usually of rectangular cross section. The user may model each element as a composite of longitudinal reinforcing bars confined within a mass of concrete by stirrups which, in turn, have a protective cover of unconfined concrete. He may also represent wide flange metal beams. Leaf springs may be used to connect elements eccentrically at joints or to model partially constrained internal joints and external supports. He may impose loadings with specified time histories. He can model concentrated and/or distributed forces and masses.

SINGER predicts the equilibrium positions of the structural system either neglecting or considering inertia effects. It represents large changes to the initial geometry of the structure due to loading and models proportional, plastic, strain hardening, unloading and reloading branches of the stress-strain relations. It models yielding and fracture of materials and elements.

It characterizes each equilibrium configuration by data defining the state of points in the structure. These state data cite the displacement, velocity, acceleration, and fiber strains at the joints of the structure. Additional data quantify the internal forces and stresses at cross-sections where they may be excessive. Other output establishes the element and total system stored and dissipated energy.

SINGER accepts and produces output in either English or System International units. (For the convenience of the user the conversion constants between these units is given in Table 1).

Table 1

CONVERSION FACTORS FROM ENGLISH SYSTEM (EG) OF UNITS
TO INTERNATIONAL SYSTEM (SI) OF UNITS

Unit	Multiply	By	To Obtain
Area	$in.^2$	6.4516* E-04	m^2
Density (Specific Weight)	$lb/in.^3$	2.7144714 E+05	N/m^3
Force	lb	4.4482216152605* E+00	N
Length	in.	2.54* E-02	m
Mass	$lb.s^2/in.$	1.75126835 E+02	kg
Mass Density	$lb.s^2/in.^4$	1.0686895 E+07	kg/m^3
Mass Moment of Inertia	$lb.s^2 in.$	1.12984829 E-01	$kg \cdot m^2$
Stress (Pressure)	lb/in^2	6.8947572 E+03	N/m^2
Volume	$in.^3$	1.6387064* E-05	m^3

* exact, by National Bureau of Standards definitions.

SINGER provides special data management capabilities. These include logic for saving data for a subsequent restart, performing a restart, and accumulating a data retrieval file for subsequent selective data acquisition.

This guide describes the input data expected and discusses the output data and its interpretation. The SINGER Program Document (reference 1) augments user information with data about program structure, subroutine functions and flow charts. The demonstration volume (reference 2) describes demonstration problems and their results. The Technical Report (reference 3) details the mathematical model of the code.

The sign convention used in SINGER for displacements and forces depends on the reference axis chosen. Joint data (coordinates, forces, displacements, velocities, and accelerations) are referred to the global reference axis. The global axes must be chosen so that the Y-axis is in a direction opposite to gravity (See Figure 1a). Quantities are positive when in the direction of the positive global axes.

Element data (section properties, distributed loadings, and stress resultants) are referred to a local reference axis. The local x-axis coincides with the reference axis of the element, and its positive direction is specified from the first listed joint to the second listed

1.   Barker, R. M., Melosh, R. J., and Holzer, S. M., "SINGER: A Computer Code for General Analysis of Two Dimensional Reinforced Concrete Structures", Volume 2, Program Document, Kirtland AFB, Albuquerque, New Mexico, Sep, 1974.

2.   Barker, R. M., Melosh, R. J., Holzer, S. M., and Bradshaw, J. C., "SINGER: A Computer Code for General Analysis of Two Dimensional Reinforced Concrete Structures", Volume 4, Demonstration Problems, Kirtland AFB, Albuquerque, New Mexico, Sep, 1974.

3.   Holzer, S. M., Melosh, R. J., Barker, R. M., and Somers, A. E., "SINGER: A Computer Code for General Analysis of Two Dimensional Reinforced Concrete Structures", Volume 1, Technical Report, Kirtland AFB, Albuquerque, New Mexico, Sep. 1974.

joint (See Figure 1b and Table 7).   The local y   and z-axis coincide

with the principle axes of the element. The local z-axis is usually

taken to coincide with the global z-axis. Quantities are positive

when in the direction of the positive local axes.

The guide is organized into four sections. The next section

describes input data deck form and card entries. The third section

illustrates the output and discusses its interpretation. The final

section contains information on modeling strategy and suggestions for

controlling problem time and accuracy.

a) Global joint coordinate system

b) Local (element) coordinate system
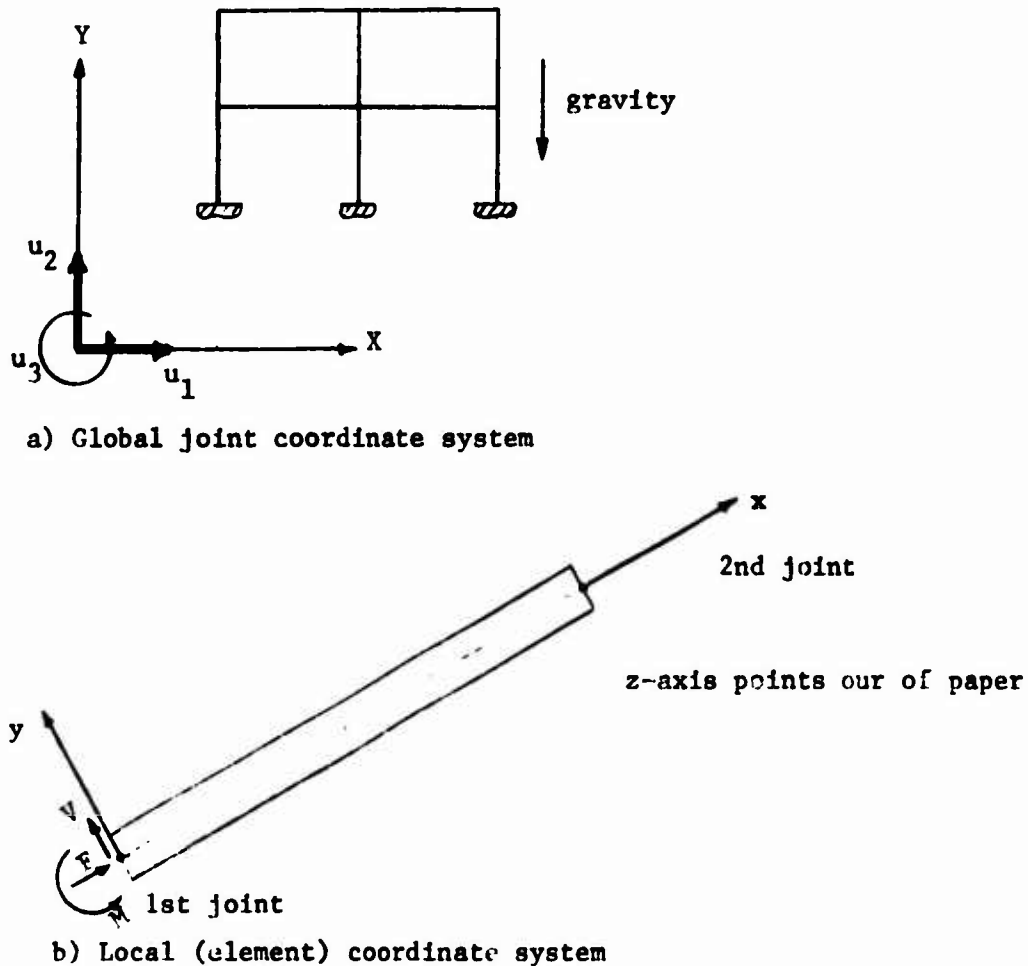
Figure 1. Coordinate Reference Systems

INPUT DATA

The input data consists of sets of data for each problem. Each set is composed of eight data blocks. Each block consists of two or more cards of data. This section provides detailed information for preparing the input data blocks.

2.1 THE INPUT DATA DECK

Figure 2 shows how the problem data sets form the Input Data Deck. Any number of problems can be batched together in one computer run. As long as all cards are punched in the appropriate format, SINGER will proceed from problem to problem.

Two cards terminate the Input Data Deck. The next to the last card contains the message END DATA beginning in Column 1 and ending in column 8. This card activates logic to indicate that no further data cards are to be read. The last card may contain zeros or be left blank. It is not read and only serves the purpose of having all of the data blocks follow the same pattern of ending with a zero card.

Figure 3 shows the contents of each Problem Data Set. Each deck includes cards for each of the eight Data Blocks. Data Blocks must appear in the order shown in the figure.

2.2 DATA BLOCKS

Each data block contains data for describing a particular feature of the structural problem of interset. Together, data in these blocks either completely particularize the parameters in the mathematical model

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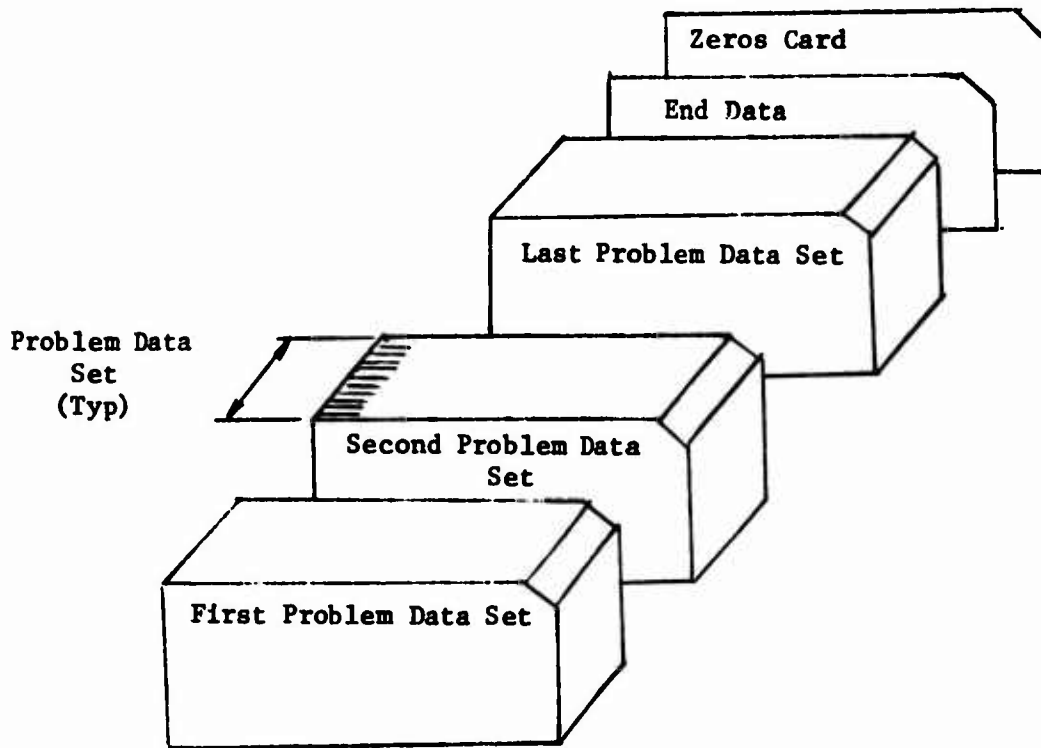
Figure 2.   Input Data Deck
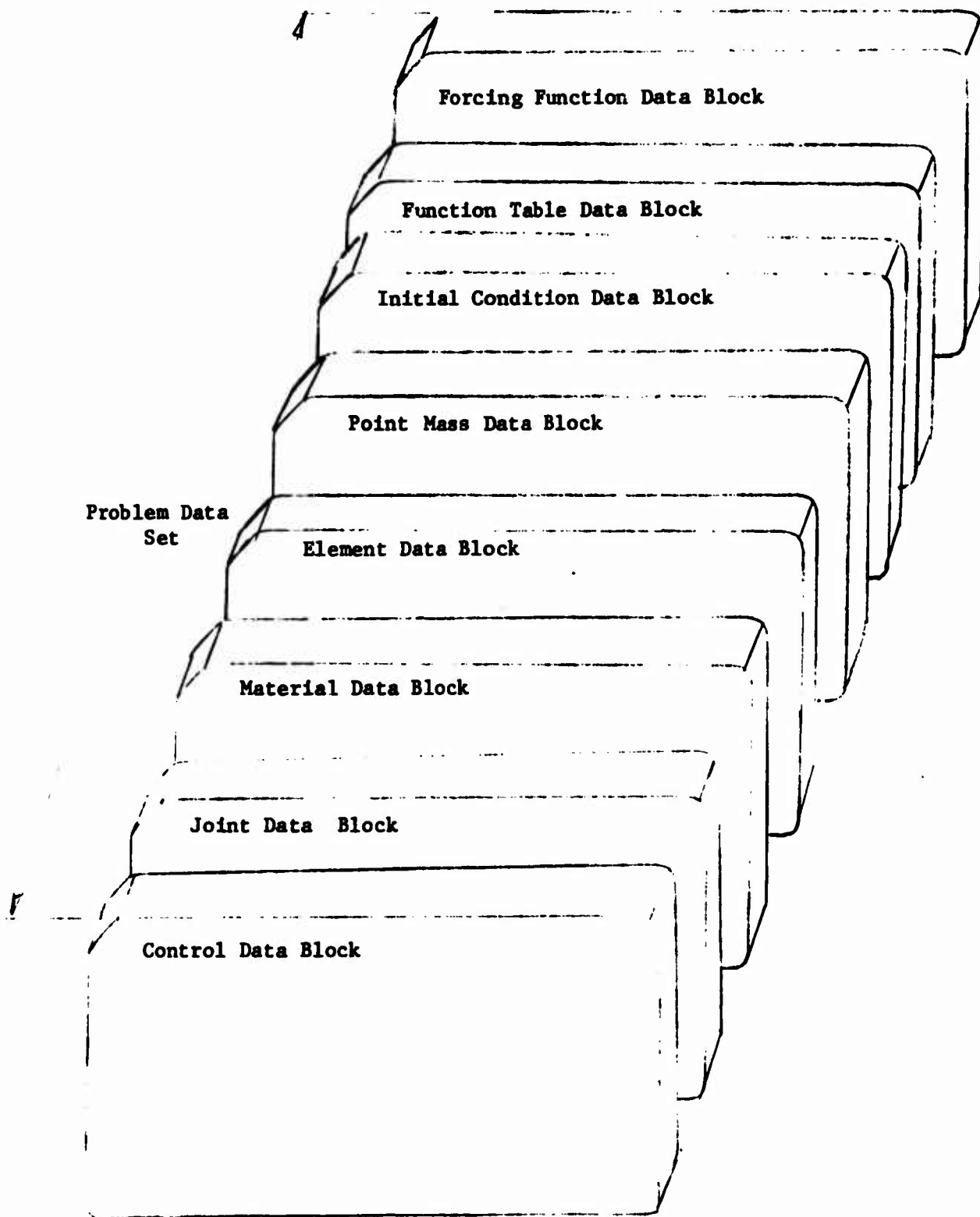
Figure 3. Problem Data Set

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of the system or, by default, evoke values included in the computer code which represent the developer's best judgment of what these values should be to insure a faithful representation of a reinforced concrete framework.

Figure 4 indicates the anatomy common to each Data Block. The Block is initiated by a Block Title Card which may contain any alphanumeric information. Data on this card is printed with block input thereby permitting user identification of data in each block. It serves no other purpose. Each block is terminated by Zeros Card. This card must contain zeros at least through column 5. It signals the end of the Block. Numerical Data Cards fall between these extremes. Even if all Numerical Data Cards are omitted, the Block Title Card and Zeros Card must be in the Problem Data Set.

Numerical Data Cards are punched in fixed format with fields of alphabetic, integer, or floating point data as appropriate. Punched data may appear in none or all 80 columns of the card. Generally, the first entries designate option parameters and the later entries provide problem data.

The eight tables on the pages that follow define input data form and interpretation for each of the eight input blocks of a problem data set. These tables are footnoted so they will be self-contained. Figures are also included to clarify the meaning of input.

The special notation below is used in these tables as abbreviations:

b - indicates a blank (unpunched) card field

d*- indicates the default interpretation-the interpretation made
    for all field input whose meaning is not defined elsewhere
    in the input table. (e.g. Table 2 indicates that a "X" punched
    in column 16, since it is not a "C", will cause a STOP if a
    conditional error is encountered in calculations.)

