NATIONAL CENTER FOR EARTHQUAKE
ENGINEERING RESEARCH
State University of New York at Buffalo

SARCF-II USER'S GUIDE
SEISMIC ANALYSIS OF REINFORCED CONCRETE FRAMES

by

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The capabilities of the program SARCF have been extended and an updated user's guide is presented. The purpose of program SARCF-II (Seismic Analysis of Reinforced Concrete Frames, Version II) is to compute nonlinear responses of reinforced concrete frames subjected to deterministic or randomly generated earthquake ground motions. Expected damage values are calculated with an option to perform automated damage-controlled design iterations until a user-specified damage distribution has been achieved. In addition, this program reproduces the load-deformation curves for quasi-static displacement controlled experiments. Currently, the program handles reinforced concrete frames consisting of beam and beam-column elements, and grid structures consisting of beam elements.

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PREFACE

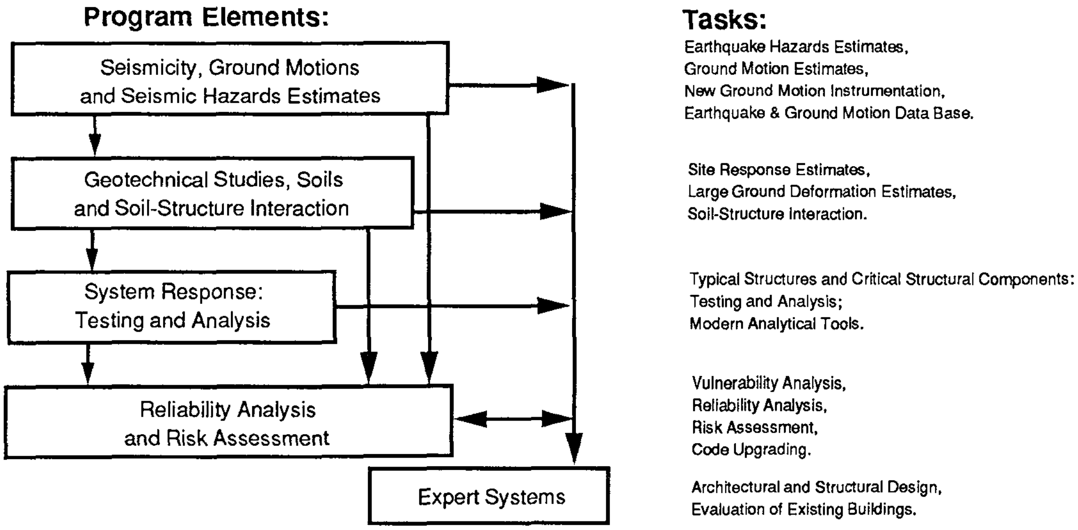
The National Center for Earthquake Engineering Research (NCEER) is devoted to the expansion and dissemination of knowledge about earthquakes, the improvement of earthquake-resistant design, and the implementation of seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures and lifelines that are found in zones of moderate to high seismicity throughout the United States.

NCEER's research is being carried out in an integrated and coordinated manner following a structured program. The current research program comprises four main areas:

- Existing and New Structures
- Secondary and Protective Systems
- Lifeline Systems
- Disaster Research and Planning

This technical report pertains to Program 1, Existing and New Structures, and more specifically to reliability analysis and risk assessment.

The long term goal of research in Existing and New Structures is to develop seismic hazard mitigation procedures through rational probabilistic risk assessment for damage or collapse of structures, mainly existing buildings, in regions of moderate to high seismicity. This work relies on improved definitions of seismicity and site response, experimental and analytical evaluations of systems response, and more accurate assessment of risk factors. This technology will be incorporated in expert systems tools and improved code formats for existing and new structures. Methods of retrofit will also be developed. When this work is completed, it should be possible to characterize and quantify societal impact of seismic risk in various geographical regions and large municipalities. Toward this goal, the program has been divided into five components, as shown in the figure below:



Reliability analysis and risk assessment research constitutes one of the important areas of Existing and New Structures. Current research addresses, among others, the following issues:

1. Code issues - Development of a probabilistic procedure to determine load and resistance factors. Load Resistance Factor Design (LRFD) includes the investigation of wind vs. seismic issues, and of estimating design seismic loads for areas of moderate to high seismicity.
2. Response modification factors - Evaluation of RMFs for buildings and bridges which combine the effect of shear and bending.
3. Seismic damage - Development of damage estimation procedures which include a global and local damage index, and damage control by design; and development of computer codes for identification of the degree of building damage and automated damage-based design procedures.
4. Seismic reliability analysis of building structures - Development of procedures to evaluate the seismic safety of buildings which includes limit states corresponding to serviceability and collapse.
5. Retrofit procedures and restoration strategies.
6. Risk assessment and societal impact.

Research projects concerned with reliability analysis and risk assessment are carried out to provide practical tools for engineers to assess seismic risk to structures for the ultimate purpose of mitigating societal impact.

In this study, the capabilities of the program SARCF-II have been extended and an updated user's guide is presented. The SARCF-II computes nonlinear responses of reinforced concrete frames subjected to deterministic or randomly generated earthquake ground motions. Expected damage values are calculated with an option to perform automated damage-controlled design iterations until a user-specified damage distribution has been achieved. In addition, this program reproduces the load-deformation curves for quasi-static displacement controlled experiments. Currently, the program handles reinforced concrete frames consisting of beam and beam-column elements, and grid structures consisting of beam elements.

ABSTRACT

The capabilities of the program SARCF have been extended and an updated user's guide is presented herein. The purpose of program SARCF–II ("Seismic Analysis of Reinforced Concrete Frames, Version II") is to compute nonlinear responses of reinforced concrete frames subjected to deterministic or randomly generated earthquake ground motions. Expected damage values are calculated with an option to perform automated damage-controlled design iterations until a user-specified damage distribution has been achieved. In addition, this program reproduces the load-deformation curves for quasi-static displacement controlled experiments.

Presently, the program handles reinforced concrete frames consisting of beam and beam-column elements, and grid structures consisting of beam elements.

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SECTION 1

INTRODUCTION

The purpose of this report is to document a new version of the program SARCF written by Y.S. Chung *et al.* [1]. SARCF–II is a computer program for the computation of the nonlinear dynamic response of reinforced concrete frames. The general characteristics and the theoretical aspects of the program can be found in Reference [1]. This program has been written in Fortran-77 for VAX computer systems and for SUN micro-computer systems. It has been derived from DRAIN-2D [8], a general purpose computer program for the dynamic analysis of inelastic plane structures.

The modifications to the original version are described in Section 2, Section 3 presents the updated user's guide, Section 4 contains useful information about the installation and execution procedures, and Section 5 presents five examples to illustrate the the capabilities and use of the program.

SECTION 2

MODIFICATIONS TO THE ORIGINAL VERSION

The program SARCF–II includes the following enhancements from the original version [1]:

1. The numerical simulation of the quasi-static experimental load-deformation curves is now possible.

2. The computation of section properties, i.e. the yield moment, ultimate moment and failure moment, has been improved by considering the effect of the axial force. Figure 2-1 shows that higher axial force incurs greater ultimate moment capacity, but less ultimate curvature.

3. The empirical equation for the pinching effect has been modified based on a comparison of numerical simulations with Ohno's experimental results [9]. The coordinates of the cracking-closing point can then be expressed as [1]:

   $$M_p^+ = \alpha_p M_n^+$$

   $$\phi_p^+ = \alpha_p \phi_n^+$$

   where

   $$\alpha_p = \begin{cases} 0 & \text{if} \quad \frac{a}{d} \leq 1.5 \\ \sqrt{0.4\frac{a}{d} - 0.6} & \text{if} \quad 1.5 < \frac{a}{d} \leq 4.0 \\ 1 & \text{if} \quad \frac{a}{d} > 4.0 \end{cases}$$

   $\frac{a}{d}$: Shear span ratio

   a : Shear span, assumed to be equal to $\frac{l}{2}$

   l : Clear span length

   d : Cross-sectional depth

4. The automated damage-controlled design option is now applicable to the case when input frame structure is subjected to deterministic earthquake data.