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Zeros Card

None to any number of cards

Numerical Data Cards

Block Title Card
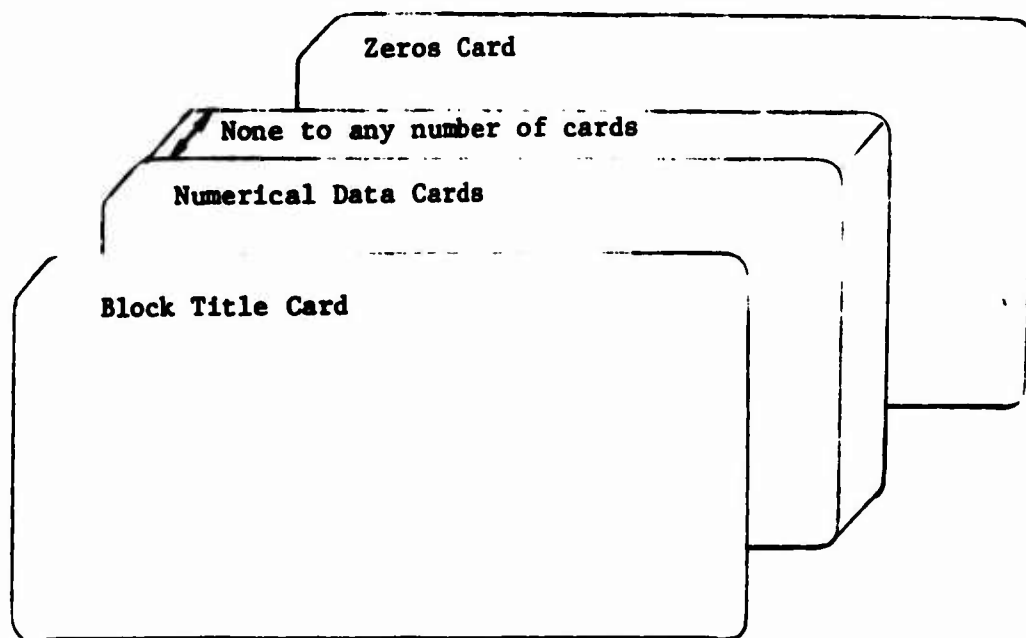
Figure 4. Data Block Organization

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R - indicates the card is required to be in the input deck
   (omission of a R means the card may be omitted)

Ø - a zero

Card formats are listed using FORTRAN notation. The data should be
right justified in the fields specified. The sign of all input data
must be positive unless otherwise indicated.

Input punched as zero or left blank activates default logic. For
control information and option parameters (printout and simulation
options) default logic makes a desirable choice for the information --
either what the program developers regard as the most probable choice
or that which will tend to minimize calculations. In the case of
data, default logic supplies nonzero values, when necessary, using
standard data. Examples of default actions are provided in the input
tables which follow.

Table 2

CONTROL DATA BLOCK

Card	Cols.	Format	Item
1/R	1-80	20A4	Problem Title (to appear on each page of output)
2/R	1-5	I5	ISTART = source of input data[1] $\emptyset$,b = card input 1(one) = peripheral unit 11
	6-10	A2,3X	IUNITS = system of unit flags EE,d* = English-in and English-out ES = English-in and System International-out SS = System International-in and System International-out SE = System International-in and English-out
	11-15	A2,3X	ILIN = analysis complexity flag II,d* = infinitesmal joint rotations[2] (linear analysis) FI = finite joint rotations
	16-20	A1,4X	ISTOP = error override flag $\emptyset$,b = stop on conditional stop errors[3] C = continue simulation despite conditional stop errors
	21-25	A1,4X	IPRINT = print level flag[4] M = minimum (summaries of problem description and results) S,d* = standard (adds input tables and solution progress) D = detailed (adds unbalanced joint forces and energies) E = extensive (adds on extended solution search printout)
	26-30	A1,4X	ISTRES = stress print flag N,d* = no stresses or strains S = stresses and strains R = stress resultants B = all stresses, strains, and stress resultants
	31-35	I5	ITAPE = receptacle for continuation data[5] $\emptyset$,b = no continuation data written 1(one) = peripheral unit 11
	36-40	A1,4X	IPLOT = data retrieval file flag d* = no retrieval data to be written R = write retrieval file on peripheral unit 10

Table 2 (Cont.)

Card	Cols.	Format	Item
3/R	1-5	A1,4X	IANAL = Analysis type flag S,d* = static analysis D = dynamic analysis
	6-10	5X	Ignored
	11-20	E10.0	TBEGIN = time to start integration, seconds or number of zero load step
	21-30	E10.0	THALT = time to stop integration, seconds or number of last load step
	31-40	E10.0	TINK = approximate time interval for printing response data, seconds of integration time (automatically printed every step for static analysis)
	41-50	E10.0	SERR = maximum tolerable relative error in the energy of unbalanced forces[6]
	51-60	E10.0	TPROB = maximum machine time for problem, CPU minutes
4/R	1-10	E10.0	CA = ultimate unconfined concrete strain coefficient[7] (d* = 1.0)
	11-20	E10.0	CB = bar buckling end restraint coefficient[7] (d* = 2.0)
	21-30	E10.0	CC = shear crackling failure curve slope coefficient[7] (d* = 3.5)
	31-40	E10.0	CD = shear cracking axial force effect coefficient[7] (d* = 0.0)
	41-50	E10.0	CE = lateral reinforcement failure coefficient[7] (d* = 1.333)
5/F	1-80	20A4	All zeros or blanks (ends data block)

[1] Input data is either all from a card file or part from a card file and part from a peripheral unit. In the latter case, the card file includes only the Control Data Input Block.

[2] Limiting analysis to infintesimal rotations ($\cos\alpha = 1$, $\sin\alpha = 0$) reduces calculations in coordinate transformations and solution search.

[3] Conditional errors are indicated when unusual input or calculated data are found. These may or may not be real errors. For example, a negative time to start integration is flagged as a conditional error because use of the negative time axis is not common.

[4] See Section 3 of this report for printout options and form.

[5] If continuation data is written, it is done either when data processing is stopped because of a fatal error or when execution continues beyond 15 CPU minutes or if estimate of calculation time exceeds allowable problem time (TPROB) or upon completion of the analysis.

[6] $SERR \geq 2^{-p/2}$ where p is the number of bits in the mantissa. This is the maximum relative energy error (deviation from the minimum) that the analyst will accept. The default value is about $1. \times 10^{-5}$.

[7] Coefficients CA, CB, CC, CD, and CE modify the failure criteria limits for the expressions developed in Appendix B of the Technical Report. Summarized below in the English system of units are the expressions which contain these coefficients. (Section numbers refer to the Technical Report).

B.3.1.1 Unconfined Concrete Crushing Strain

$$\varepsilon_{f1} = CA \left[\frac{3+0.002f_c'}{f_c' - 1000} \leq 0.0035 \right] \qquad 1.0 \leq CA \leq 1.23$$

where ε_{f1} = unconfined concrete crushing strain and f_c' = compressive cylinder strength of concrete.

B.3.1.3 Buckling of Longitudinal Reinforcement

$$f_{cr} = CB \frac{\pi^2 E_t}{16(s/D)^2} \qquad \begin{array}{cc} \text{Pinned ends} & \text{Fixed ends} \\ 1.0 \leq CB \leq 4.0 \end{array}$$

where f_{cr} = critical compressive stress in longitudinal bar, E_t = tangent modulus of longitudinal reinforcing material, s = spacing of lateral reinforcement, and D = diameter of longitudinal bar.

B.3.2.1 Diagonal Shear Cracking

$$v_{cn} = 1.5 \sqrt{f_c'} + CC \cdot 1000pd \left| \frac{V}{M} \right| + \alpha \frac{N}{bd} \qquad 3.5 \leq CC \leq 5.83$$

where v_{cn} = nominal cracking shear stress with axial force; p = longitudinal steel percentage; d = effective depth of element; b = width of element; V, N, and M = shear force, axial force, and bending moment, respectively, at critical section; and α = coefficient for axial force effect in which

tension, $\alpha_t = 0.025 (4 - CD)$

compression, $\alpha_c = 0.025 (4 + 2 CD)$ $\qquad 0 \leq CD \leq 1.0$

also

$$1000pd \left| \frac{V}{M} \right| \leq \frac{3}{7} CC.$$

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B.3.2.2 Yielding of Web Reinforcement

$$f_v = CE \frac{sb}{A_v} (v - v_{cn}) \qquad\qquad \frac{4}{7} \le CE \le \frac{4}{3}$$

where f_v = stress in web reinforcing bar, A_v = area of web reinforcing bars, and v = nominal shear stress due to shear force, V.

Table 3

JOINT DATA BLOCK

Card	Cols.	Format	Item	
1/R	1-80	20A4	Block title (to lead Joint Data Block printout)	
All joint numerical data cards[1]	1-5	I5	Joint number	
	6-10	5X	Ignored	
	11-20	E10.0	$\pm x$ coordinate of the joint, in. or m	
	21-30	E10.0	$\pm y$ coordinate of the joint,[2] in. or m	
	31-32	2X	Ignored	
	33	A1	x-displacement, R,d* = restrained, $\emptyset$,b = unrestrained	Restraint Codes
	34	A1	y-displacement, R,d* = restrained, $\emptyset$,b = unrestrained	
	35	A1	z-rotation, R,d* = restrained, $\emptyset$,b = unrestrained	
Last/R	1-80	I5,5X, 2E10.0 2X,3A1	All zeros or blanks (ends data block)	

[1]Joints must be numbered sequentially beginning from one; no number may be skipped and the total number of joints equals the largest joint number. Joint data cards need not be input in sequential order.

[2]The convention which must be followed is that the global Y-axis must always be vertical and positive in the direction opposite to gravity.

Table 4

MATERIAL DATA BLOCK[1]

Card	Cols.	Format	Item
1/R	1-80	20A4	Block title (to lead Material Data Block printout)
2/R	1-5	A4,1X	Material name
	6-10	A1,4X	IMAT = material type flag U = unconfined concrete C = confined concrete S,d* = steel
	11-20	E10.0	Crushing strength (concrete) or yield strength (steel)[2], psi or N/m^2, f'_c or f_y
	21-30	E10.0	Poisson's Ratio, elastic, ν
	31-40	E10.0	Elastic shear modulus, psi or N/m^2, G
	41-50	E10.0	Material density, lb/in^3 or N/m^3, ρ
	51-60	E10.0	Cyclic loading curve data[3]
	61-70	E10.0	
3/R	1-10	A4,1X,A1, 4X	Card identification[4]
	11-80	7E10.0	σ_1, ϵ_1; σ_2, ϵ_2; ... σ_4
4/R	1-10	A4,1X,A1, 4X	Card identification[4]
	11-80	7E10.0	ϵ_4, σ_5, ϵ_5; σ_6, ϵ_6, σ_7, ϵ_7
Last/R	1-80	A4,1X,A1, 4X, 6E10.0	All zeros or blanks (ends data block)

For each material

Coordinates of Stress-Strain Points[5]

[1]For each material the uniaxial stress-strain curve is modeled by a
maximum of six straight-line segments defined by seven pairs of stress-
strain coordinates. For concrete, no tensile stress is assumed and
the compressive values (indicated by minus signs) are input as shown
in Figures 5 and 6. For steel, only one side of the curve is given
(Figure 7) with the other side generated as a mirror image. The only
restriction on the stress-strain curve is that the stress must be
uniquely defined for any given strain.

[2]This data is required only if cards 3 and 4 are blank or all zero.
(See also note 5)

[3]This data particularizes the loading and unloading curves.
   a) For concrete, cols. (51-60) contain the k of Figures 5 and 6
      This defines the slope of the drop-elastic curve. k must
      be greater than or equal to zero. (data in columns 61-80
      is ignored).
   b) For steel, cols. (51-60, 61-70) define the (σ, ϵ) coordinates
      of point 8 in Figure 7. The unloading curve parallels the
      1-2 leg. If reloading occurs with opposite σ, the reloading
      curve is a mirror image of the 1-8-3 folded line of Figure 7.

[4]If punched, this data must match the same column data of card 2.
Thus it may be used to check that all material data for a particular
material has been kept together.

[5]If all (σ, ϵ) points are zero (indicated by leaving cards 3 and 4
blank) the default stress-strain curves are used. These are defined
by the default data cited with Figures 5, 6, and 7. (Table 5). If
a steel with a yield strength different from those tabulated is input,
the stress-strain pairs are automatically interpolated.
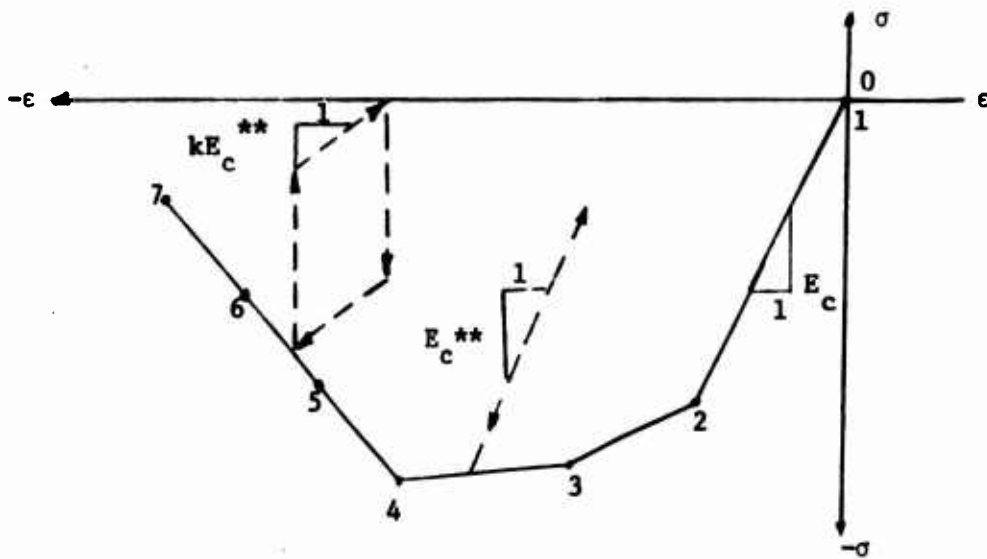
Default Data

Point	Stress σ	Strain ϵ
1	0.00	0.00
2	$-0.50f'_c$	-0.586×10^{-3}
3	$-0.85f'_c$	-1.225×10^{-3}
4	$-1.00f'_c$	-2.000×10^{-3}
5	$-0.50f'_c$	$\dfrac{3+.002f'_c}{1000 - f'_c}$
6	$-0.35f'_c$	*
7	$-0.20f'_c$	*

*Extrapolated from straight line through points 4 and 5

**Unloading curve slope is E_c when strain at which unloading initiates is greater than ϵ_4. Otherwise the kE_c unloading loop is used.

Figure 5. Unconfined Concrete Stress-Strain Curve

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Default Data

Point	Stress, σ	Strain, ϵ
1	0.00	0.00
2	$-0.50f_c'$	-0.586×10^{-3}
3	$-0.85f_c'$	-1.225×10^{-3}
4	$-1.00f_c'$	-2.000×10^{-3}
5	$-(f_c' + \Delta f_c)$	$-(.002 + \Delta\epsilon_c)$
5.5	$-0.50f_c'$	$\dfrac{-(3+.002f_c')}{(f_c'-1000.)} - \dfrac{3}{4}p'' \sqrt{\dfrac{b''}{s}}$
6	$-0.20f_c'$	*
7	$-0.20f_c'$	$\epsilon_7 = 0.3$

$\Delta f_c = \frac{3}{4} p'' f_y''$

$\Delta\epsilon_c = 0.17p'' \sqrt{b''/s}$

p'' = ratio of volume of lateral reinforcement to confined concrete

f_y'' = yield stress of lateral reinforcement

b'' = width of confined concrete

s = spacing of lateral reinforcement

*Extrapolated from a straight line through points 5 and 5.5

**Unloading curve slope is E_c when strain at which unloading initiates is greater than ϵ_5. Otherwise the kE_c unloading loop is used.

Figure 6. Confined Concrete Stress-Strain Curve
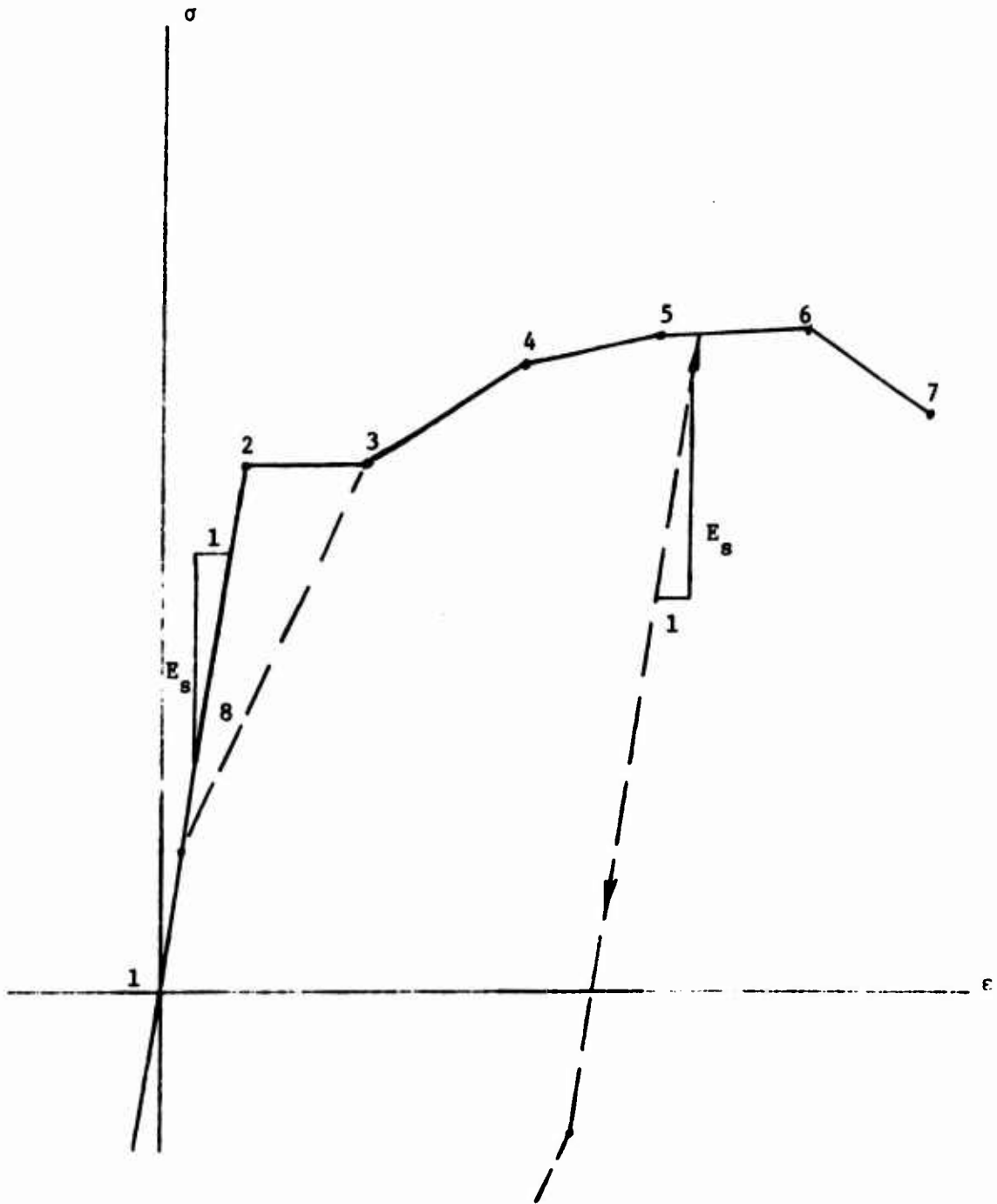
Figure 7. Steel Stress-Strain Curve

Table 5

STRESS-STRAIN DATA FOR STEEL*

(DEFAULT DATA)

Point	f_y = 33,000 Stress	Strain	f_y = 36,000 Stress	Strain	f_y = 40,000 Stress	Strain	f_y = 50,000 Stress	Strain	f_y = 60,000 Stress	Strain	f_y = 75,000 Stress	Strain
1	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	33000	.00114	36000	.00125	40000	.00138	50000	.00173	60000	.00208	75000	.00260
3	33000	.0140	36000	.01400	40000	.0230	50000	.0130	60000	.0060	75000	.0027
4	49000	.059	52000	.059	66000	.062	72000	.048	90000	.033	110000	.026
5	56000	.104	58000	.104	77000	.101	89000	.084	103000	.060	124000	.050
6	58000	.150	60000	.150	80000	.140	92000	.120	106000	.087	130000	.073
7	56000	.210	59000	.200	76000	.200	90000	.154	100000	.136	124000	.115
8**	25700	.000888	29100	.00101	14900	.000514	35800	.001237	54200	.001879	75000	.00260

*Data in English units

**Unloading curve point (point 8 of Figure 7). Specific values are obtained from this table on default using linear interpolation. If extrapolation is required, an error message is produced.

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Table 6

ELEMENT DATA BLOCK[1]

Card[2]	Cols.	Format	Item
1	1-20	20A4	Block title (to lead Element Data Block printout)
1/R[3]			Element parameter card 1 (see Table 7)
2			Concrete data card (see Table 8)
3,4,...L(max L=12) (L=no. of longitudinal bar groups)			Longitudinal reinforcement card (see Table 9)
L+1,L+2,...M(M≤L+6) (M = no. of lateral bar groups)			Lateral reinforcement card[4] (see Table 10)
M+1			Wide flange reinforcement card (see Table 11)
M+2			Leaf spring flexibility card (see Table 12)
Last/R	1-5	I5	All zeros or blanks (ends data block)

[1] Groups of cards for each element can be input in any order. All cards in the group have the same format.

[2] Except as noted in footnote 4, each element parameter card may be followed by any of the other card types listed. At least one such card must be included and cards, if given, must follow the sequence given.

[3] This card is omitted for a wide flange or leaf spring element.

[4] Lateral reinforcement cards cannot be introduced unless preceded by one or more longitudinal reinforcement cards.

Table 7

ELEMENT PARAMETER CARD

Cols.	Format	Item
1-5	A4,1X	Blank
6-10	I5	Element number[1]
11-15	I5	Joint number for one end of the member, or the "F" (first) end.
16-20	I5	Joint number for the other end of the member, or the "S" (second) end
21	A1	IACT = element action flag L, = restricted linear material behavior (Hooke's law) C,d* = changeable, initially Hookean but may become nonlinear due to loading N = non-linear material behavior
22	A1	ISHEAR = shear model flag N,d* = don't check S = check using linear behavior range
23	A1	IBOND = steel bond check flag ACI 318-71[2] N,d* = don't check H = check using ACI 318-71 specs
24-30	A1, I1, A4, 1X	Read and ignored
31-40	E10.0	$\pm h_t$ = distance to reference axis from top of element[3], in. or m.
41-50	E10.0	$\pm d$ = distance to centroid of bottom rebar group[3] from top of element[2], in. or m.
51-60	E10.0	$\pm d'$ = distance to centroid of top rebar group[3] from top of element[2], in. or m.
61-70	E10.0	X_F = distance from "F" end to section used in failure check[3], in. or m.
71-80	E10.0	X_S = distance from "S" end to section used in failure check end[3], in. or m.

[1]If no element number is specified by the user, elements are assigned numbers corresponding to their order in input.

[2]This check is a comparison of the effective length of the reinforcement group with the development length required to reach a bar stress of f_y (Sec. 12.5, ACI 318-71).

[3]Figure 8, below, clarifies the meaning of these input data. The X distances are from the joint to the section (usually at face of supports) where flexure and shear failure checks are made. The X_i values do not effect the prediction of joint displacements. The reference axis position is arbitrary and immaterial to response prediction. Either end may be the first or second end.
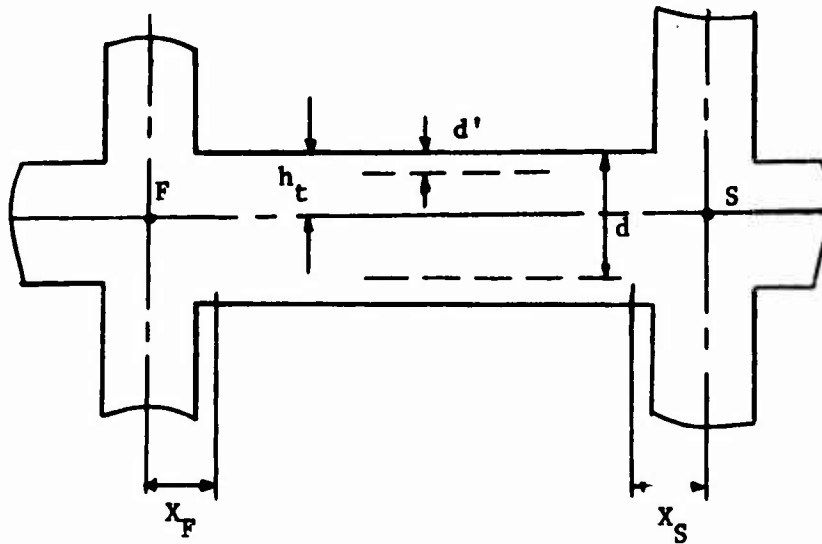
Figure 8. Element Gross Geometry

Table 8

CONCRETE DATA CARD

Cols.	Format	Item
1-5	A4,1X	Unconfined concrete material name[1]
6-10	I5	Element number[2]
11-20	2I5	Read and ignored
21-25	4A1,I1	Read and ignored
26-30	A4,1X	Confined concrete material name[1]
31-40	E10.0	h = element height[3], in. or m.
41-50	E10.0	b = element width[3], in. or m.
51-60	E10.0	d'' = confined depth of element[3], in. or m.
61-70	E10.0	b'' = confined width of element[3], in. or m.
71-80	E10.0	Read and ignored

[1] Unconfined concrete is that not bound by stirrups. The confined concrete goes within the stirrups. Material data must be included in the Material Data Block for each concrete name.

[2] If no element number is specified by the user, this number will be that of the preceding parameter card (see Table 7).

[3] Figure 9, on the next page, clarifies the meaning of these input data.
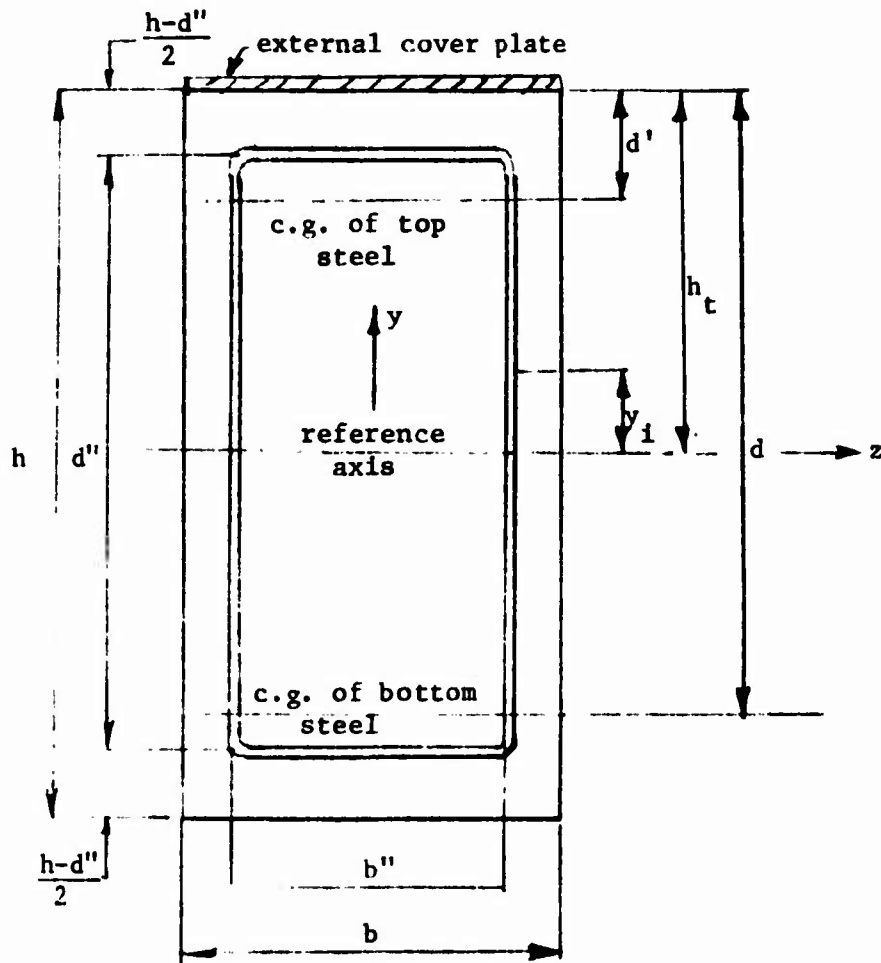
Note relationship between h and the element's y-axis. The element's x-axis points into paper.

When setting up a composite member with an external cover plate, the element height (h) is to be given as the height of the concrete section (i.e, it does not include the thickness of the plate). The cover plate area and distance from the reference axis is specified by way of a longitudinal reinforcement card (Table 9).

Figure 9. Element Cross Section Dimensions

Table 9

LONGITUDINAL REINFORCEMENT CARD[1]

Cols.	Format	Item
1-5	A4,1X	"BARS" - Alphanumeric to indicate that longitudinal reinforcement is to be input
6-10	I5	Reinforcement group number[2]
11-15	I5	Number of bars[4]
16-20	I5	Bar size number[3,4]
21	A1	Reinforcement continuity code at the "F" end of the current reinforcement group; 0-reinforcement terminated; 1-rebar bent or continued
22	A1	Reinforcement continuity code at the "S" end of the current reinforcement group, 0 or 1
23-25	2A1,I1	Read and ignored
26-30	A4,1X	Reinforcement material name
31-40	E10.0	Area of reinforcement group[4], in.^{2} or m.^{2}
41-50	E10.0	$\bar{y}_1$ = distance to steel from reference axis[5], in. or m.
51-60	E10.0	X_F = distance from "F" end of member to beginning of reinforcement group[5], in. or m.
61-70	E10.0	X_S = distance from end of reinforcement to "S" end of element,[5] in. or m.
71-80	E10.0	Read and ignored

[1] Up to ten longitudinal reinforcement groups are allowed on each element. One Longitudinal Reinforcement Card is read for each group.

[2] The user may number the reinforcement groups. The numbers must be specified without skipping numbers and starting from 1. If the reinforcement group number is not specified, groups are assigned numbers corresponding to their order in input.

[3] If metric bar sizes are being used, the bar size number should be the diameter of the bar in millimeters.

[4] Two options are provided for calculating the reinforcement group area. The user may input the area of the group directly or the number of bars and the bar size number. If the user inputs the number of bars and the bar size number, subroutine TABL will calculate the area and the bar size diameter, if the bar size is specified, it will (optionally) determine if bond is sufficient, and if reinforcement buckling is likely to occur. If only the group area is input, these calculations are skipped.

[5] Figure 10, below, clarifies the meaning of these data.
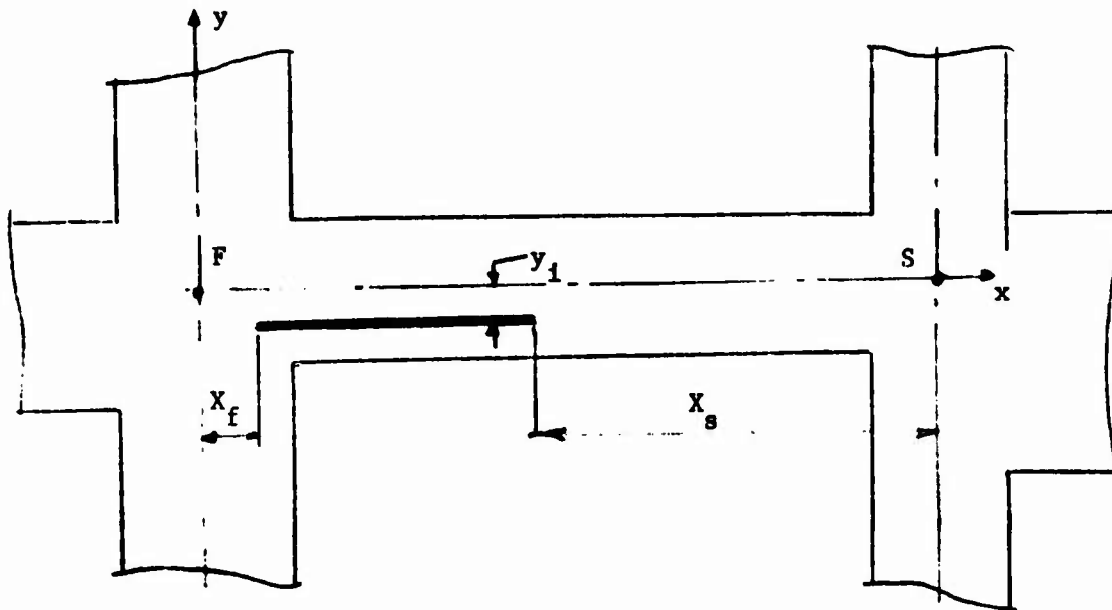
Figure 10. Longitudinal Reinforcement Dimensions

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Table 10

LATERAL REINFORCEMENT CARD[1]

Cols.	Format	Item
1-5	A4,1X	"STIR" = stirrup group or "TIES" = tie group, identification[2]
6-10	I5	Lateral reinforcement group number[3]
11-15	I5	Bar size number of lateral reinforcement[4]
16-20	I5	Number of spaces in each stirrup or tie group (See Fig.11)
21-24	4A1	Read and ignored.
25	I1	Number of legs for individual stirrup or tie
26-30	A4,1X	Lateral reinforcement material name
31-40	E10.0	A_v = total vertical area of lateral reinforcement group[5], in.^{2} or m^2.
41-50	E10.0	S = spacing of stirrups in this group, or spacing of ties, in., or m.
51-60	E10.0	X_F = distance from "F" end of element to beginning the current tie or stirrups spacing, in. or m.
61-70	E10.0	V_s = volume of steel per stirrup[5], in.^{3} or m.^{3}.
71-80	E10.0	Read and ignored

[1] From 1 to 6 stirrup or tie groups may be specified for lateral reinforcement. One lateral reinforcement card is read for each such group.