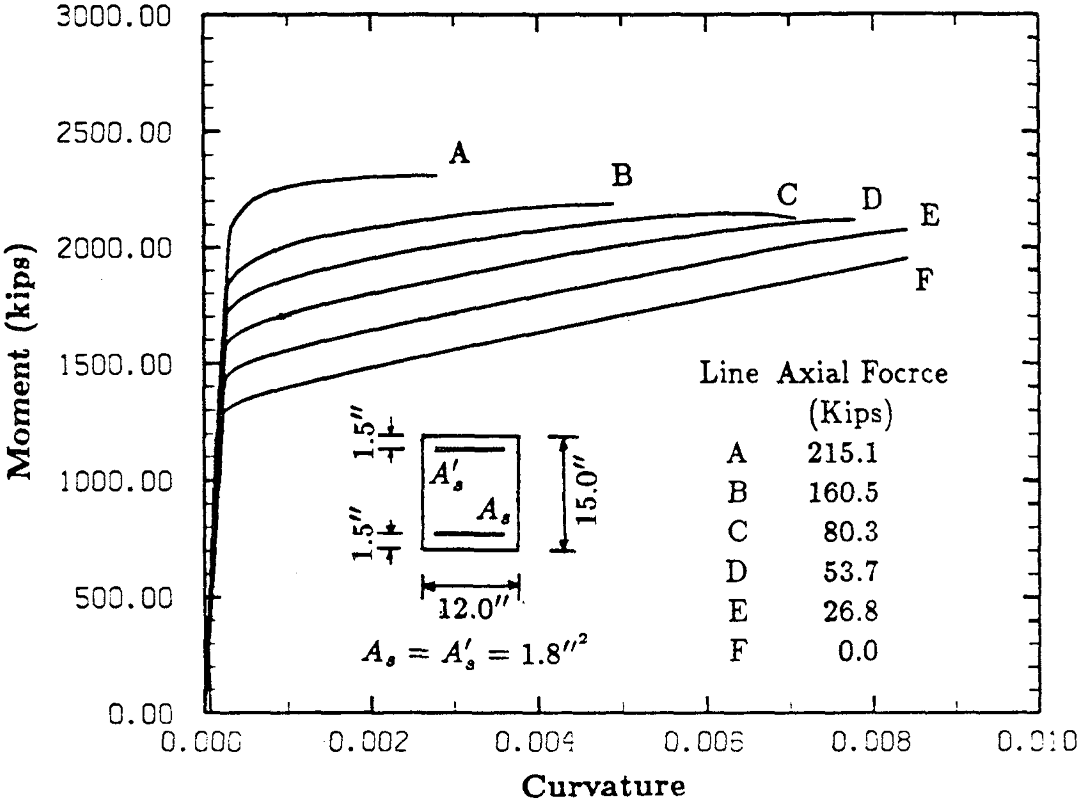


FIGURE 2-1 Effect of Axial Force on the Primary Moment-Curvature Curve

5. Structures with any geometry can be analyzed. The summary of damage indices is intended for building structures.
6. The interstory drift and the curvature ductility ratio (for the bending moment) are computed.
7. It is possible to compute the free vibration response after the earthquake has ended.
8. The response of a structure damaged by a previous analysis can be computed.
9. Two output files, called fort.71 and fort.70, contain the acceleration at the base and the top of the building so that the program MUMOID for the identification of the equivalent linear system can be used Ref. [4]. Another file called fort.80 with the instantaneous natural period allows for the computation of the global damage index defined in Ref. [4].
10. Plane structures, with load perpendicular to its plane (grid structures), can be analyzed.
11. The structural elements can be defined by using the dimensions of the concrete section and the amount of reinforcing steel or by directly supplying the skeleton curve for the $M - \phi$ relationship.
12. The failure of the elements has been introduced. When the curvature is greater than the failure curvature the member bending stiffness is reduced to a very small value (1.), for the corresponding plastic area.
13. An output file with the necessary information for a graphic output is created. A graphic postprocessor called SARCF-G has been implemented in a Silicon Graphics IRIS-4D workstation to observe the displacements and damage indices in real time.

14. Through a debugging process the former version has been modified in the following aspects:

    a. Computation of the length of the plastic hinges to include only the part of the element that has a bending moment greater than the yield moment.

    b. The correct axial force used for the computation of the geometric stiffness is now used.

    c. The positive and negative yield moments for the initial node have been corrected so that they have the opposite sign they have for the final node.

    d. Static analysis is now possible and the initial bending moments from the static analysis are considered in the dynamic analysis.

SECTION 3

SARCF–II USER'S GUIDE

Input data are entered in a batch mode consisting of seven items arranged in the following sequence:

1. "START" card and analysis control data.
2. Structure information.
3. Element information.
4. Load information.
   a. Static load information.
   b. Earthquake data, either deterministic or randomly generated.
   c. Controlled-displacement records for quasi-static experiments.
5. Analysis information.
   a. Eigenvalue information (optional).
   b. Damage index information (optional).
   c. Automated damage-controlled design procedure (optional).
6. Output specifications.
7. "STOP" card.

Static loads may be applied to the structure prior to the application of the dynamic loading, but the response to such static loads must remain elastic.

The present version makes limited use of fixed dimension statements, so that several important input variables are subjected to upper limits. These restrictions are clearly indicated in the input specifications below. However, because of the use of PARAMETER statements, it is relatively easy to relax any one of these capacity restrictions, if necessary.

3.1 Description of the Problem

3.1.1 START Card (A5,3X,18A4)

Provide a single card with the following information:

Columns 1 - 5 : Enter the word "START".
6 - 80 : Designate the title of this problem.

3.1.2 Analysis Control Data (8I5)

Provide a single card with the following control data:

Columns 1 - 5 : Code for reproduction of the quasi-static experimental result ("KQSTA").
  1 : reproduce the experimental load-deformation curves.
  0 : do not reproduce.

6 - 10 : Code for type of earthquake data ("KEARTH").
  1 : for randomly generated earthquake data.
  0 : for deterministic earthquake data.

11 - 15 : Code for damage index ("KDAMAGE").
  1 : compute damage indices.
  0 : do not compute damage indices.

16 - 20 : Code for an automated damage-controlled design analysis ("KAUTO").
  1 : perform automated damage-controlled design.
  0 : do not perform automated damage-controlled design.

21 - 25 : Data checking code ("KDATA").

This code specifies two items: 1) whether to perform a complete analysis or only a data check run; 2) whether to store all element data in core or on a scratch file with the result of increased peripheral processing cost.

1 : data check run only.

0 : complete analysis execution, with element data stored on a scratch file. (On this version this option is not available).

-1 : complete analysis execution, with element data stored in core.

26 - 30 : Code for computation on a damaged structure ("K2EARTH").

This code specifies whether the analysis would be carried out on the original structure or on a structure damaged by a previous earthquake.

0 : Analysis of the original structure.

1 : Analysis of a damaged structure. A file called fort.2, with the information of the damaged structure, is necessary in the working directory. This is a scratch file with element information that is written each time the program is run.

2 : Analysis of a damaged structure using a previous acceleration record. When the program is run with K2EARTH equal to zero two output files called fort.72 and fort.73 are created containing the input acceleration in the horizontal and vertical directions. If K2EARTH equal to two is used, it is possible to use the same input acceleration for a second analysis of the damaged structure. These two files must be in the working directory to be read at execution time. This is useful when the first analysis is done using an artificially generated earthquake, as it would be impossible to randomly generate the same earthquake.

3 : Analysis of the undamaged structure using a previous acceleration record. The files fort.72 and/or fort.73 must be in the working directory. This option may be used to repeat

a computation that was done using an artificially generated earthquake in order to get a different output.

31 - 35 : Graphic output code ("KGRAF"). When KGRAF is greater than zero a file called fort.59 is created with the necessary information to obtain a graphic output using SARCF-G. SARCF-G is a graphic postprocessor available for Silicon Graphics IRIS-4D workstations. The numerical value of KGRAF indicates the amount of compression of the output, i.e. if KGRAF is equal to four, the displacements and damaged indices are be saved on the file fort.59 every four time steps. This allows for a reduction of the size of the file fort.59 when the integration time step is small. For good results the product KGRAF x DT should be less than 0.03 seconds (see Section 3.4.1 for the definition of DT).

36 - 40 : Type of structure code ("KGRID"). This code specifies the type of structure to be analyzed.

0 : Frame structure. The structure lies in the XY plane. The input acceleration has two components, i.e. acceleration in the X and Y directions. Three internal forces are considered: axial force, shear force and bending moment about the Z axis. Applied forces consist of forces in the plane XY and moments about the Z axis. Each node has three degrees of freedom, displacements in the X and Y directions and rotation about the Z axis.

1 : Grid structure. The structure lies in the XY plane. The input acceleration has two components, i.e. rotational acceleration

about the X axis direction, and acceleration in the Z direction. Three internal forces are considered, torsional moment, shear force and bending moment. Applied forces consist of forces perpendicular to the XY plane (Z direction) and moments with their axis in the XY plane. Each node has three degrees of freedom, rotations about the X and Y axes and displacement in the Z direction.

41 - 45 : Code for failure of elements ("KNFAIL").

0 : The failure of elements is implemented. The bending stiffness of the elements is reduced to a small value (EI equal to one), when the curvature is greater than the failure curvature, and the local damage index is set equal to one.

1 : The failure of elements is not implemented.

3.2 Structure Information

All data necessary to describe the structure are to be supplied in the order and format as described below. Some data have to be input specifically, while others will default to previously defined values. Consistent units must be used throughout. If the automated damage-controlled design option is exercised, then only. U.S. customary units (foot, pound and kips) are permitted.

3.2.1 Structural Geometry Control Card (11I5,I10)

Columns 1 - 5 : Number of stories ("NSTORY").

6 - 10 : Number of bays ("NBAY").

If the number of bays is the same for each story, enter this number here. If it is variable, enter zero here and specify the numbers of bays in Section 3.2.2 below.

11 - 15 : Number of nodes ("NJTS").

(e.g. (NBAY+1) × (NSTORY+1))

16 - 20 : Number of control nodes, of which x and y coordinates are to be specified ("NCONJT"). See Section 3.2.3.A.

21 - 25 : Number of node generation commands ("NCDJT").

See Section 3.2.3.B.

26 - 30 : Number of zero displacements commands ("NCDDOF").

See Section 3.2.4.

31 - 35 : Number of identical displacements commands ("NCDDIS").

See Section 3.2.5.

36 - 40 : Number of lumped mass commands ("NCDMS").

See Section 3.2.6.

41 - 45 : Number of different element groups in structure ("NELGR").

46 - 50 : Structure stiffness storage code ("KODST"). A duplicate structure stiffness matrix is always retained, periodically updated and stored in either the core, if sufficient memory is available, or else it is stored on a scratch file. Whether the duplicate stiffness matrix can fit into the core or not can be determined in a data check run (KDATA equal to one, see Section 3.1.2) by setting KODST equal to zero.

0 : store stiffness duplicate in core.

1 : store stiffness duplicate on scratch file (Option not available).

51 - 55 : Symmetry option code ("KSYM").

1 : only left half of structure is modeled.

0 : no use of symmetry is made.

-1 : only right half of structure is modeled.

56 - 65 : Blank COMMON length to be allocated.

Enter the number of double-precision words. The length of blank COMMON to be allocated depends on the size of the problem and is difficult to compute by hand. This important information is provided in a data check run (KDATA equal to one, Section 3.1.2). The current program defaults to COMMON A(50000). If this memory allocation is insufficient, the main program of SARCF–II may be recompiled with an appropriately increased COMMON allocation.

Note : The number of bays, the number of stories and the symmetry option code, are only used for the computation of the weighted average of the local damage index, which is defined for building frames [2]. For other structural configurations any non-zero value can be used for the number of bays and the number of stories and the value of the weighted average of the local damage index should be disregarded.

3.2.2 Number of Bays (16I5)

Omit if the structure has the same number of bays in each story, i.e. if a non-zero value for NBAY was entered in Section 3.2.1. If the number of bays varies, enter for each story the actual number of bays, starting with the ground story and proceeding to the top. If the number of stories exceeds 16, use two or more cards, as needed.

3.2.3 Node Generation Cards

The node generation cards allow the omission of input data for frames which exhibit some regularity. For example, if all story heights are equal, it suffices to specify the coordinates of only the top and bottom nodes (defined as "control nodes") and to prompt the automatic generation of the coordinates for all nodes in between. Note that all control nodes are to be defined first, one node per card, followed by all the node generation commands, with one command per card.

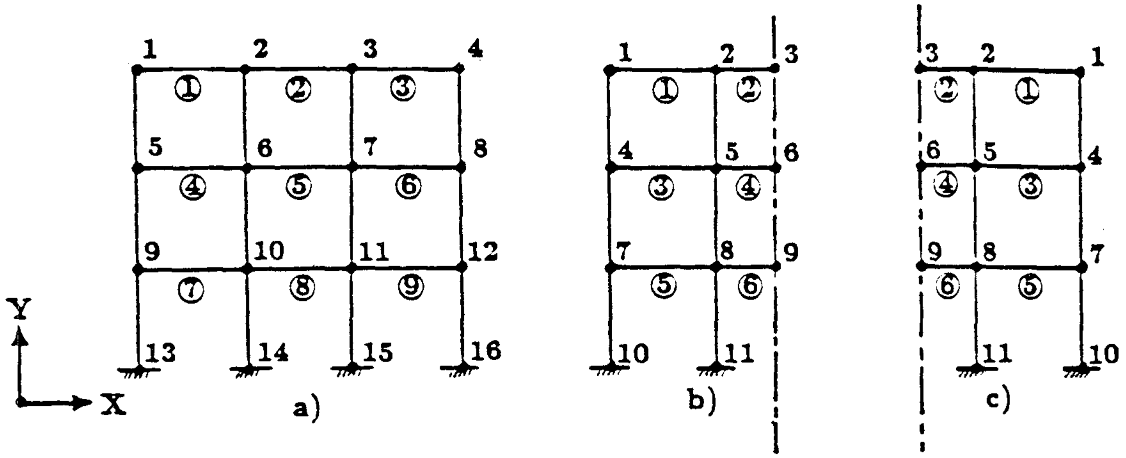


FIGURE 3-1 Node and Element Numbering Sequence

Node numbers can be assigned in any arbitrary sequence, taking into consideration that the displacement and acceleration time histories are automatically provided for node number one (See Section 4). The difference between node numbers linked by an element should be made as small as possible in order to reduce the stiffness matrix's band width, and consequently the computer time. If use of the automated damage-controlled design option is made, nodes must be numbered sequentially, starting from the top story as shown in figure 3-1. If the node generation option is not used, enter all the nodes as "control nodes".

3.2.3.A Control Node Cards (I5,2F10.0)

Columns 1 - 5 : Node number.
6 - 15 : X coordinate of node.
16 - 25 : Y coordinate of node.

3.2.3.B Node Generation Commands(4I5)

Omit if NCDJT is equal to zero. (See Section 3.2.1)

Columns 1 - 5 : First node number in the line of nodes.
6 - 10 : Last node number in the line of nodes.
11 - 15 : Number of nodes to be generated along the line, i.e. the number of nodes between control nodes.
16 - 20 : Node number increment between any two successive nodes. Default value = 1.

3.2.4 Zero Displacements Commands (6I5)

These commands allow the specification of a series of nodes having identical boundary conditions, identified by the following code:

1 : For fixed boundary condition.
0 : For free boundary condition.