[2] As far as the analysis is concerned, there is no distinction between lateral reinforcement designated as "STIR" or "TIES". Two terms are provided to permit the user to use conventional terms - stirrups for beams and ties for columns.

[3] The stirrup or tie groups may be specified by the user. If not, groups are assigned numbers corresponding to their order in input.

[4] If metric bar sizes are being used, the bar size number should be the bar diameter in millimeters.

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If the user wishes he may input the area, A_v, directly and not input the bar size and number of legs. If both entries are used, the program determines the area and volume of stirrups. If only the area is given, the user must also supply, V_s, the volume of steel per stirrup.
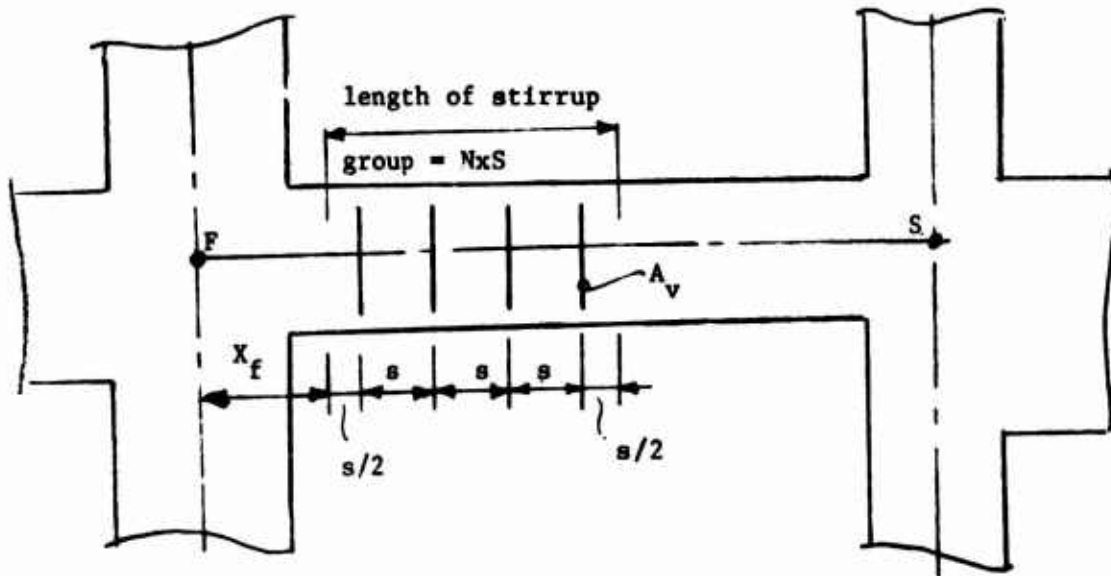
Figure 11. Lateral Reinforcement Dimensions

Table   11

WIDE FLANGE REINFORCEMENT CARD

Cols.	Format	Item
1-5	A4,1X	"WFST" = wide flange card identification
6-10	I5	Element number[1]
11-15	I5	Joint number of the "F" end of the element[2]
16-20	I5	Joint number of the "S" end of the element[2]
21	A1	IACT = element action flag[2]; L, C(d*) , or N (see page 29)
22-25	3A1,I1	Read and ignored
26-30	A4,1X	Wide flange material name
31-40	E10.0	h_t = Distance from top surface to reference axis, in. or m.
41-50	E10.0	h = Depth of element, in. or m.
51-60	E10.0	t_w = Thickness of element web, in. or m.
61-70	E10.0	b = Width of element, in. or m.
71-80	E10.0	t_f = Thickness of element flange, in. or m.

[1] If no element number is specified by the user, this number will be assigned as that of the preceding element parameter card (see Table 7) or if this is zero, the next number in sequence.

[2] If joint numbers and IACT are omitted, the values will be taken from the previous element parameter card and the wide flange beam will be regarded as the steel reinforcement of a reinforced concrete element.
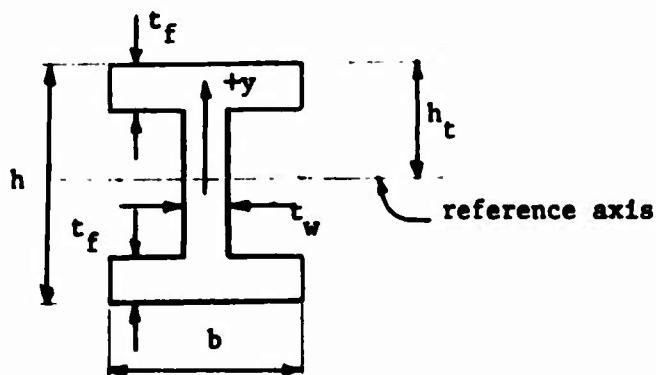
Figure 12. Wide Flange Beam Cross Section

Table 12

LEAF SPRING FLEXIBILITY CARD[1]

Cols.	Format	Item
1-5	A4,1X	"LEAF" = leaf spring card identification
6-10	I5	Leaf spring number[2]
11-15	I5	Joint number of F end of spring[3]
16-20	I5	Joint number of S end of spring[3]
21-30	4A1, I1, A4, 1X	Read and ignored
31-40	E10.0	A_{11} = lateral deflection for unit tip lateral load[4], in./lb. or m./N
41-50	E10.0	A_{12} = z axis rotation for unit tip lateral load[4], rad/lb. or rad/N
51-60	E10.0	A_{22} = z axis rotation for unit tip z moment[4], rad./in.lb. or rad./m.N
61-70	E10.0	A_{33} = element x axis elongation for unit tip axial load, in./lb. or m./N
71-80	E10.0	Leaf spring storable energy limit[5], in-lb or m-N.

[1] Defines load-deflection coefficients for a linear leaf spring. Using a leaf spring to connect two elements provides for implying any degree of interelement continuity.

[2] Leaf springs have a numbering system which is separate from those assigned to other elements. This numbering begins with one and then proceeds in sequence.

[3] Since two joint numbers must appear on this card, it can be put anywhere in the element data block.

[4] Flexibility data is interpretated as influence coefficients for forces and moments as illustrated in Figure 13, on the next page. Note that the flexibility data is defined relative to the element local coordinates (as defined in Table 16, footnote 2). (At most, this axis direction only effects the sign of A_{12}.)

[5] When leaf spring behavior involves strain energy equal or greater than this limit, a warning message is printed. An extremely large limit inhibits the warning.
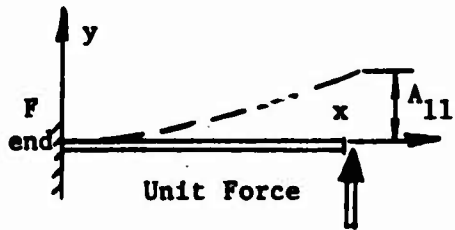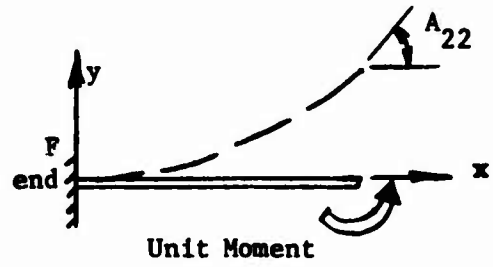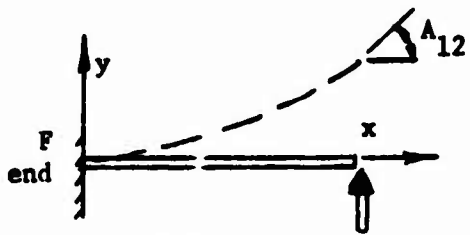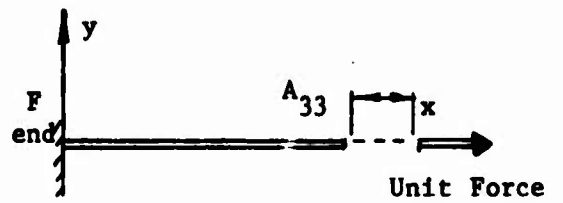
Figure 13. Leaf Spring Flexibility Data

Table 13

POINT MASS DATA BLOCK[1]

Card	Cols.	Format	Item
1 /R	1-80	20A4	Block title (to lead Point Mass Data Block)
One card for each concentrated mass (minimum none)	1-5	I5	Joint number
	6-10	5X	Not read
	11-40	3E10.0	M_x = mass parameter for motion in the x-direction, lb.s.^{2}/in.,or kg.
			M_y = mass parameter for motion in the y-direction, lb.s.^{2}/in., or kg.
			I_z = mass moment of inertia for rotation about z-axis,lb.s^{2}in. or kg.m^2.
Last /R	1-5	I5, 5X 3E10.0	All zeros or blanks (ends data block)

[1]The program generates lumped masses due to element weight when the material density is non-zero, except for leaf spring elements. If their mass is to be represented, it is introduced as point mass data.

Table 14

INITIAL CONDITION DATA BLOCK[1,2]

Card	Cols.	Format	Item
1/R	1-80	A	Block title (to lead Initial Condition Data Block)
Cards 2 through next to last	1-5	I5	Joint number
	6-10	A1,4X	Type of initial condition D,d* = displacement[3], in. or m. V = velocity, in/sec or m/s A = acceleration in./sec^2 or m/sec^2 J = jerk in/sec^3 or m/sec^3 F = force[4,5] lb or N.
	11-20	E10.0	x-direction component
	21-30	E10.0	y-direction component
	31-40	E10.0	z-axis rotation component
Last/R	1-5	I5,A1, 4X, 3E10.0	All zeros or blanks (ends data block)

[1] If no initial conditions are specified, (Cards 2 through next to last are omitted), a static analysis is performed.

[2] Initial conditions for all degrees of freedom at joint are either "given" or "unspecified". They are "given" by including an initial condition card for the joint. Conditions for all degrees of freedom at the joint are taken from the card. They are implied to be "unspecified" if no initial condition card references the joint.

[3] A one g gravitational acceleration is assumed to act in the negative y direction. This induces inertia forces for all structural material with a non-zero density in the material table.

[4] When initial displacements or forces are given, SINGER does a time zero static analysis. For initial displacements, this produces associated initial stresses. For initial forces, this yields an initial state of displacement. When the integration starts, these forces are removed. (The option of giving initial forces relieves the user of calculating an initial displacement state).

[5] If more than one set of forces are given for a particular joint, forces are accumulated to develop a set of total joint forces.

Table 15

FUNCTION TABLE DATA BLOCK[1]

Card	Cols.	Format	Item
1/R	1-80	20A4	Block title (to lead Function Table Data print-out)
2/R	1-5	I4,1X	Function number[2]
	6-10	5X	Ignored
	11-70	6E10.0	t_1, F_1; t_2, F_2; ... function coordinates[3]
3/R	1-5	I5	Function number[2]
	6-10	5X	Ignored
	11-70	6E10.0	...; t_n, F_n function coordinates[3]
Last /R	1-5	I4,6X 6E10.0	All zeros or blanks (ends data block)

[1] The function tables define reference functions for describing time or load step variations of joint forcing functions.

[2] The functions must be numbered sequentially beginning at one; no number may be skipped or omitted; the total number of functions equals the largest function number. The function data cards must be ordered sequentially by function number

[3]Each function is defined by straight-line segments connecting prescribed points, as shown in Figure 14. There is no explicit limit on the number of points.

(There is an implicit limit on the number of points. The function tables data is stored dynamically in data arrays along with other program data. When the array size is exceeded an error message is printed.)

The function must be single-valued in time or load step; "backwards" slopes are not permitted. For vertical slopes, the average value of the two end points is used.
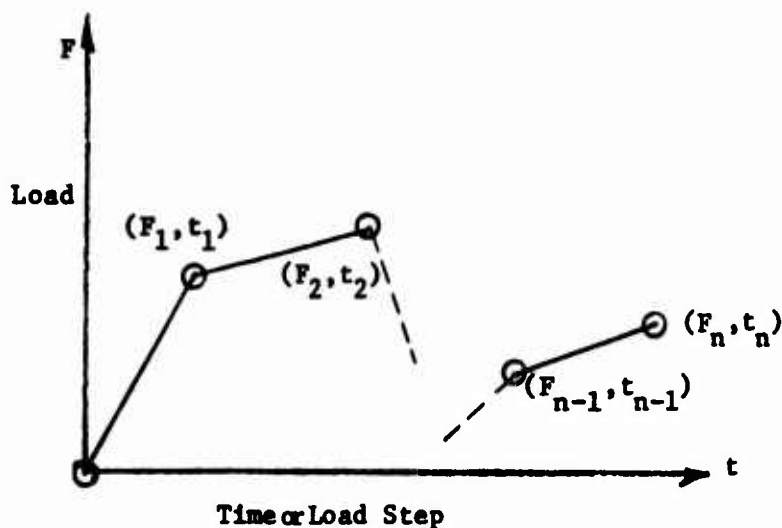
Figure 14. Function Form

Table 16

FORCING FUNCTION DATA BLOCK[1]

Card	Cols.	Format	Item
1 /R	1-80	20A4	Block title (to lead Forcing Function Data Block)
	1-5	I5	Joint number loaded joint[2],p
	6-10	I5	Joint number of reference joint[2], Q
	11-15	A1,4X	P,d* = distributed loading intensity at point p (normal to element axis),lb/in$_2$ or N /M
			X = x-direction concentrated force$_2$, lbs or N
			Y = y-direction concentrated force$_2$, lbs or N
			Z = z-direction concentrated moment, lbs or N
each force	16-19	I4	Referenced function number
component	20	A1	K,d* = constant function of magnitude LA
			S = sinusoidal function
			C = cosinusoidal function
	21-60	4E10.0	SF, LA, TA, TP[3]
			SF = scale factor (d* = 1.0)
			LA = load addition constant, lbs or N.
			TA = time addition constant, s.
			TP = time period for sinusoidal or cosinusoidal functions (not used otherwise), s.
Last /R	1-5	2I5, A1,4X, I4,A1,4E10.0	All zeros or blanks (ends data block)

[1] The joint forcing function data defines time or load-step varying forcing functions applied at the joints or on elements.

[2] When a concentrated load is desired, only the loaded joint number is needed, so the reference joint number is ignored. Specification of the reference joint number indicates a linearily distributed load is involved with the magnitude of the pressure, per unit length, specified for the loaded joint P and varying linearily to a zero value at the reference joint Q. This pressure is assumed to act normal to the element reference axis. A positive pressure is outward to the left when proceeding from P to Q. The relation of this direction to the P-Q element ends and the global axis is illustrated in Figure 15.
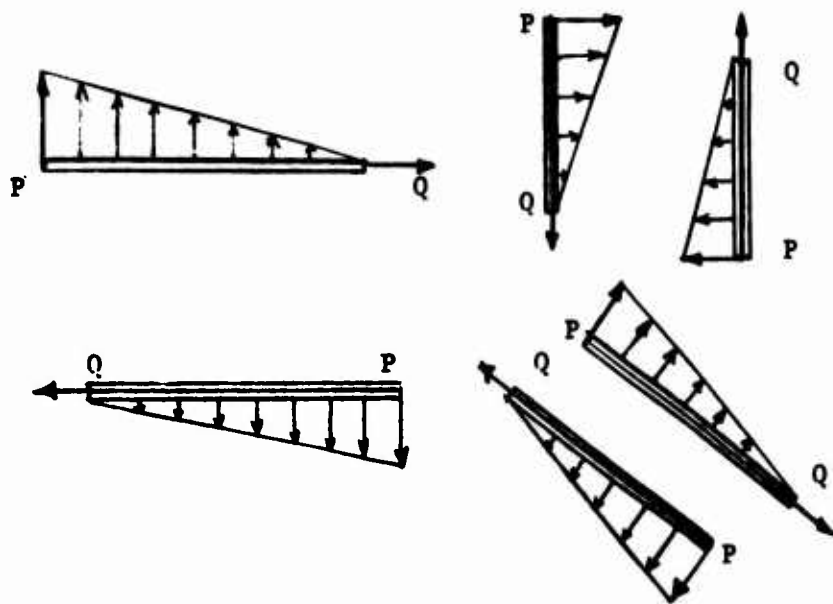
Figure 15. Positive Direction of Distributed Pressure
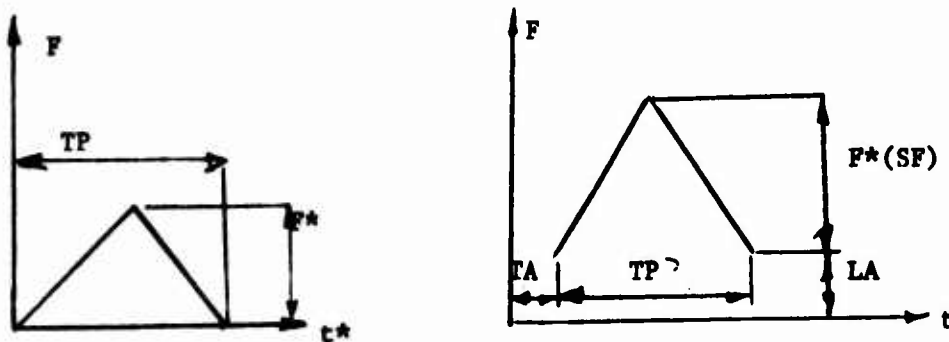
Figure 16. Function Scaling Parameters

[3] The time variation is described by a reference function as suggested by Figure 16. The reference function obtained from the function tables, may be scaled by a multiplication factor (SF) ,shifted in magnitude by an addition factor (LA), or shifted in time by a time factor (TA). Multiple forcing functions at a joint are superimposed.