Enter NCDDOF cards, with one command per card. See Section 3.2.1.

Columns 1 - 5 : First node number in series.
6 - 10 : Code for X displacements (rotation about the X axis if KGRID= 1).
11 - 15 : Code for Y displacements (for Z displacements if KGRID= 1).
16 - 20 : Code for rotations about the Z axis (rotation about the Y axis if KGRID= 1).
21 - 25 : Last node number in series. Leave blank for a single node.
26 - 30 : Node number increment between any two successive nodes in series. Default = 1.

3.2.5 Identical Displacements Commands (16I5)

One command for each card. Omit if NCDDIS is equal to zero. See Section 3.2.1. Nodes may be slaved to share the same equation number for any selected degree of freedom. This option may be used to model hinges as two different nodes with the same coordinates, sharing the same horizontal and vertical displacements but with different rotations.

Columns 1 - 5 : Displacement code:
  1 : For X displacement (rotation about the X axis if KGRID= 1).
  2 : For Y displacement (for Z displacements if KGRID= 1).
  3 : For rotation about the Z axis (rotation about the Y axis if KGRID= 1).
6 - 10 : Number of nodes having identical displacement (Maximum =14).
11 - 15 : First node.
16 - 20 : Second node etc.

List up to 14 nodes in this card. If there are more than 14 nodes with identical displacement, two or more commands will be used, with the nodes in increasing order in each command. The smallest node number has to appear on each command card.

3.2.6 Lumped Mass Commands (I5,3F10.0,2I5,F10.0)

One command per card. Omit if NCDMS is equal to zero. See Section 3.2.1. Even if KQSTA is equal to zero in Section 3.1.2, i.e. for reproduction of the quasi-static experimental load-deformation curves, all the masses must be input so that natural frequencies of the undamaged frame structure can be obtained.

Columns 1 - 5 : First node number in series.

6 - 15 : Mass associated with X displacement (rotary inertia about the X axis if KGRID is equal to 1).

16 - 25 : Mass associated with Y displacement (Mass associated with Z displacement if KGRID is equal to 1).

26 - 35 : Rotary inertia about the Z axis (rotary inertia about the Y axis if KGRID is equal to 1).

36 - 40 : Last node number in series. Leave blank for a single node.

41 - 45 : Node number difference between any two successive nodes in series. Default = 1.

46 - 55 : Scale factor by which input masses are to be divided ("SCALE"). The default value is the one specified in the preceding command, so that the same factor applies to all subsequent commands until it is changed. Thus, it needs to be specified at least for the first command. If masses are input as weights, enter the gravity constant for SCALE. For example, a 100 *kip* weight (or $\frac{100}{386.4} = 0.2588\ k - sec^2/in$ mass) may be input as a mass "100.", with scale factor "386.4".

3.2.7 Damping Information (4F10.0)

Four different types of damping may be specified. However, if in Section 3.1.2 KQSTA is equal to one, all the damping factors have to be equal to zero.

Columns	1 - 10 :	Mass proportional damping factor, α.
	11 - 20 :	Tangent stiffness proportional damping factor, β.
	21 - 30 :	Original stiffness proportional damping factor, β_o.
	31 - 40 :	Structural damping factor, δ.

Note : Use of structural damping may be problematic, especially for inelastic structures. A possible cause is that the damping forces tend to accentuate small oscillations in numerical computations. The proportionality factors, α and β for the damping equation, $[C] = \alpha\,[M] + \beta\,[K]$, can be determined by specifying damping ratios, λ_1 and λ_2 for any two modes of vibration, i.e. the first and second modes. Say, the equation, $\lambda_n = \frac{\alpha}{2\omega_n} + \frac{\beta\omega_n}{2}\ :\ n = 1, 2$, can be used for the proportional damping factors.

3.3 Element Information

A multi-purpose frame-grid element is incorporated in this program version. For the automatic design option, and for the computation of the average of the damage index, it is necessary to differentiate between beam and beam-column elements according to the horizontal or vertical position in a building frame. All elements of a structure must be divided into groups. All elements in any given group must be of the same type, and typically all elements of the same type will be included in a single group. However, elements of the same type may be subdivided into more than one group if desired. The number of groups, NELGR, was specified in Section 3.2.1. NELGR should be less or equal to two.

If the automated damage-controlled design option is not utilized, element groups may be input in any convenient sequence. Otherwise, the beam element group has to be input before the beam-column element group. In any case, the elements within a group must be numbered in sequence. In addition, in the automated damage-controlled design option, elements are to be sequentially numbered from the top story as shown in figure 3-1.

The parameters defining the moment-curvature skeleton curve which describes the hysteretic behavior of the non linear elements, can be computed from the steel and concrete properties and the cross-sectional dimensions. When the automated damage-controlled design option is not exercised, the skeleton curve can be input directly. In this way, it is possible to define linear elements by defining a high yield bending moment. It is also possible to model truss elements by defining a small bending stiffness. If the skeleton curve is known, non-rectangular concrete sections can also be modeled. For the elements for which the skeleton curve is defined directly, it is not necessary to define concrete, steel or cross section types. Instead, the element properties are input after the Element Generation Commands (see Section 3.3.8).

Each group needs all the following data:

3.3.1 Group Control Information (8I5)

Columns 1 - 5 : Group type number.
  1 : for beam element.
  2 : for beam-column element.
6 - 10 : Number of elements in this group ("NMEM").
11 - 15 : Number of different reinforcing steel types ("NSTL").
  See Section 3.3.2.
16 - 20 : Number of different concrete types ("NCON").
  See Section 3.3.3.
21 - 25 : Number of different cross section types ("NSEC").
  See Section 3.3.4.
26 - 30 : Number of different end eccentricity types ("NECC").

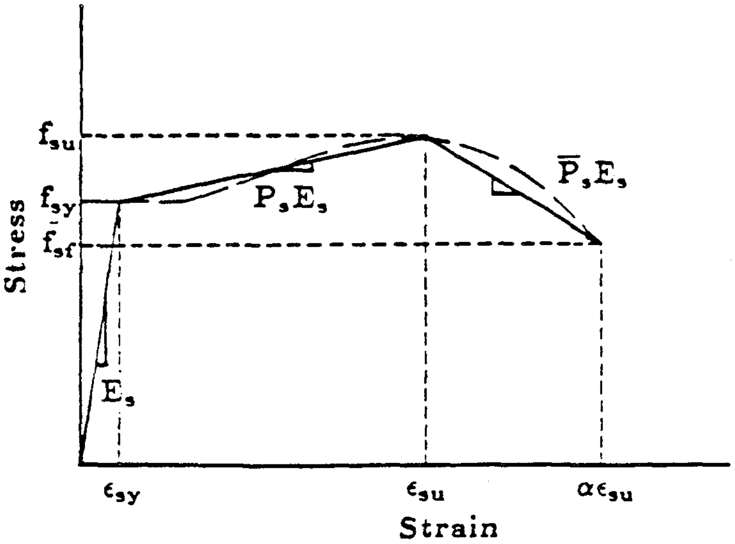


FIGURE 3-2 Stress-Strain Curve for Reinforcing Steel

See Section 3.3.5.

31 - 35 : Number of different fixed-end forces patterns ("NFEF").

See Section 3.3.6.

36 - 40 : Number of different initial element force patterns ("NINT").

See Section 3.3.7.

3.3.2 Reinforcing Steel Types (I5,F15.4,F10.4,F10.2,F10.5)

Supply NSTL cards (see Section 3.3.1), one for each different reinforcing steel. See figure 3-2 for definitions. Assign each type a number, starting with 1, up to a maximum of six.

If the skeleton curve is input directly for all the elements in the group, NSTL should be equal to zero. Therefore, no cards should be included for this section.

Columns 1 - 5 : Type number.

6 - 20 : Young's modulus, E_s.

21 - 30 : Strain hardening ratio, as a fraction of Young's modulus, P_s.