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2.3 IMPLICIT MODELING FEATURES

SINGER contains special logic corresponding to three of the input blocks. This logic makes implicit in the input specifications the ability for refining the finite element model, introducing joint eccentricities at connections, and/or representing linearly varying pressure loadings only by adding to the input data. The next paragraphs clarify how the user can prepare input to exploit these features of the input specification.

2.3.1 Addition of Interior Joints

The input specification provides for a complete description of the structural configuration. Occasionally, however, it is necessary to represent the system with a more refined mathematical model. This may be prompted by SINGER output or the user's desire for greater accuracy, for example. This is accomplished by adding interior joints to the joint data block.

An interior joint is a joint that is on the axes of an element between the F and S terminating joints. In input data, it is indistinquishable from other joints in the input data block. It is detected by discovering that the joint lies on a line between a pair of element joints.

When an interior joint is detected, it causes replacement of the pertinent element data by data for two elements with the same aggregate span and characteristics. Once this has been done, the interior joint loses its identity. Because of this, the interior joint logic has no limit on the number of interior joints the user may require between any two joints of the configuration descriptive data.

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Loss of the identity of interior joints also means that output does not make this distinction. Joint displacements for interior joints appear with the interior joint number. Element behavior is specified for both parts of a subdivided element just as if the user had prepared the input in the form of two separate sets of element data.

Note that an interior joint is only effective in generating additional element data and associated printouts. It does not change the mass or joint loading data, even for distributed loads. If it is necessary to refine the materials, mass or loading, the user must revise the input data.

2.3.2 Joint Eccentricities

The ability to represent joint eccentricities is implicit in the input specifications for element data. Eccentricities are defined using leaf spring input.

For example, suppose it is desirable to model an eccentric connection between two elements: one with F and S joints 1, 2; the other with joint 3, 4. Then, if the eccentric connection is between joints 2 and 3, a leaf spring with zero flexibility coefficients is added to the input. If the eccentricity does not exist, of course, joint 2 and 3 would be assigned the same joint number by the analyst.

Note that, unlike linear analysis simulators, the representation of eccentricities is not "exact". Accordingly, output describing response will imply as much flexibility in the leaf spring as the user permits by his specification of tolerance on energy error in the Control Data Block Input Data.

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2.3.3 Linearly Varying Pressure Loadings

A uniformly distributed load is represented as the superposition of two distributed loads in the Forcing Function Data Block. The two loads must involve the same joint pairs for the loaded and reference joint.

Suppose, for example, element 1-2 is loaded with a uniform pressure of intensity q. One joint loading card would indicate joint 1 as the loaded joint and 2 as the reference. The load intensity would be q. The other joint loading card would involve joint 2 as the loaded joint an 1 as the reference. In this case, because the loading is outward to the right going from the loaded joint to the reference joint, the load intensity would be -q.

As illustrated in Figure 17, the superposition of these two loadings represents the uniformly distributed load.

The superposition permits representing any linearlily varying load between two joints. A given linearly distributed load can be fractionated into as many superimposable components as desirable.

Note that the distributed loading is not represented exactly in the mathematical model, just as the distributed mass of the structure is approximated. Exact representation would require evaluating equilvalent joints loads for each deformation state. Accordingly, SINGER logic may caution the user to introduce interior joints or improve the joint loading input resolution for a more accurate simulation.
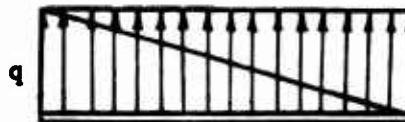
Figure 17. Superposition of Distributed Loadings

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SECTION 3

OUTPUT DATA

Output data includes both printed data and data stored on peripheral storage units. Printed results define the time history of the structural configuration changes and data transferred to retrieval files on peripheral storage units facilitates plotting structural behavior and restarting the analysis. This section describes and illustrates the form and interpretation of this output.

3.1 PRINTED OUTPUT

Printer output consists of a definition of the problem statement, available after all input has been read and checked; data describing the state of the system, printed upon completion of calculations for each time period; and diagnostic messages, printed when anomalies arise during the simulation.

The amount of printed output depends on the options elected and specified in the Control Data Block. The amount depends on the print-out increment level and the dimensional units involved in input and output.

Table 17 lists the increments of printed output for each level selected and for each group of output. For a given level of output, all data at that and all lower levels is printed. Thus, as the table shows, at the detailed option level, input data printouts include the table of the input data for each input data block as well as the summary description of the problem under study.

When the dimensional units for input and output are mixed (i.e. one is in English units and the other is System International units) the amount of

Table 17

PRINTOUT INCREMENTS FOR EACH OPTION LEVEL

Option Level	Input Data Increment	State Data* Increment	Message Increment
1. Minimum	Problem description summary	Joint response Element energies Accuracy summary	Fatal and critical messages
2. Standard	Input tables of Block Data	Solution progress summary	–
3. Detailed	–	Unbalanced joint forces and energies	Potentially critical messages
4. Extensive	–	Detailed solution search progress	–

*Element internal forces and/or stresses and strains are printed if required by the ISTRES flag of Block 1 input data, regardless of the printout option level.

printed output is increased. The mix incites printing of the input

data in both sets of units to provide a copy of input data in the

same dimensional units as the output.

Each page of printed output has a heading, subtitling and problem

data or comments. The page heading consists of a centered copy of the

first card of input from Control Data Block and the page number. Titling

designates the group of output. The problem data includes tabulated

numbers, and names with column labels defining dimensional units, and

relevant diagnostic messages.

There are a maximum of 120 characters per line of printout. Type-

written notes do not appear on the computer printout but have been added

to provide a self-contained interpretation of page data.

Actual SINGER printouts may differ from these tables because the ones

given here were produced by the original version of the code on the IBM 370.

This version prints a maximum of 66 lines per page, uses the EBCDIC

character set, and prints from double-precision floating point data.

3.1.1 Printed Input Data

Printed input consists of seven groups of pages; one group corresponding

to each of the last seven input blocks. An eighth group of pages defines

the finite element analysis articulation. The last group of pages of

input printouts provides a summarizing description of the structural

configuration under study.

The example problem of Figure 18 is used to describe the nature of

the printed input data developed by SINGER. Tables 18 through 24 illustrate

the listings which correspond to the last seven input blocks. These data

completely describe the structural configuration - geometry, materials,

and boundary conditions.
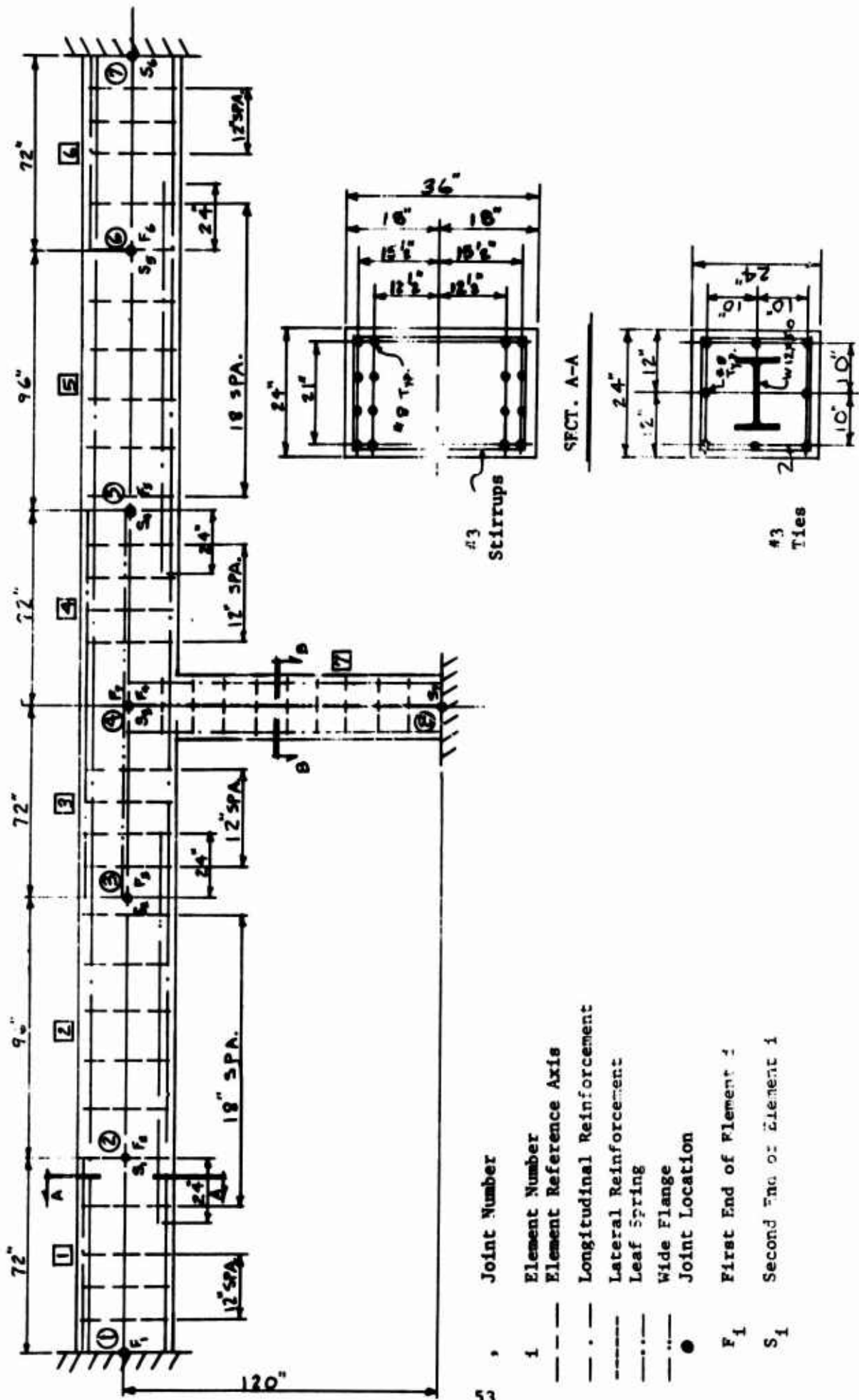
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Figure 18. Reinforced Concrete Frame Example

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Table 18. Joint Coordinate Data

KIRTLAND TEST PROBLEM

JOINT COORDINATE DATA BLOCK

JOINT COORDINATES AND RESTRAINTS

JOINT NO.	X-COORDINATE IN.	Y-COORDINATE IN.	X-DISPLACEMENT	Y-DISPLACEMENT	Z-ROTATION
1	0.0	0.0	0	0	0
2	0.72000D 02	0.0	1	2	3
3	0.168000D 03	0.0	4	5	6
4	0.24000D 03	0.0	7	8	9
5	0.31200D 03	0.0	10	11	12
6	0.40800D 03	0.0	13	14	15
7	0.48000D 03	0.0	0	0	0
8	0.24000D 03	-0.12000D 03	0	0	0
9	0.36000D 02	0.0	16	17	18

0 identifies an omitted degree of freedom

≠0 defines the number of the degree of freedom

input of interior joint
activated bisection of
detailed element 1-2.

MATERIAL PROPERTIES DATA BLOCK

MATERIAL CONSTANTS

MATERIAL   WEST   REINFORCING STEEL
YIELD STRENGTH   0.3600000D 05   LB/IN.**2
YOUNGS MODULUS   0.2880000D 08   LB/IN.**2
POISSON'S RATIO   0.3000000D 00
ELASTIC SHEAR MODULUS   0.1200000D 08   LB/IN.**2
MATERIAL DENSITY   0.0   LB/IN.**3
UNLOADING CURVE CONSTANTS   2.910000D 04   1.010000D-03
STRESS-STRAIN CURVE POINTS-
  STRESS (LB/IN.**2)   0.0   3.60000D 04   3.50000D 04   5.20000D 04   5.80000D 04   6.00000D 04   5.9000   04
  STRAIN (IN./IN.)   0.0   1.25000D-03   1.40000D-02   5.90000D-02   1.04000D-01   1.50000D-01   2.0000   -01

MATERIAL   CONU   UNCONFINED CONCRETE
CRUSHING STRENGTH   0.4200000D 04   LB/IN.**2
YOUNGS MODULUS   0.3583618D 08   LB/IN.**2
POISSON'S RATIO   0.2000000D 00
ELASTIC SHEAR MODULUS   0.1493174D 08   LB/IN.**2
MATERIAL DENSITY   0.0   LB/IN.**3
UNLOADING CURVE CONSTANTS   2.500000D-01   0.0
STRESS-STRAIN CURVE POINTS-
  STRESS (LB/IN.**2) -2.10000D 04 -3.57000D 03 -4.20000D 03 -2.10000D 03 -1.47000D 03 -8.4000   02
  STRAIN (IN./IN.)   -5.86000D-04 -1.22500D-03 -2.00000D-03 -3.56250D-03 -3.87500D-03 -4.1875   -03

MATERIAL   CONC   CONFINED CONCRETE
CRUSHING STRENGTH   0.4200000D 04   LB/IN.**2
YOUNGS MODULUS   0.3602058D 07   LB/IN.**2
POISSON'S RATIO   0.2000000D 00
ELASTIC SHEAR MODULUS   0.1500858D 07   LB/IN.**2
MATERIAL DENSITY   0.0   LB/IN.**3
UNLOADING CURVE CONSTANTS   2.500000D-01   0.0
STRESS-STRAIN CURVE POINTS-
  STRESS (LB/IN.**2) -2.10000D 03 -3.57000D 03 -4.20000D 03 -8.40000D 02
  STRAIN (IN./IN.)   -5.83000D-04 -1.27500D-03 -2.00000D-03 $$ -1.0000   00
                                                        $$ $$ **THESE VALUES DEPEND ON STIRRUP SPACING.

MATERIAL   REST   REINFORCING STEEL
YIELD STRENGTH   0.6000000D 05   LB/IN.**2
YOUNGS MODULUS   0.2884615D 08   LB/IN.**2
POISSON'S RATIO   0.3000000D 00
ELASTIC SHEAR MODULUS   0.1200000D 08   LB/IN.**2
MATERIAL DENSITY   0.0   LB/IN.**3
UNLOADING CURVE CONSTANTS   5.420000D 04   1.87000000D-03
STRESS-STRAIN CURVE POINTS-
  STRESS (LB/IN.**2)   0.0   6.00000D 04   6.00000D 04   9.00000D 04   1.03000D 05   1.05000D 05   1.30000D 05
  STRAIN (IN./IN.)   0.0   1.87000D-03   3.00000D-03   5.00000D-02   8.70000D-02   1.36000D-01

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Table 20 Element Data

KIRTLAND TEST PROBLEM

PAGE 3

ELEMENT DATA BLOCK

ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 1- 2.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 2- 3.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 3- 4.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 4- 5.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 5- 6.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 6- 7.
ACI 318-71 BOND CHECK WAS MADE FOR ELEMENT 4- 8.
} all elements are listed for which the bond check was made.

USING CRITERION OF 10.7, ACI 318-71, ELEMENT 1- 2 IS A DEEP BEAM(BEAM).**
USING CRITERION OF 10.7, ACI 318-71, ELEMENT 3- 4 IS A DEEP BEAM(BEAM).**
USING CRITERION OF 10.7, ACI 318-71, ELEMENT 4- 5 IS A DEEP BEAM(BEAM).**
USING CRITERION OF 10.7, ACI 318-71, ELEMENT 6- 7 IS A DEEP BEAM(BEAM).**
} This check can be ignored if element is a subdivision of a member whose depth to overall length ratio is less than 0.4.

ELEMENT CONTROL VARIABLES

ELEMENT	JOINTS	ELEMENT TYPE	CONCPETES	BEHAVIOR	SHEAR
1	1- 2	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
2	2- 3	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
3	3- 4	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
4	4- 5	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
5	5- 6	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
6	6- 7	R/C-STIRRUPS	CONU CONC	CHANGES	IGNORE
7	4- 8	WF IN R/C	CONU CONC	CHANGES	IGNORE

IGNORE = check shear deformations and continue
STOP = stop caculations if shear effects significant

ELASTIC = single slope for stress-strain curve
CHANGES = slope may change with strain
INELAS = slope changes with strain
Name of unconstrained and constrained concrete for the element.

R/C - STIRRUPS = reinforced concrete with stirrups
R/C - TIED = reinforced concrete (colum) with ties
WF IN R/C = wide flange beam embedded in concrete
WF BEAM = wide flange beam, no concrete
LEAF SPRING = leaf spring element

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Table 2Q (cont'd)

KIRTLAND TEST PROBLEM

BASIC ELEMENT CROSS DIMENSIONS

ELEMENT NUMBER	JOINT NUMBERS	JOINT SPAN AT 1ST JOINT, IN.	JOINT SPAN AT 2ND JOINT, IN.	EFFECTIVE LENGTH,IN.	SECTION WIDTH, IN.	SECTION HEIGHT, IN.	CONFINED DEPTH, IN.	CONFINED WIDTH, IN.
1	1- 2	0.0	0.0	7.200000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
2	2- 3	0.0	0.0	9.600000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
3	3- 4	0.0	1.200000 01	6.000000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
4	4- 5	1.200000 01	0.0	6.000000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
5	5- 6	0.0	0.0	9.600000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
6	6- 7	0.0	0.0	7.200000 01	2.400000 01	3.600000 01	3.200000 01	2.2000 01
7	6- 8	0.0	0.0	1.200000 02	2.400000 01	2.400000 01	2.200000 01	2.2000 01

KIRTLAND TEST PROBLEM

ELEMENT CROSS SECTION DATA

ELEMENT NUMBER	JOINT NUMBERS	DEPTH- TOP TO LOWER REBAR,IN.	DEPTH- TOP TO UPPER REBAR,IN.	DEPTH- TOP TO REF. AXIS, IN.
1	1- 2	3.100000 01	5.000000 00	1.800000 01
2	2- 3	3.100000 01	5.000000 00	1.800000 01
3	3- 4	3.100000 01	5.000000 00	1.800000 01
4	4- 5	3.100000 01	5.000000 00	1.800000 01
5	5- 6	3.100000 01	5.000000 00	1.800000 01
6	6- 7	3.100000 01	5.000000 00	1.800000 01
7	6- 8	2.700000 01	2.000000 00	1.700000 01

Table 20. (cont'd)

KIRTLAND TEST PROBLEM

LONGITUDINAL REINFORCEMENT GROUPS

BASE ELEMENT	JOINT NUMBERS	GROUP NUMBER	SPAN-1ST JOINT TO REBAR, IN.	SPAN-REBAR TO 2ND JOINT, IN.	EFFECTIVE REBAR SPAN, IN.	REBAR AREA, IN.**2	DEPTH-REBAR TO CENTROID, IN.	MAT'L
1	1- 2	1	0.0	3.10000D 01	4.100000 01	3.141590 00	1.550000 01	REST
1	1- 2	2	0.0	0.0	7.200000 01	3.141590 00	1.250000 01	REST
1	1- 2	3	7.00000D 01	0.0	-7.000000 01	3.141590 00	-1.250000 01	REST
1	1- 2	4	0.0	0.0	7.200000 01	3.141590 00	-1.550000 01	REST
2	2- 3	1	0.0	0.0	9.500000 01	3.141590 00	1.250000 01	REST
2	2- 3	2	0.0	0.0	9.600000 01	3.141590 00	-1.250000 01	REST
2	2- 3	3	0.0	0.0	9.600000 01	3.141590 00	-1.550000 01	REST
3	3- 4	1	3.10000D 01	0.0	4.100000 01	3.141590 00	1.550000 01	REST
3	3- 4	2	0.0	0.0	7.200000 01	3.141590 00	1.250000 01	REST
3	3- 4	3	0.0	6.70000D 01	5.000000 00	3.141590 00	-1.250000 01	REST
3	3- 4	4	0.0	0.0	7.200000 01	3.141590 00	-1.550000 01	REST
4	4- 5	1	0.0	3.10000D 01	4.100000 01	3.141590 00	-1.250000 01	REST
4	4- 5	2	6.70000D 01	0.0	5.000000 00	3.141590 00	-1.550000 01	REST
4	4- 5	3	0.0	0.0	7.200000 01	3.141590 00	-1.250000 01	REST
4	4- 5	4	0.0	0.0	9.600000 01	3.141590 00	-1.250000 01	REST
5	5- 6	1	0.0	0.0	9.500000 01	3.141590 00	-1.550000 01	REST
5	5- 6	2	0.0	0.0	9.600000 01	3.141590 00	-1.550000 01	REST
5	5- 6	3	0.0	0.0	4.100000 01	3.141590 00	1.550000 01	REST
6	6- 7	1	0.0	0.0	7.200000 01	3.141590 00	1.250000 01	REST
6	6- 7	2	0.0	7.90000D 01	-7.000000 00	3.141590 00	-1.250000 01	REST
6	6- 7	3	0.0	0.0	7.200000 01	3.141590 00	-1.550000 01	REST
7	4- 8	1	7.10000D 01	0.0	1.200000 02	2.356190 00	1.000000 01	REST
7	4- 8	2	0.0	0.0	1.200000 02	1.570800-01	0.0	REST
7	4- 8	3	0.0	0.0	1.200000 02	2.356190 00	-1.000000 10	REST

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Table 20. (cont'd)

KIRTLAND TEST PROBLEM

LATERAL REINFORCEMENT GROUPS

BASE ELEMENT	JOINT NUMBERS	GROUP NUMBER	REBAR TYPE	MAT'L NAME	REBAR AREA,IN.**2	SPACING OF REBARS, IN.	NO. OF SPACES	START OF GROUP, IN.	YIELD STRESS LB/IN.**2	CONFINEMENT FACTOR 'PDP'
1	1- 2	1	STIRRUPS	REST	4.41786D-01	1.20000D 01	3	6.00000 00	6.00000D 04	3.52606D-03
1	1- 2	2	STIRRUPS	REST	4.41786D-01	1.80000D 01	2	4.50000 01	6.00000D 04	1.91934D-03
2	2- 3	1	STIRRUPS	REST	4.41786D-01	1.80000D 01	6	9.00000 00	6.00000D 04	1.91934D-03
3	3- 4	1	STIRRUPS	REST	4.41786D-01	1.20000D 01	4	5.00000 00	6.00000D 04	3.52606D-03
4	4- 5	1	STIRRUPS	REST	4.41786D-01	1.20000D 01	4	6.00000 00	6.00000D 04	3.52606D-03
5	5- 6	1	STIRRUPS	REST	4.41786D-01	1.80000D 01	5	-3.00000 00	6.00000D 04	1.91934D-03
6	6- 7	1	STIRRUPS	REST	4.41786D-01	1.80000D 01	1	9.00000 00	6.00000D 04	1.91934D-03
6	6- 7	2	STIRRUPS	REST	4.41786D-01	1.20000D 01	3	3.00000 01	6.00000D 04	3.52606D-03
7	1- 2	1	TIES	REST	2.20893D-01	1.20000D 01	9	6.00000 00	6.00000D 04	2.26584D-03

$$p''\sqrt{b''/s}$$

KIRTLAND TEST PROBLEM

WIDE FLANGE DIMENSIONS FOR COMPOSITE ELEMENTS

BASE ELEMENT	JOINT NUMBERS	THICKNESS, FLANGE,IN.	WIDTH OF FLANGE,IN.	THICKNESS OF WEB, IN.	DEPTH OF BEAM, IN.
7	4- 8	6.41000D-01	8.07700D 00	3.71000D-01	1.21900D 01

KIRTLAND TEST PROBLEM

LEAF SPRING ELEMENT PARAMETERS

LEAF SPRING	JOINT NUMBERS	DISPL. OF TIP FORCE, LB/IN.	ROTATION OF TIP FORCE, LB/IN.	ROTATION OF TIP MOMENT,IN.*LB/RAD	ELONGATION OF AXIS FORCE,LB/IN.	STORABLE ENERGY LIMIT,IN.-LB
1	3- 5	1.02041D 05	-2.04082D 04	2.04082D 05	1.00000D 07	1.00000D 32

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Table 21. Lumped Mass Data

KIRTLAND TEST PROBLEM

POINT MASS DATA BLOCK

LUMPED MASSES AS READ FROM CARDS
PLUS MEMBER MASSES LUMPED AT JOINTS

JOINT	MASS FOR X-DIRECTION (LB*S**2/IN.)	MASS FOR Y-DIRECTION (LB*S**2/IN.)	MASS MOMENT OF INERTIA (LB*S**2*IN.)
1	1.26000 01	1.26000 01	0.0
2	4.20000 00	4.20000 00	0.0
4	0.0	0.0	1.46000 00

Table 22. Initial Condition Data

INITIAL CONDITION DATA REPORT

INITIAL CONDITION DATA

JOINT	CONDITION TYPE	X COMPONENT	UNITS	Y COMPONENT	UNITS	Z COMPONENT	UNITS
1	DISPLACEMENT	0.0	IN.	0.0	IN.	3.600000 06	CM
2	LOAD	-1.500000 03	LB	-1.000000 06	LB	0.0	LB–IN.
3	VELOCITY	0.0	IN./S	-1.000000 04	IN./S	0.0	RAD/S
4	ACCELERATION	0.0	IN./S**2	0.0	IN./S**2	-3.500000 04	RAD/S**2

Dimensional units based on user's specification

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Table 23. Function Table Data

KIRTLAND TEST PROBLEM

FUNCTION TABLE DATA BLOCK

FUNCTION TABLES

FUNCTION TABLE NO. 1 — NUMBER OF POINTS 6

TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)
1.00000D-01	1.000000 02	2.00000D-01	3.000000 02	3.00000D-01	4.000000 02
4.00000D-01	4.500000 02	5.00000D-01	4.000000 02	5.00000D-01	3.000000 02

FUNCTION TABLE NO. 2 — NUMBER OF POINTS 5

TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)
5.00000D-02	-1.00000D 03	1.00000D-01	-5.00000D 02	1.50000D-01	-2.00000D 02
2.00000D-01	0.0	2.50000D-01	5.00000D 02		

FUNCTION TABLE NO. 3 — NUMBER OF POINTS 3

TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)	TIME (S)	FORCE (LB)
1.00000D 00	0.0	2.000000 00	1.000000 04	3.00000D 00	0.0

Table 24. Joint Forcing Function Data

KIRTLAND TEST PROBLEM

JOINT FORCING FUNCTION DATA BLOCK

JOINT FORCING FUNCTION DATA

JOINT LOADED	REFERENCE JOINT	LOAD (LB) DIRECTION	FUNCTION NUMBER	SCALE FACTOR	LOAD (LB) ADDITION	TIME (S) ADDITION	TIME (S) PERIOD
1	0	Y	1	6.00000D 00	0.0	1.00000D-01	0.0
1	0	Z	3	1.00000D 00	0.0	0.0	0.0
2	0	X	COS	1.00000D 00	5.00000D 02	0.0	5.00000D 00
3	0	X	SINE	1.00000D 00	5.00000D-01	6.00000D-01	4.30000D-01
4	2	NORM	2	6.00000D-01	0.0	5.55000D-01	0.0

The subtitling for each group contains the block title prepared by the user and included as the first card in the input block. This title is reproduced just as it appears on the input card. It is printed, left justified. (If the user wants this title centered, he must center it about column 60 on the card input).

Subtitling also includes the labels which lead each column of tabular data. These labels specify the dimensional units prescribed by the user in the Control Data Block.

If more than one page is required for an output group, the second and subsequent pages start with the page heading and column labels. The title is not repeated. This policy is common to all groups of pages of printed data.

Table 25 represents the group of printed output which lists all elements of the finite element models. This list differs from the printout of input blocks by including elements created by interior joints. If an element has been formed because of a subdivision it is identified as "BISECTED" and its properties are obtained from the detailed data given previously for the parent element. If an element is not subdivided it is identified as "DETAILED". This table also indicates the type of element (reinforced concrete or wide flange), its gross length, and material name.

Table 26 indicates the nature of the summary description for a problem. This data defines the interpretation of input options. The table also indicates additons to the number of degrees of freedom of the analysis because of the characteristics of the elements. The analyst need only be aware of them insofar as they cause reductions in the storage space available for data of the mathematical model. In general, one degree of freedom is

Table 25. Element Summary Data

KIRTLAND TEST PROBLEM

SUMMARY DATA FOR FINITE ELEMENTS USED IN SIMULATION

ELEMENT	JOINTS	KIND	TYPE	LENGTH	MATERIAL
1	1- 9	BISECTED	R/C	0.36000000D 02	CONU
2	2- 3	DETAILED	R/C	0.96000000D 02	CONU
3	3- 4	DETAILED	R/C	0.72000000D 02	CONU
4	4- 5	DETAILED	R/C	0.72000000D 02	CONU
5	5- 6	DETAILED	R/C	0.96000000D 02	CONU
6	6- 7	DETAILED	R/C	0.72000000D 02	CONU
7	4- 8	DETAILED	R/C	0.12000000D 03	CONU
8	9- 2	BISECTED	R/C	0.36000000D 02	CONU

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Table 26. Summary Description of Problem

KIRTLAND TEST PROBLEM   Page 15

CHARACTERISTICS OF THE SIMULATION

ITEM CLASS   ITEM DESCRIPTION
----------   ----------------

PARAMETERS   6 JOINTS
OF THE   9 ELEMENTS
STRUCTURE   4 MATERIALS
                    5 POINT MASSES

KINEMATIC   25 DEGREES OF FREEDOM (TOTAL)
                    8 ELEMENT DEGREES OF FREEDOM
CONDITIONS   0 LEAF SPRING RIGIDITY CONSTRAINTS
                    9 DISPLACEMENTS PRESCRIBED AS ZERO

FORCE   5 JOINT LOADING CONDITIONS
                    1 DISTRIBUTED LOADINGS
CONDITIONS   3 FUNCTION TABLES

INITIAL   1 JOINTS WITH DISPLACEMENTS GIVEN
                    1 JOINTS WITH VELOCITIES GIVEN
CONDITION   1 JOINTS WITH ACCELERATIONS GIVEN
                    0 JOINTS WITH JERKS GIVEN
DA--   4 JOINTS WITH POINT FORCES GIVEN

ASSUMPTIONS   TIME-HISTORY STARTS AT   0.0   SECONDS.
                    IT STOPS AT   3.0000 00 SECONDS.
                    MAXIMUM TOLERABLE RELATIVE ENERGY ERROR IS   1.0000D-06.
OF THE   THE MAXIMUM COMPUTER RUN TIME FOR THIS CASE IS   1.5000 01 MINUTES.
                    INPUT IS IN ENGLISH UNITS. OUTPUT IS IN ENGLISH TOO.
                    JOINT ROTATIONS ARE ASSUMED FINITE. ELEMF DISTORTIONS INFINITESIMAL.
SIMULATION   CALCULATIONS ARE STOPPED ON POTENTIALLY FATAL AND FATAL ERRORS.
                    SHEAR MACRO FAILURE IS DEFINED BY CA= 1.0000 00, CB= 2.0000C 00.
                    CC= 3.5000D 00 CD=   0.0   , AND CE= 1.3333D 00 DSSEG-1

OPTIONS   INPUT DATA IS IN PUNCHED CARDS.
                    ALL POINT STATEMENTS CITING RESULTS ARE EXECUTED.
OF THE   PRINTOUTS INCLUDE STRESSES, STRAINS, AND STRESS RESULTANTS.
                    PRINTOUTS OCCUR EVERY 1.0000D-01 SECONDS, OR LESS, OF THE HISTORY.
INPUT & OUTPUT   CONTINUATION DATA IS WRITTEN ON UNIT 11
                    A DATA RETRIEVAL FILE IS WRITTEN ON FILE 10.

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Table 26. (cont'd)

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KIRTLAND TEST PROBLEM

STORAGE STILL AVAILABLE FOR MODELING ⎤ ── based on existing allocation
41 JOINTS   ⎦   of core storage
37 ELEMENTS
5 MATERIALS
65 FREEDOMS

STORAGE LOCATION INDEXES IN DATA ARRAY (ACIN).

MINIMIZATION DATA	0
FUNCTION TABLES	325
FORCING FUNCTIONS	353
PLASTIC STRAIN DATA	373
END OF ARRAY	373
SPACES ALLOCATED	10000

STORAGE LOCATION INDEXES IN KDATA ARRAY (ACIN).

FUNCTION TABLES	0
FORCING FUNCTIONS	6
PLASTIC STRAIN DATA	31
STRESS HISTORY DATA	39
END OF ARRAY	47
SPACES ALLOCATED	500

added for each frame element. The frame element freedom provides for an improved deformation model, as described in the technical document.