31 - 40 : Yield stress, f_{sy}.

41 - 50 : Ultimate strain, ϵ_{su}.

3.3.3 Concrete Types (I5,3F10.4)

Supply NCON cards (see Section 3.3.1), one for each different concrete type. See figure 3-3 for definitions. Assign each type a number, starting with one, up to a maximum of nine.

If the skeleton curve is input directly for all the elements in the group, NCON should be equal to zero. Therefore, no cards should be included for this section.

Columns 1 - 5 : Type number.

6 - 15 : Uniaxial concrete strength, f'_c.

16 - 25 : Strain at maximum stress, ϵ_o.

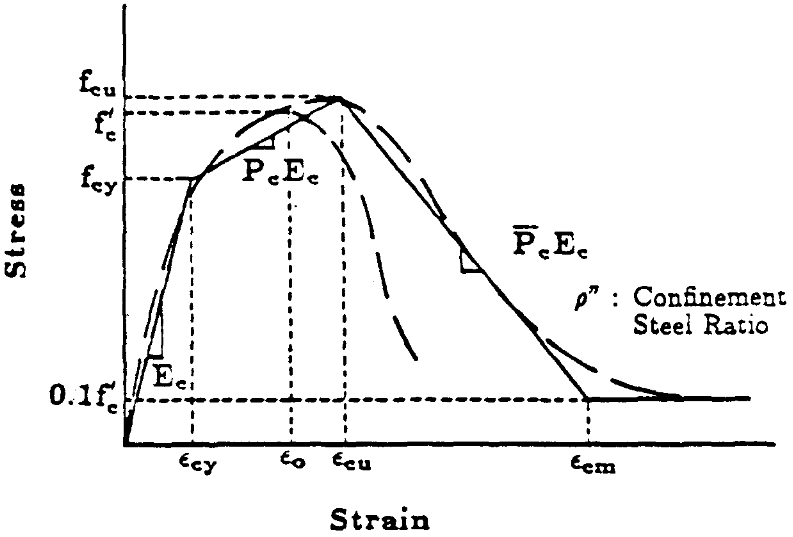


FIGURE 3-3 Stress-Strain Curve for Concrete

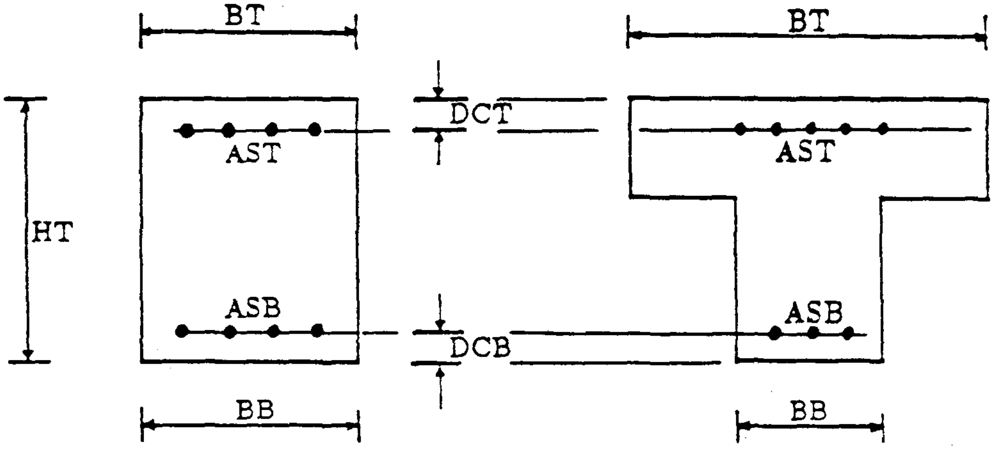


FIGURE 3-4 Idealized Concrete Cross Sections

26 - 35 : Confinement steel ratio, ρ''.

$$\rho'' = \frac{2(b'' + d'')A_v}{b''d''s}$$

where,

b'' : Width of the confined concrete core
d'' : Depth of the confined concrete core
A_v : Cross sectional area of transverse steel
s : Spacing of transverse steel

3.3.4 Cross Section Types (I5,2F10.4,F5.2,F10.4,2F5.2,F10.4,F5.2,F10.4)

Supply NSEC cards (see Section 3.3.1), one for each different cross section. See figure 3-4 for definitions. Assign each type a number, starting with one, up to a maximum of 13. Input a negative type number for a section which is symmetrical about the horizontal axis.

If the skeleton curve is input directly for all the elements in the group, NSEC should be equal to zero. Therefore, no cards should be included for this section.

Columns 1 - 5 : Type number (Negative for a symmetrical section).
6 - 15 : Height of the cross section ("HT").
16 - 25 : Bottom width of the cross section ("BB").
26 - 30 : Distance from the bottom face to the centroid of bottom reinforcing steel ("DCB").
31 - 40 : Area of bottom reinforcing steel ("ASB").
41 - 45 : Positive strength degradation parameter, ω^+, for compression side.
46 - 50 : Negative strength degradation parameter, ω^-, for tension side.
These parameters depend on various factors, such as the longitudinal steel ratio, the confinement ratio, the axial force. Values between 1.5 and 2.5 have been found to lead to realistic results.

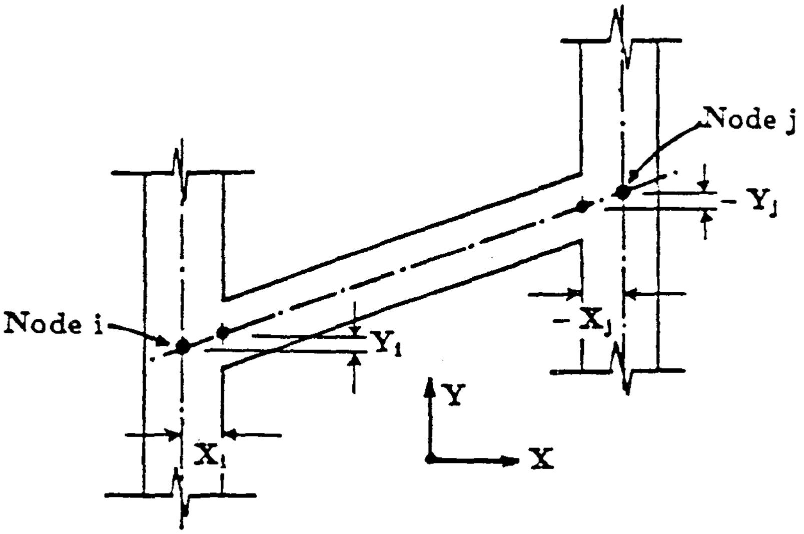


FIGURE 3-5 End Eccentricities of Frame Element

51 - 60 : Top width of cross section ("BT").

Leave blank or zero for a symmetrical section.

61 - 65 : Distance from the top face to the centroid of top reinforcing steel ("DCT").

Leave blank or zero for a symmetrical section.

66 - 75 : Area of top reinforcing steel ("AST").

Leave blank or zero for a symmetrical section.

3.3.5 End Eccentricities (I5,4F10.4)

Plastic hinges may form near the face of a connection rather than inside a beam-column joint. This behavior can be modeled with rigid links connecting nodes with the respective element ends, as shown in figure 3-5.

Supply NECC cards (see Section 3.3.1), one for each different kind of eccentricity. Omit if NECC is equal to zero. All eccentricities are measured from the node to the element end. The eccentricity is considered positive when the element end is in the direction of the X or Y axes, and negative otherwise. Assign each different eccentricity type a number, starting with one, up to maximum 15.

Columns 1 - 5 : Type number.

6 - 15 : X_i = X eccentricity at end i.

16 - 25 : X_j = X eccentricity at end j.