The self-explanatory descriptive summary of Table 26 is the last printout of problem descriptive data. It will be the last SINGER printed output whenever there are fatal or critical errors in the input data. If there are no errors the response data described in the next section is printed.

3.1.2 Printed Response Data

These data describe the state of the structure at particular points in time. They include groups of pages which establish the state of joint deflection, which identify the internal state of the finite elements, summarize the status of the system, and describe solution progress and accuracy. The amount of data printed in each group varies with the printout level selected by the user.

The minimum number of load steps or time points at which printouts are made is controlled by the user's Block 1 input data. The maximum number depends on the time interval used in numerical integration. In general, the state data is printed at time points selected to attain the user's specified relative accuracy.

Groups of printouts occur for each load step or time step. Table 27 lists the types of print tables that may be provided in the order in which they are printed out in each printout group. Table numbers are those of this report. The same tables are printed regardless of whether the analysis is static or dynamic.

Table 28 illustrates printout of the search progress. This printout illustrates the detailed level. It includes values of scaled variables at the beginning and end of each "linear minimization" - a

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Table 27

TABLES IN A PRINTOUT GROUP

Table No.	Table Title	Table Contents
28	MINIMIZATION PERFORMANCE	Values of the work function and supporting data developed during solution search.
30	JOINT STATUS	Components of joint displacements for all joints.
31	INTERNAL ENERGY	Data defining the distribution of stored and dissipated energy among elements of the structure.
32,34	AVERAGE STRESSES	Data defining the stress state in elements of the structure.
33,35	SOLUTION ACCURACY	Data defining errors in conservation of energy and satisfaction of equilibrium.

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Table 28. Minimization Performance

PLASTIC BEAM - CANTILEVERED WITH A VERTICAL LOAD ON THE FREE END. 6 ELEMENTS.

SOLUTION FOR LOAD STEP 2.00000D 00
MINIMIZATION PERFORMANCE

INITIAL POINT
FUNCTION VALUE
-9.68249170D-07

VARIABLES

-2.04559956D-06	1.76438153D-03	3.42497739D-03	-1.41950473BD-05	5.64234326D-03
6.22720160BD-03	-4.14061614D-05	1.41011121693D-02	8.40670026BD-03	-8.39832280D-05
2.32479248D-02	9.63476043D-03	-1.34740576550-03	3.37301816D-02	1.08975375D-02
-2.00166491D-04	4.48306725D-02	1.12094935TD-02	-2.76298215D-07	1.05220372360-07
-5.11166091D-08	2.69677699D-08	8.20485222D-08	1.16126708D-07	

LINEAR MINIMIZATION   1
GRADIENTS.

-1.21238748D-11	-6.05931892D-13	9.80283869D-14	1.65662815D-11	-4.20816997D-12
-1.01435310BD-12	1.19591498BD-12	3.28689079D-12	1.17220864D-12	-1.10674466D-11

· · ·

LINEAR MINIMIZATION   4
GRADIENTS.

2.33402402D-09	2.56416261D-10	-5.42939845D-11	-1.06441927D-09	-4.12291750D-11
1.01875056D-10	-1.37923581D-09	-7.03018570BD-11	5.32223924D-11	-9.14555004D-10
-4.38206434D-11	-6.51318709D-11	-6.48635175D-10	1.40065484D-11	-1.82435938D-11
1.35755478D-09	-7.98900064D-11	4.86618772D-10	9.73808689D-10	3.75401484D-09
1.32618037D-09	1.42353810BD-10	-8.38318097BD-10	-1.41447864D-09	
6.39405512D 00	1.16541692D 00	3.88245817D-01	6.43781601D 00	1.66367333D 00
3.88659283D-01	6.40736561D 00	1.16707655D 00	3.88296628D-01	6.43054116D 00
1.65418102D 00	3.88364301D-01	6.44255491D-01	1.56608517D 00	3.88324285D-01
3.23105940D 00	5.83542725D-01	1.94343627D-01	7.33121162D 00	7.31250327D 00
7.31905471D 00	7.38135974D 00	7.31193005D 00	7.35461939D 00	

FRACTION OF DIRECTION TAKEN

-9.99160041D-07
1.00000000D 00
-9.99160041D-07
1.65500000D 00
* -9.99160041D-07
1.00000000D 00

FUNCTION SUBROUTINE CALLS=   9
GRADIENT SUBROUTINE CALLS=   96
MINIMIZATION ACCURACY
=   0.62033186D-07

FUNCTION VALUE
-9.99160041D-07

VARIABLES

-3.31604304D-06	2.14242745BD-03	4.15882050D-03	-2.03226801D-05	8.75547863D-03
7.56145966D-03	-6.10505391D-05	1.70133741D-02	1.02279312D-02	-1.23827179BD-04
2.82900731D-02	1.20924259D-02	-2.04562674D-03	4.09570223D-02	1.32324372D-02
-2.95130028D-04	5.44410958D-02	1.36104976D-02	-7.07384907D-07	-2.24415165D-07
-7.56750378D-08	3.97638570D-08	1.20978064D-07	1.54277399D-07	

CONVERGENCE OF MINIMIZATION TO SPECIFIED ACCURACY.
NORMAL COMPLETION OF MINIMIZATION.

THERE ARE NO NEWLY YIELDED MEMBERS (TEST).

TOTAL FORCE MEASURES,   ZERO-TIME ERROR=   0.0
                        HALF-TIME ERROR=   0.0
                        FULL-TIME ERROR=   0.14234D-05

one-dimensional search in the direction developed from the current measurement of the gradient and the estimate of the curvatures of the work function space. At the minimum level, this printout is reduced to only values of the work function.

Table 29 provides more complete information on the interpretation of most of the labels used in the printout of Table 28. A special message also indicates the basis for stopping the search. This particular run indicates that the run completion is "NORMAL" - i.e. the minimization accuracy desired has been obtained. Other runs may state "LINEAR MINIMI-ZATION FAILED TO CHANGE THE FUNCTION VALUE" or "THE MAXIMUM NUMBER OF LINEAR MINIMIZATIONS WAS EXCEEDED." The former comment means the work function could not be changed by moving in the last search direction. The latter comment means insufficient minimizations were allowed to develop an adequate solution.

Table 30 represents the printout of joint state data. These data define the state of motion of deflection at all element-connected joints specified by the analyst. This printout is always produced regardless of the print option level. It is always the first response data printed after search completion.

There are three subgroups of pages which comprise printed data of element response. These provide element energy distribution, internal stress -strain data, and/or element internal forces. Energy is activated at the minimum print level. Stress-strain and internal force printouts are activated by the ISTRES flag of Control Block input.

Table 31 illustrates the element energy response printout. The energy data suggest the relative importance of each element to the

Table 29

MINIMIZATION PERFORMANCE DATA

Item	Interpretation
FUNCTION VALUE	Value (unscaled) of the function whose minimum is defined by the equilibrium configuration of the system.
VARIABLES	Values (translation displacements are scaled by 1.0/ average element length) for each unrestrained displacement unknown.
GRADIENTS	The derivative (measured numerically) of the work function with respect to each of the variables.
CURVATURES	Estimates of the diagonals of the influence matrix for the system (non-dimensional). These estimates are exact after NDF iterations if the system is linear.
FRACTION OF DIRECTION TAKEN	The scalar multiplier, relative to that predicted from curvature estimates, for each trial in the search direction.
FUNCTION SUBROUTINE CALLS	The total number of times the total energy of the system has been evaluated for this time or load step search.
GRADIENT SUBROUTINE CALLS	The total number of gradients evaluated (always a multiple of NDF unless user's step size guesses were too small).
MINIMIZATION ACCURACY	The largest displacement change of the linear minimization.
TOTAL ERROR MEASURES	The largest component of relative energy error (residual force times displacement/total energy).

Table 30. Joint Status Printout

PLASTIC BEAM - CANTILEVERED WITH A VERTICAL LOAD ON THE FREE END, 5 ELEMENTS.

JOINT STATUS AT 2.0000D 00 SECONDS

JOINT AND DIRECTION	DISPLACEMENT IN.(RAD.)	VELOCITY IN.(RAD.)/SEC.	ACCELERATION IN.(RAD.)/SEC./SEC.
1 DX	0.0	0.0	0.0
1 DY	0.0	0.0	0.0
1 RZ	0.0	0.0	0.0
2 DX	-7.2385D-05	0.0	0.0
2 DY	5.1418D-02	0.0	0.0
2 RZ	4.1588D-03	0.0	0.0
3 DX	-5.0231D-04	0.0	0.0
3 DY	1.9357D-01	0.0	0.0
3 RZ	7.5615D-03	0.0	0.0
4 DX	-1.4652D-03	0.0	0.0
4 DY	4.0832D-01	0.0	0.0
4 RZ	1.0208D-02	0.0	0.0
5 DX	-2.9719D-03	0.0	0.0
5 DY	6.7750D-01	0.0	0.0
5 RZ	1.2098D-02	0.0	0.0
5 DX	-4.9095D-03	0.0	0.0
6 DY	9.8297D-01	0.0	0.0
5 RZ	1.3232D-02	0.0	0.0
7 DX	-7.0831D-03	0.0	0.0
7 DY	1.3066D 00	0.0	0.0
7 RZ	1.3610D-02	0.0	0.0

DX = displacement in x direction,
DY = displacement in y direction, and
RZ = rotation about z axis

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Table 31. Internal Energy Distribution

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PLASTIC BEAM - CANTILEVERED WITH A VERTICAL LOAD ON THE FREE END, 6 ELEMENTS.

INTERNAL ENERGY (IN.-LB.) - - DISTRIBUTION AT 2.0000D 00 SECONDS

ELEMENT * IDENTITY	RECOVERABLE ENERGY	DISSIPATED ENERGY	ELEMENT ENERGY	PERCENT OF ** RECOVERABLE	PERCENT OF DISSIPATED	PERCENT OF *** PARTICIPATION
1- 2	4.6788D 03	0.0	4.6788D 03	42.130	0.0	42.130
2- 3	3.1363D 03	0.0	3.1363D 03	28.241	0.0	28.241
3- 4	1.9023D 03	0.0	1.9023D 03	17.129	0.0	17.129
4- 5	9.7684D 02	0.0	9.7684D 02	8.796	0.0	8.796
5- 6	3.5988D 02	0.0	3.5988D 02	3.241	0.0	3.241
5- 5	5.1412D 01	0.0	5.1412D 01	0.463	0.0	0.463

*Element first and second joint numbers

**Percent of total element energy which is stored as elastic work

***Amount of energy in each element divided by total system energy and expressed as a percentage.

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behavior of the system for the current time interval. Since the
solution accuracy is controlled by controlling the energy error, these
data are the most meaningful data on element response. The recoverable
energy is the strain energy stored as elastic work. The dissipated
energy is that energy lost due to yielding. The meaning of percentage
is clarified by footnotes on Table 31. Data is printed for every
element of the structure. Elements are listed in the same sequence as
in the element articulation printout of Table 25 .

Tables 32 and 33 illustrate printouts defining the state of stress
and strain and internal force of a wide flange beam element. Tables 34 and
35 illustrate similar printouts for a reinforced beam element. Only
stress resultants are printed for leaf springs.

Table 36 exhibits the solution accuracy summary produced upon
completion of an integration step. This summary is automatically produced
regardless of the print level selected. The data defined the energy input
to the system and its allocation as stored and dissipated energy. They
relate the energy status and the change of status from that of the
previously reported time.

The relative value of the energy which is unaccounted for provides a
measure of the cumulative accuracy of the simulation. The source of this
error is inexactness in locating the true minimum energy state in the
solution search and round-off or manipulation error. Thus, this error
can often be reduced by reducing the energy tolerance allowed by the user
in specifying Control Block input. There is a minimum value to which this
error measure can be expected to be reduced due to limited precision in
computer calculations.

In Table 36, residual forces define the value of unbalanced force
in each equilibrium equation. These are identified with each joint degree

Table 32 Wide Flange Stresses and Strains

PLASTIC BEAM - CANTILEVERED WITH A VERTICAL LOAD ON THE FREE END, 6 ELEMENTS.

AVERAGE STRESSES (LB./IN.**2) IN NONCOMPOSITE WIDE FLANGE ELEMENTS AT 2.00000 00 SECONDS

END	ELEMENT	SITE IN THE CROSS SECTION	NORMAL STRESS	NORMAL STRAIN	LOADING STATE*	PERCENT OF YIELD	PERCENT OF FRACTURE
1	1- 2	UPPER FLANGE	-3.2793D 04	-1.1328D-03	ELASTIC	-99.372	-0.539
		LOWER FLANGE	3.2873D 04	1.1356D-03	ELASTIC	99.616	0.541
2	1- 2	UPPER FLANGE	-2.7325D 04	-9.6395D-04	ELASTIC	-82.803	-0.450
		LOWER FLANGE	2.7396D 04	9.4641D-04	ELASTIC	83.018	0.451
2	2- 3	UPPER FLANGE	-2.7331D 04	-9.4415D-04	ELASTIC	-82.823	-0.450
		LOWER FLANGE	2.7390D 04	9.4621D-04	ELASTIC	83.001	0.451
3	2- 3	UPPER FLANGE	-2.1862D 04	-7.5523D-04	ELASTIC	-66.249	-0.360
		LOWER FLANGE	2.1914D 04	7.5704D-04	ELASTIC	66.407	0.360
3	3- 4	UPPER FLANGE	-2.1867D 04	-7.5539D-04	ELASTIC	-66.262	-0.360
		LOWER FLANGE	2.1910D 04	7.5689D-04	ELASTIC	66.394	0.360
4	3- 4	UPPER FLANGE	-1.6397D 04	-5.6645D-04	ELASTIC	-49.688	-0.270
		LOWER FLANGE	1.6435D 04	5.6775D-04	ELASTIC	49.802	0.270
4	4- 5	UPPER FLANGE	-1.6400D 04	-5.6655D-04	ELASTIC	-49.698	-0.270
		LOWER FLANGE	1.6432D 04	5.6764D-04	ELASTIC	49.793	0.270
5	4- 5	UPPER FLANGE	-1.0930D 04	-3.7759D-04	ELASTIC	-33.122	-0.180
		LOWER FLANGE	1.0958D 04	3.7853D-04	ELASTIC	33.205	0.180
5	5- 6	UPPER FLANGE	-1.0932D 04	-3.7765D-04	ELASTIC	-33.127	-0.180
		LOWER FLANGE	1.0956D 04	3.7848D-04	ELASTIC	33.200	0.180
6	5- 6	UPPER FLANGE	-5.4612D 03	-1.8866D-04	ELASTIC	-16.549	-0.090
		LOWER FLANGE	5.4827D 03	1.8940D-04	ELASTIC	16.514	0.090
6	6- 7	UPPER FLANGE	-5.4616D 03	-1.8867D-04	ELASTIC	-16.550	-0.090
		LOWER FLANGE	5.4823D 03	1.8939D-04	ELASTIC	16.613	0.090
7	6- 7	UPPER FLANGE	9.9513D 00	3.4377D-07	ELASTIC	0.030	0.000
		LOWER FLANGE	9.9464D 00	3.4360D-07	ELASTIC	0.030	0.000

*Loading state may be "ELASTIC," "PLASTIC," or "FRACTURE."

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Fig. 53. Wide Flange Beam Stress Resultants

PLASTIC BEAM CONSIDERED WITH A VERTICAL LOAD ON THE FREE END, 6 ELEMENTS.

NONCOMPOSITE WIDE FLANGE ELEMENT INTERNAL FORCES AT 2.00000 00 SECONDS

UNITS - POUNDS, INCHES

ELEMENT IDENTITY	STRESS RESULTANT	AT FIRST LISTED END	AT SECOND LISTED END
1- 2	AXIAL	-7.8285D 02	7.8285D 02
	SHEAR	-1.7002D 04	1.7002D 04
	MOMENT	-2.4479D 05	2.0399D 06
	CURVATURE	-1.8904D-04	-1.5753D-04
2- 3	AXIAL	-5.7441D 02	5.7441D 02
	SHEAR	-1.7001D 04	1.7001D 04
	MOMENT	-2.0399D 06	1.6319D 06
	CURVATURE	-1.5753D-04	-1.2602D-04
3- 4	AXIAL	-4.1377D 02	4.1377D 02
	SHEAR	-1.7000D 04	1.7000D 04
	MOMENT	-1.6319D 05	1.7239D 06
	CURVATURE	-1.2602D-04	-9.4516D-05
4- 5	AXIAL	-3.0096D 02	3.0096D 02
	SHEAR	-1.6999D 04	1.6999D 04
	MOMENT	-1.2239D 06	8.1593D 05
	CURVATURE	-9.4516D-05	-6.3010D-05
5- 6	AXIAL	-2.3600D 02	2.3600D 02
	SHEAR	-1.6999D 04	1.6999D 04
	MOMENT	-8.1593D 05	4.0796D 05
	CURVATURE	-6.3010D-05	-3.1505D-05
6- 7	AXIAL	-2.1887D 02	2.1887D 02
	SHEAR	-1.6999D 04	1.6999D 04
	MOMENT	-4.0796D 05	-1.8375D-01
	CURVATURE	-3.1505D-05	1.4190D-11

Table 34 Reinforced Concrete Beam Stresses and Strains

REINFORCED CONCRETE RING SECTION - RING 1   RADIUS = 39.5 INCHES

AVERAGE STRESSES (LB./IN.**2) IN REINFORCED CONCRETE ELEMENTS AT 1.0000D 00 SECONDS

END	ELEMENT	SITE IN THE CROSS SECTION	NORMAL STRESS	NORMAL STRAIN	LOADING STATE	PERCENT OF YIELD	PERCENT OF FRACTURE
1	1- 2	STEEL, UPPER	5.0851D 03	1.7565D-04	ELASTIC	11.663	0.096
		STEEL, LOWER	-8.3837D 03	-2.8958D-04	ELASTIC	19.229	0.158
		EDGE CONC., UPPER	0.0	5.2457D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	0.0	1.7565D-04	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-1.2840D 03	-2.8958D-04	ELASTIC	24.836	0.029
		EDGE CONC., LOWER	-2.2988D 03	-6.3850D-04	ELASTIC	44.464	16.438
2	1- 2	STEEL, UPPER	4.7300D 03	1.6338D-04	ELASTIC	10.849	0.089
		STEEL, LOWER	-7.9585D 03	-2.7490D-04	ELASTIC	18.254	0.150
		EDGE CONC., UPPER	0.0	4.9209D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	0.0	1.6338D-04	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-1.2189D 03	-2.7490D-04	ELASTIC	23.576	0.027
		EDGE CONC., LOWER	-2.1732D 03	-6.0361D-04	ELASTIC	42.034	15.540
2	2- 3	STEEL, UPPER	4.6570D 03	1.6086D-04	ELASTIC	10.681	0.088
		STEEL, LOWER	-7.9649D 03	-2.7529D-04	ELASTIC	18.280	0.150
		EDGE CONC., UPPER	0.0	4.8797D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	0.0	1.6086D-04	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-1.2206D 03	-2.7529D-04	ELASTIC	23.610	0.028
		EDGE CONC., LOWER	-2.1688D 03	-6.0241D-04	ELASTIC	41.950	15.509
3	2- 3	STEEL, UPPER	3.5606D 03	1.2299D-04	ELASTIC	8.167	0.067
		STEEL, LOWER	-6.8193D 03	-2.3555D-04	ELASTIC	15.641	0.128
		EDGE CONC., UPPER	0.0	3.9189D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	0.0	1.2299D-04	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-1.0444D 03	-2.3555D-04	ELASTIC	20.201	0.024
		EDGE CONC., LOWER	-1.8162D 03	-5.0445D-04	ELASTIC	35.129	12.987
3	3- 4	STEEL, UPPER	3.4617D 03	1.1957D-04	ELASTIC	7.940	0.065
		STEEL, LOWER	-6.8024D 03	-2.3497D-04	ELASTIC	15.602	0.128
		EDGE CONC., UPPER	0.0	3.8547D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	0.0	1.1957D-04	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-1.0418D 03	-2.3497D-04	ELASTIC	20.151	0.023
		EDGE CONC., LOWER	-1.8033D 03	-5.0087D-04	ELASTIC	34.879	12.895
4	3- 4	STEEL, UPPER	1.7545D 03	6.0603D-05	ELASTIC	4.024	0.033
		STEEL, LOWER	-5.0654D 03	-1.7497D-04	ELASTIC	11.618	0.095
		EDGE CONC., UPPER	0.0	2.3728D-04	CRACKED	100.000	100.000
		CONF. CONC., UPPER	2.0	5.2633D-05	CRACKED	100.000	100.000
		CONF. CONC., LOWER	-7.7579D 02	-1.7497D-04	ELASTIC	15.006	0.017
		EDGE CONC., LOWER	-1.7660D 03	-3.5164D-04	ELASTIC	24.448	9.053

Table 35. Reinforced Concrete Beam Stress Results

REINFORCED CONCRETE RING SECTION - RING 1   RADIUS = 39.5 INCHES

REINFORCED CONCRETE ELEMENT INTERNAL FORCES AT 1.0000D 00 SECONDS

UNITS - POUNDS, INCHES

ELEMENT IDENTITY	STRESS RESULTANT	AT FIRST LISTED END	AT SECOND LISTED END
1- 2	AXIAL	-1.4967D 04	1.4967D 04
	SHEAR	1.0052D 04	-1.0052D 04
	MOMENT	3.5519D 04	3.3610D 04
	CURVATURE	2.3261D-04	2.1914D-04
2- 3	AXIAL	-1.2493D 04	1.2493D 04
	SHEAR	8.9475D 03	-8.9875D 03
	MOMENT	3.3570D 04	2.8251D 04
	CURVATURE	2.1808D-04	1.7927D-04
3- 4	AXIAL	-8.6814D 03	8.6814D 03
	SHEAR	6.9869D 03	-6.9869D 03
	MOMENT	2.8081D 04	1.9994D 04
	CURVATURE	1.7727D-04	1.1778D-04
4- 5	AXIAL	-4.1438D 03	4.1438D 03
	SHEAR	4.1985D 03	-4.1985D 03
	MOMENT	1.9714D 04	9.1848D 03
	CURVATURE	1.1509D-04	4.2069D-05
5- 6	AXIAL	-4.0397D 03	4.0397D 03
	SHEAR	6.1098D 03	-6.1098D 00
	MOMENT	8.7007D 03	-8.6599D 03
	CURVATURE	3.9001D-05	-3.8761D-05
6- 7	AXIAL	-8.5659D 03	8.5659D 03
	SHEAR	-4.2187D 03	4.2187D 03
	MOMENT	-9.2160D 03	-1.9818D 04
	CURVATURE	-4.1830D-05	-1.1496D-04
7- 8	AXIAL	-1.2476D 04	1.2476D 04
	SHEAR	-7.0595D 03	7.0595D 03
	MOMENT	-2.0262D 04	-2.8303D 04
	CURVATURE	-1.1766D-04	-1.7731D-04

Table 36. Solution Accuracy Summary

PLASTIC BEAM - CANTILEVERED WITH A VERTICAL LOAD ON THE FREE END, 5 ELEMENTS.

SOLUTION ACCURACY AT 2.0000D 00 SECONDS

UNITS - POUNDS, INCHES

INPUT ENERGIES	STORED ENERGIES	DISSIPATED ENERGIES
INITIAL = 7.5323D 03	STRAIN = 1.1106D 04	PREVIOUS = 0.0
ADDED = 3.5737D 03	KINETIC = 0.0	CURRENT = 0.0
INPUT = 1.1106D 04	STORED = 1.1106D 04	LOST = 0.0

***ENERGY UNACCOUNTED FOR IS 0.004 PERCENT OF TOTAL INPUT.

JOINT AND DIRECTION	VALUE OF IMPOSED LOAD	RESIDUAL FORCE, MAX.	RESIDUAL ENERGY, MAX.	REL. ENERGY* ERROR
1 DX	0.0	0.0	0.0	0.0
1 DY	0.0	0.0	0.0	0.0
1 RZ	0.0	0.0	0.0	0.0
2 DX	0.0	-4.2354D-11	1.2774D-16	-1.2785D-10
2 DY	0.0	-8.8924D-12	-1.9951D-14	1.9567D-08
2 RZ	0.0	1.8580D-12	7.7295D-15	-7.7360D-09
3 DX	0.0	2.4421D-11	-5.1531D-16	5.1576D-10
3 DY	0.0	8.5618D-13	6.9055D-15	-6.9113D-09
3 RZ	0.0	-7.7301D-13	-5.8491D-15	5.8500D-09
4 DX	0.0	2.8791D-11	-1.7577D-15	1.7592D-09
4 DY	0.0	6.1155D-12	1.0404D-13	-1.0413D-07
4 RZ	0.0	2.9997D-12	3.0620D-14	-3.0646D-08
5 DX	0.0	2.4332D-12	-3.0130D-16	3.0155D-10
5 DY	0.0	2.2025D-13	6.2174D-15	-6.2226D-09
5 RZ	0.0	3.0446D-12	3.6834D-14	-3.6865D-08
6 DX	0.0	-1.2950D-11	2.6691D-15	-2.6513D-09
6 DY	0.0	-3.4724D-12	-1.4222D-13	1.4234D-07
6 RZ	0.0	1.0134D-12	1.3409D-14	-1.3421D-08
7 DX	0.0	-2.7945D-12	8.2473D-16	-8.2543D-10
7 DY	1.7900D 04	6.5874D-13	3.5863D-14	3.5893D-08
7 RZ	0.0	-4.5104D-12	-6.1389D-14	6.1441D-08

*Residual energy/total energy

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of freedom. The residual energy is the external work of the residual

forces (residual force times displacement changes in this step).

3.1.3 Messages

The three types of printed messages are described and illustrated in

Table 37. Logic producing these messages occurs in practically every

subroutine and printouts are produced as this logic is encountered.

Each error message indicates in parentheses the subroutine name of its

origin.

Table 18 through 36 illustrate printout output when no error messages

arise. Since error messages are printed as they arise, the pattern of

each of these printouts is changed when errors occur.

3.2 RETRIEVAL FILE DATA

Two types of data files are transferred to peripheral storage units:

a plot file and a calculation recovery file. The plot file stores data,

defining the state of the structure, for later printing or plotting.

The recovery file provides data for continuing integration of the equations

of motion in another computer run.

Plot files are written when Control Block input so specified. A

file is transferred to the specified peripheral unit at every time point

for which there is a printout of response state data. This file contains

a complete record of the state of the structure at the end of each time

interval.

A recovery file is written just before terminating calculations, as

long as a recovery peripheral unit has been specified, and no fatal or

critical errors have occurred. This file is transferred when the integration

is completed for the time interval of interest. When calculations must be

Table 37

ERROR MESSAGE CHARACTERISTICS

Message Type	Action	Examples	Features of Form
Informational	Print a message and continue calculations.	CONVERGENCE OF MINIMIZATION TO SPECIFIED ACCURACY.	A simple unadorned statement. Printout is directed by a WRITE statement.
Recoverable	Print a message, take corrective action and continue.	*NEGATIVE MASS DETECTED AT JOINT 8 IGNORED, POSITIVE VALUE STORED (MASS).*	The statement is preceeded and followed by one asterisk. Printout is directed by a WRITE statement
Warning	Print a message and continue if ISTOP flag (Block 1 input) is "C", otherwise stop.	**USING CRITERION OF 10.7, ACI 318-71, ELEMENT 21-6 IS A DEEP BEAM (BEAM).**	The statement is preceded and followed by two asterisks. Printout is usually directed by a WRITE statement.
Fatal	Print a message and stop calculations.	***INSUFFICIENT STORAGE SPACE AVAILABLE FOR JOINT FORCING DATA (JFOR).***	The statement is preceded and followed by three asterisks. Printout is directed by a PRINT statement.

*Underlined terms vary with problem.

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terminated before integration is completed, a recovery file is also automatically transferred to facilitate continuation of calculations on another computer run.

The recovery file contains all data necessary for continuing integration from the last time point completed successfully. For recovery only, the data for Input Block 1 needs to be included in input. Data from this block reinitiates the simulation. Accordingly, input for this block must be changed to reflect the continuation conditions as described by the footnotes of Table 2.

Table 38 provides a summary of all input data blocks and groups of output data. This table identifies the data saved in the plot and recovery files. Retrieval files contain only binary coded data. Each of these files is written by a single FORTRAN WRITE statement.

Table 38

RETRIEVAL FILE DATA

Data	Plot File	Recovery File
Problem Descriptive Data		
Control Block Data	No	No
Remaining Input Blocks	No	Yes
Problem summary data	No	Yes
Joint Deflection Data		
Deflection, and velocity in each degree of freedom	Yes	Yes
Acceleration in each degree of freedom	Yes	No
Element State Data		
Energy distribution	Yes	No
Internal loads	Yes	No
Stresses and strains	Yes	Yes
Element status summary	No	No
Solutions Progress Data		
Summary data	No	Yes
Joint balance data	No	No
Solution progress data	No	No
Error Messages	No	No

SECTION 4

PROBLEM SETUP

The computer running time and analysis efficiency depend on how the user describes the problem using the input data. The purpose of this section is to give a user some general guidelines for setting up the problem and controlling the solution accuracy.

In preparing input, one of the user's objectives is to define the problem for the computer so that it can develop accurate results efficiently. Efficiency is especially important in nonlinear analysis where excessively detailed models can result in an increase of orders of magnitude in processing time. These excesses can be reduced by using the analysts' understanding of the program and the structural behavior to simplify the problem definition.

In decreasing order of importance to processing time, the user's objective should be to minimize the number of degrees of freedom, the complexity of element representation, and the solution search time.

4.1 REDUCING THE NUMBER OF EQUATIONS

For all but the smallest problems, the majority of the computer resources are devoted to solving the nonlinear equations. Since the number of calculations for solution is a function of the number of equations (experience suggests a factor of two to ten), reducing the number of equations is important.

Reducing equations means modeling with the fewest joints and degrees of freedom per joint. Where applicable, only half, or a quadrant of the

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system should be modeled using symmetry or assymmetry boundary conditions to imply the rest of the system. Joints which will not move significantly in a given direction, such as the axial motions of a laterally-loaded continuous beam, should be restrained. Distributed loadings should be chosen rather than introducing interior joints for a centrally-loaded span, if the central load work will be comparable to the work of statically equivalent end loads. Joints that are close together, compared with other joints, should be combined in a single joint. If the structure becomes broken into two parts, each part should be separated to reduce total calculations.

4.2 ' REDUCING THE COMPLEXITY OF ELEMENT REPRESENTATION

The number of calculations in equation solving is directly proportional to the number of energy (and gradient) evaluations. Since each of these involves determining the energies in each element, reducing the number and complexity of element models directly reduces data processing time.

Several modeling devices are available with SINGER for reducing element complexity. Since, in many impact problems, much of the system behaves in the linear stress-strain range throughout the loading history, the user is permitted to designate that energy calculations can be simplified to the linear range for particular elements. Judicious use of leaf springs, instead of modeling with other line elements, replaces models which require integration over the volume of the element, with a matrix multiplication involving relatively few calculations. Similarly, grouping longitudinal steel into fewer groups and using wideflange beams instead of reinforced concrete models reduces energy integration calculations.

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4.3 REDUCING THE SOLUTION SEARCH TIME

The solution search time is measured by the number of linear minimizations needed to arrive at an acceptable solution of the equations of equilibrium guidelines for modeling to minimize the time center around providing good guesses for the load or time step and reducing the complexity of nonlinearity.

4.3.1 Selection of Load or Time Steps

In obtaining response to static loadings, the load can be applied over a number of steps, if physically meaningful. This approach tends to reduce search by keeping configuration changes small enough so convergence is rapid for each step and thereby, the total search time is reduced. If load steps are too large, the user will observe that progress in reducing the work function may be slow. This difficulty is often eliminated simply by restarting the analysis search using the recovery feature of SINGER.

For dynamic loadings, search time is reduced by requiring integration time steps of the order of one-fifth the shortest period of resonance. This eliminates needless time cutting and multiplying that will occur if SINGER determines the appropriate time step by trial and error. Some of this trial and error will occur naturally when the structure goes plastic. Then, the search can be reduced by restarting with user supplied time steps.

4.3.2 Reducing the Complexity of Nonlinearity

The complexity of nonlinearity is reduced by limiting the type of

nonlinearity, simplifying material representations, and, in dynamic response analysis, by simplifying the mass model.

Types of nonlinearity include orientation and material nonlinearities. Designating that only small angle changes can occur at joints (sine (angle) = angle, cosine (angle) = 1.0) reduces the equations to representing nonlinear strain-displacement terms in geometry. Since in many problems these terms only weakly couple axial and lateral motions, the equations become nearly linear and the solution search is achieved in less than NDF search steps for each new loading, where NDF is the number of degrees of freedom.

Material nonlinearities are eliminated by modeling each material with a single line. Since folded line models involve a jump discontinuity in effective Young's Modulus at each fold, the single line eliminates approximations made over the discontinuity and consequent added search steps. Likewise, extending the domain of material linearity, reducing the number of folds, and minimizing the fold angle change reduce the number of search steps.

Simplifying the mass model usually involves reducing the total number of masses by lumping at fewer joints. The effect of this reduction is to increase the shortest resonance period and consequently permit larger time steps in dynamic response prediction. Since the shortest period can be bounded by the period associated with movement of only the smallest mass, reducing the number of masses should usually involve increasing the magnitude of the smallest mass.

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