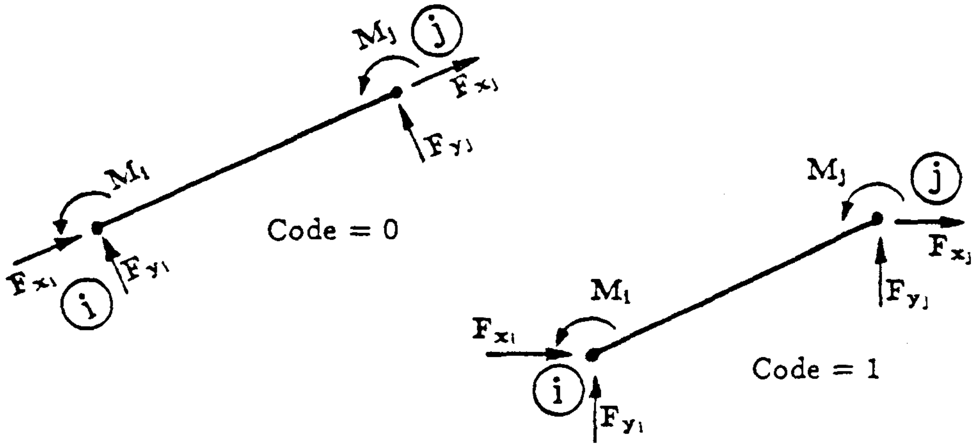
26 - 35 : Y_i = Y eccentricity at end i.

36 - 45 : Y_j = Y eccentricity at end j.

3.3.6 Fixed-End Force Patterns (2I5,7F10.0)

Static dead and live loads applied along the lengths of beams and beam-column elements may be taken into account by specifying fixed-end forces as shown in figure 3-6. The static load code KSTAT (see Section 3.4.1) must be set equal to one. These forces are

a) KGRID = 0



b) KGRID = 1

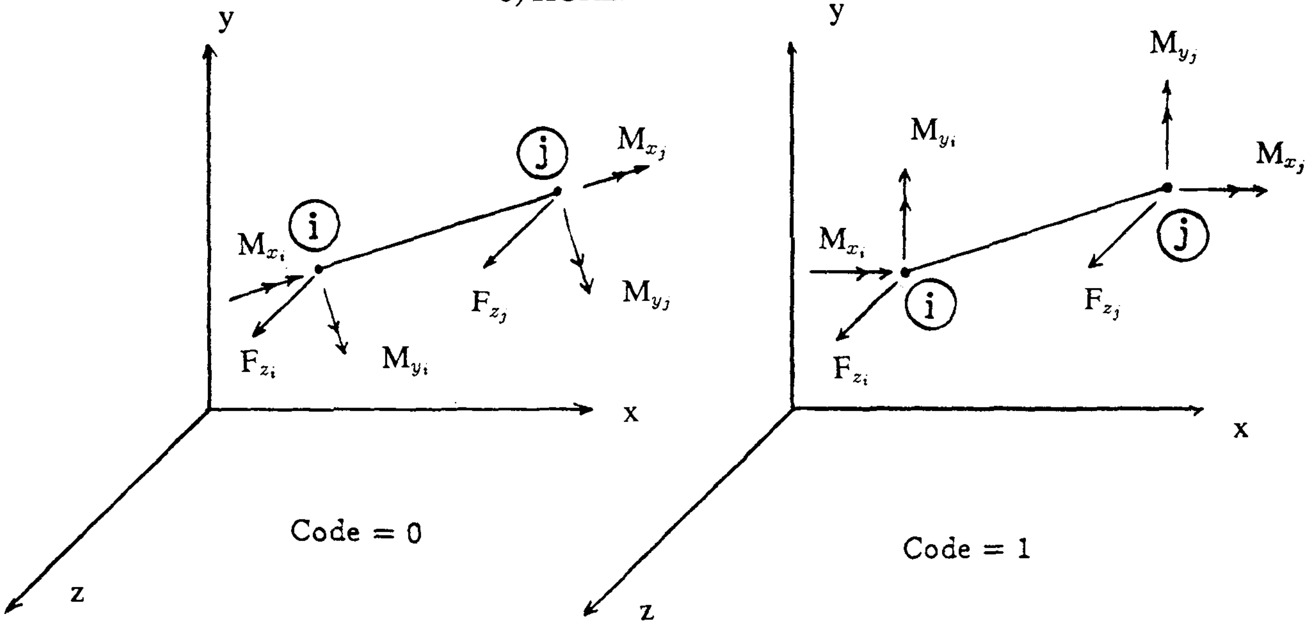


FIGURE 3-6 Fixed End Forces and Initial Force Patterns

those which must act on the element ends to prevent end displacements. The sign convention for these forces is as shown in figure 3-6.

If the static load code KSTAT (see Section 3.4.1) is equal to one, this fixed end forces are applied as static nodal loads on the structure with the opposite sign.

Supply NFEF cards (see Section 3.3.1), one for each different fixed-end force pattern. Omit if NFEF is equal to zero. Assign each different fixed-end force pattern a number, starting with one, up to a maximum of 35.

Columns 1 - 5 : Pattern number.
6 - 10 : Coordinate system code.
  0 : Forces refer to element coordinate system, (figure 3-6).
  1 : Forces refer to global coordinate system, (figure 3-6).
11 - 20 : Fixed end force, F_{x_i} (M_{x_i} if KGRID is equal to one).
21 - 30 : Fixed end force, F_{y_i} (F_{z_i} if KGRID is equal to one).
31 - 40 : Fixed end moment, M_{z_i} (M_{y_i} if KGRID is equal to one).
41 - 50 : Fixed end force, F_{x_j} (M_{x_j} if KGRID is equal to one).
51 - 60 : Fixed end force, F_{y_j} (F_{z_j} if KGRID is equal to one).
61 - 70 : Fixed end moment, M_{z_j} (M_{y_j} if KGRID is equal to one).
71 - 80 : Live load reduction factor. The fixed-end forces specified for each element may account for the live load reduction as permitted, e.g. by the Uniform Building Code for members with large tributary areas. For dead loads, however, this reduction factor is ignored.

3.3.7 Initial Element Force Patterns (I5,6F10.0)

For structures for which static analyses are carried out separately, initial member forces such as those due to prestress may be specified by use of initial element force patterns. These forces are not applied as static nodal loads, therefore, they only change the initial forces such as bending moment, shear or axial forces. The same sign convention indicated for fixed-end force patterns is used. The geometric stiffness, if used, is based on the initial axial force plus any axial force due to static loading, and may be included for the dynamic loading on frame structures, if required.

Supply NINT cards (see Section 3.3.1), one for each different initial element force pattern. Omit if NINT is equal to zero. Assign each different initial element force pattern a number, starting with one, up to a maximum of 30.

If the pattern number is a negative number, the initial force supplied in columns 6–15 is the initial axial force in the case of a grid structure (KGRID equal to one). The rest of the columns are not read. This should not be used for frame structures. A compressive axial load is considered positive, and only positive axial loads should be input. The value of the axial load will be used by the subroutine FMPHI to compute the skeleton curve. If a negative value for the axial load is entered, the program considers it to be zero.

Columns 1 - 5 : Pattern number.
A negative pattern number should be used for grid structures where only an initial axial force, F_{x_i}, is to be indicated. Do not use for frame structures.
6 - 15 : Initial axial force, F_{x_i} (M_{x_i} if KGRID is equal to one unless the pattern number is negative).
16 - 25 : Initial shear force, F_{y_i} (F_{z_i} if KGRID is equal to one).
26 - 35 : Initial moment, M_{z_i} (M_{y_i} if KGRID is equal to one).
36 - 45 : Initial axial force, F_{x_j} (M_{x_j} if KGRID is equal to one).
46 - 55 : Initial shear force, F_{y_j} (F_{z_j} if KGRID is equal to one).
56 - 65 : Initial moment, M_{z_j} (M_{y_j} if KGRID is equal to one).

3.3.8.A Element Generation Commands (8I5,5I4,2F5.0,I5,F5.0)

For structures with similar elements, the program can automatically generate data for elements. If all data for a sequence of elements are identical (except node numbers), only two cards, one for the first and one for the last element in the sequence (the "key elements") need to be provided. In the printout of the element data, generated elements are identified by an asterisk at the beginning of the printed line.

Assign a sequential number for all the elements in the same group, starting with one, up to NMEM (See Section 3.3.1). Supply one card for each key element in increasing numerical order of the assigned element number.

The elements for which the skeleton curve is defined directly, are identified by a negative concrete type number. For those elements, it is necessary to add after the card 3.8.A, another two cards 3.8.B and 3.8.C as later described. If the skeleton curve is symmetric, only the card 3.8.B has to be added. Element generation can still be used if a group of elements has the same skeleton curve and section properties.

Columns 1 - 5 : Element number. If KSYM is not equal to zero, input a negative element number for the beam element, which is located at the symmetrical axis. For example, input -2 , -4 and -6 for element No. ②, ④ and ⑥ in figures 3-1.b and 3-1.c, respectively.

When the element number is negative, the pinching parameter defined in Section 2, is computed assuming that the actual element length is twice the distance between nodes. This can be used when two elements with the same length are used to modeled one beam or column.

6 - 10 : Node number at element end i.

11 - 15 : Node number at element end j.

16 - 20 : Node number increment for element generation.

Default = 1.

21 - 25 : Concrete type number.

If this is a negative number the definition of the skeleton curve must follow (see Sections 3.3.8.B and 3.3.8.C)

26 - 30 : Steel type number.

31 - 35 : Cross section type number.

36 - 40 : End eccentricity type number. Leave blank or input zero if there is no end eccentricity.

41 - 44 : Geometric stiffness code.

The geometric stiffness is computed using the axial loads obtained in the static analysis. The geometric stiffness is not updated during the dynamic analysis, using the varying axial loads.

1 : include geometric stiffness. Only for frame structures (KGRID equal to zero).

0 : ignore the geometric stiffness.

45 - 48 : Time history output code. If a time history of the internal forces is not required for the element covered by this command, input zero or leave blank. If a time history printout, at the intervals specified in Section 3.6.1, is required, input one.

49 - 52 : Code for the output of hysteretic curve. If hysteretic response information for this element is not required, input zero or leave blank. If such information is required, input the node number at element end "*i*" or "*j*", of this element.

53 - 56 : Fixed-end force pattern number for static dead loads on this element. Leave blank or input zero if there are no dead loads.

57 - 60 : Fixed-end force pattern number for static live loads on the element. Leave blank or input zero if there are no live loads.

61 - 65 : Scale factor to be applied to fixed-end forces due to static dead loads.

66 - 70 : Scale factor to be applied to fixed-end forces due to static live loads.

71 - 75 : Initial force pattern number. Leave blank or input zero if there are no initial forces. This must be a positive number even if a negative number was used for the definition of the Initial Force Pattern (see Section 3.3.7)

76 - 80 : Scale factor to be applied to initial element forces.

3.3.8.B Skeleton curve definition for positive moments (10E8.0)

This card must follow 3.8.A when the concrete type number is negative. If the skeleton curve is not symmetric, the card 3.8.C must follow 3.8.B and the axial stiffness has to be input as a negative number as indicated below. In that case all the properties on this card correspond to positive bending moments. See 3.8.C regarding the properties corresponding to negative bending moments. The precise definitions of the parameters described bellow can be found in Ref. [1].

Columns 1 - 8 : Axial stiffness ("EA") in units of force. If this value is positive the program assumes a symmetrical section. For non-symmetrical sections a negative value for EA must be input. (Torsional stiffness "GJ" if KGRID is equal to one).

9 - 16 : Bending stiffness ("EI1").

17 - 24 : Yield bending moment ("FMY1").

25 - 32 : Hardening ratio for inelastic loading ("P1").

P1 is given by:

$$P1 = \frac{FMU1 - FMY1}{(PHIU1)\,(EI) - FMY1}$$

33 - 40 : Curvature for the ultimate moment ("PHIU1").

41 - 48 : Curvature for the failure moment ("PHIF1").

49 - 56 : Ultimate moment ("FMU1").

57 - 64 : Failure moment ("FMF1").

65 - 72 : Strength deterioration parameter, ω^+ ("OMEGAP").

73 - 80 : Pinching parameter, α_p ("ALPHAP")

The Pinching parameter, α_p, has values between zero and one. A Pinching parameter, α_p equal to one indicates that there is no pinching due to shear, whereas α_p equal to zero produces the most pronounced pinching.

3.3.8.C Skeleton curve definition for negative moments (10E8.0)

This card must follow 3.8.B when the skeleton curve is not symmetric. All the properties on this card correspond to negative bending moments. However, positive numbers must be supplied since the program internally changes the sign of the appropriate variables. The precise definitions of the parameters described bellow can be found in Ref. [1].

Columns 1 - 8 : Blank

9 - 16 : Bending stiffness ("EI2").

17 - 24 : Yield bending moment ("FMY2").

25 - 32 : Hardening ratio for inelastic loading ("P2").

33 - 40 : Curvature for the ultimate moment ("PHIF2").

41 - 48 : Curvature for the failure moment ("PHIF2").

49 - 56 : Ultimate moment ("FMU2").

57 - 64 : Failure moment ("FMF2").

65 - 72 : Strength deterioration parameter, ω^- ("OMEGAN").

73 - 80 : Pinching parameter, α_p ("ALPHAN").

Note : If EI2 is different from EI1 or P2 from P1, an average value is used in order to obtain a symmetric global stiffness matrix. The yield moments, FMY1 and FMY2 are also changed.

3.4 Load Information

Static loads may be applied to the structure prior to the application of the dynamic loading, but the response to static load must remain elastic. For a deterministic analysis, ground acceleration data are to be input in the format described in Section 3.4.4.B. If random earthquake data are to be generated, the data described in Section 3.4.3 are to be entered. All the data for the simulation of quasi-static load-displacement experiments are to be input as described in Section 3.4.5.

3.4.1 Load Control Data (2I5,1I10,6F10.0)

Columns 1 - 5 : Static load code ("KSTAT").

1 : Static loads are to be applied prior to dynamic loads.
The static loads are the sum of the input static nodal loads (Section 3.4.2) and the static nodal loads computed from the fixed end force patterns (see Section 3.3.6).

0 : No static loads are to be included in the analysis.

6 - 10 : Number of commands specifying static loads applied directly at the nodes ("NCDLD"). See Section 3.4.2.
Leave blank or input zero if there are no static loads.

11 - 20 : Number of integration time steps to be considered in the dynamic analysis ("NSTEPS").

21 - 30 : Integration time step, Δt ("DT"). If KQSTA is equal to zero, this input value will be considered as integration step size for the reproduction of experimental load-deformation curves.

31 - 40 : Scale factor to be applied to the ground X-accelerations ("FACAXH"). However, if KQSTA is equal to zero, this factor will be applied to input controlled-displacement data.

41 - 50 : Scale factor to be applied to the time coordinates of the

X-acceleration record ("FACAMH"). However, if KQSTA is equal to zero, this factor will be applied to the time step size arbitrarily assumed in Section 3.4.5.B. This value is ignored for artificially generated earthquakes using the Kanai-Tajimi spectrum and only taken into consideration for deterministic earthquakes and artificial earthquakes generated using ARMA models.

51 - 60 : Scale factor to be applied to the ground Y-accelerations ("FACAXV"). If KQSTA is equal to zero, input zero. This value is ignored for artificially generated earthquakes using the Kanai-Tajimi spectrum and only taken into consideration for deterministic earthquakes and artificial earthquakes generated using ARMA models.

61 - 70 : Scale factor to be applied to the time coordinates of the Y-acceleration record ("FACAMV"). If KQSTA is equal to zero, input zero.

71 - 80 : Absolute value of the maximum displacement or rotation permitted ("DISMAX"). The specification of such a displacement and rotation limit presumes that when this limit is exceeded global failure occurs, at which point the execution is terminated. Default = 10^5.

Note : The product DT × NSTEPS may be greater than the duration of the earthquake if the free vibration response after the earthquake has to be computed.

3.4.2 Commands for Static Nodal Loads

Omit if there are no static loads applied directly at nodes. These commands allow the specification of a series of nodes having the same static nodal loads with the sign convention of figure 3-6. A heading card, with the scale factor to be applied to all the static nodal forces, plus one card for each command, are required.

3.4.2.A Scale Factor for Static Nodal Loads (E10.0)

Columns	1 - 10 :	Scale Factor for Static Nodal Loads.

3.4.2.B Commands for Static Nodal Loads (I5,3F10.0,2I5)

Columns	1 - 5 :	First node number in series.
	6 - 15 :	Load in X direction (Moment about the X axis if KGRID= 1).
	16 - 25 :	Load in Y direction. (In Z direction if KGRID= 1).
	26 - 35 :	Moment about the Z axis. (Moment about the Y axis if KGRID= 1).
	36 - 40 :	Last node number in series. Leave blank or zero for a single node.
	41 - 45 :	Node number difference between any two successive nodes in series. Default = 1.

Note : A node may appear in two or more commands if desired, for example, if it is a part of two different series. In such a case, the total load applied at the node will be the sum of the load from the separate commands.

3.4.3 Randomly Generated Earthquakes

Omit this set of data if KQSTA is equal to zero, i.e. for reproduction of the quasi-static experimental load-deformation curves, or if KEARTH is equal to zero, i.e. for a deterministic analysis (See Section 3.1.2), and proceed to Section 3.4.4.

3.4.3.A Data for Randomly Generated Earthquakes (2I5,3F5.2,2F10.4,F5.4,2F5.0)

Two types of randomly generated earthquakes can be used: those generated using the Kanai-Tajimi spectrum and those generated by using ARMA models.

For the second case the ARMA parameters are internally computed from the magnitude and distance to the epicenter. The correlation between these values and the parameters has been obtained for earthquakes in Japan. Single peak and double peak earthquakes can be generated. More details can be found in Ref. [5] and [6]. The acceleration history generated using ARMA Models is expressed in cm/sec^2. If other units are used a conversion scale factor can be used (see Section 3.4.1)

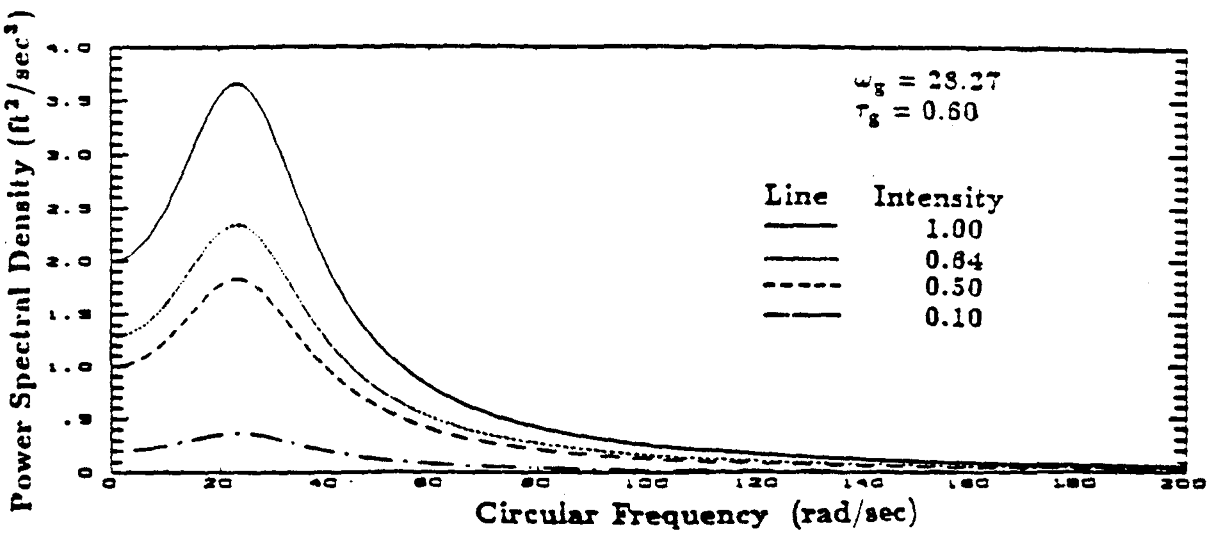


FIGURE 3-7 One-Sided Kanai Tajimi Spectrum

Columns 1 - 5 : Number of artificial earthquakes to be generated ("NEAR").

6 - 10 : Code for type of generation (IEVL). The meaning of the variables input from columns 11 to 60 depends on this code.

1 : Kanai-Tajimi spectrum with trapezoidal envelope.

2 : Kanai-Tajimi spectrum with exponential envelope.

3 : ARMA Model, single event.

4 : ARMA Model, double event.

11 - 15 : Initial peak time, t_1, for IEVL= 1;

coefficient α, for IEVL= 2;

Initial peak time in seconds (usually two sec.), for IEVL= 3, 4;

16 - 20 : Last peak time, t_2, for IEVL= 1;

coefficient β, for IEVL= 2;

Duration of the earthquake, for IEVL= 3, 4;

21 - 25 : Strong motion duration, t_3, for the trapezoidal envelope function (IEVL= 1), but leave blank or input zero for the exponential envelope function (IEVL= 2);

Distance to the epicenter, in kilometers, for IEVL= 3;

Distance to the first event, in kilometers, for IEVL= 4;

26 - 35 : Intensity factor for the input spectrum, S_o, when the one-sided Kanai-Tajimi spectrum is used, figure 3-7.

Magnitude of the earthquake, for IEVL= 3;

Magnitude event one, for IEVL= 4;

36 - 45 : Characteristic dominant frequency, ω_g, for IEVL= 1, 2;

Soil condition factor, γ_f, for IEVL= 3, 4;

46 - 50 : Characteristic dominant damping ratio, τ_g, for IEVL= 1, 2;

Distance to event two, in kilometers, for IEVL= 4;

51 - 55 : Upper cut-off frequency, ω_u, for IEVL= 1, 2;

Magnitude of event two, for IEVL= 4;

56 - 60 : Peak factor for the earthquake simulation, p_g, for IEVL= 1, 2;

Time lag between the two events, in seconds, for IEVL= 4;

Note : For firm soil conditions, the following parameter values are recommended: for $1.0g$ peak acceleration data, $S_o = 0.6378(ft^2/sec^3)$; $\omega_g = 9\pi(rad/sec)$; $\tau_g = 0.6$; $\omega_u = 300(rad/sec)$ for the Kanai-Tajimi spectrum, and $p_g = 3.0$. For $0.1g$ peak acceleration, only the S_o value changes to $0.006378(ft^2/sec^3)$. When the ARMA model is used, a value of γ_f between 0.10 and 0.43 can be used for soil ranging from soft to firm. For further information see Ref. [5, 6 and 10].

3.4.3.B Control Information (4I5,10A4)

Columns 1 - 5 : Number of time-acceleration pairs defining ground motion in X direction (rotation about the X axis if KGRID= 1) (NPTH), which will be randomly generated using IMSL subroutines [7]. Input zero or leave blank for no ground motion in this direction.

6 - 10 : Number of time-acceleration pairs defining ground motion in Y direction (Z direction if KGRID= 1) (NPTV), which will be randomly generated using IMSL subroutines. Input zero or leave blank for no ground motion in this direction.

11 - 15 : Code for echo printing accelerations as input. Leave blank or zero for no output.

1 : print.

0 : do not print.

16 - 20 : Code for echo printing accelerations as interpolated at intervals of Δt.

1 : print.

0 : do not print.

21 - 60 : Title to identify the randomly generated acceleration record.

3.4.4 Deterministic Acceleration Records

Omit this set of data if KEARTH is equal to one, i.e. for randomly generated earthquakes.

3.4.4.A Control Information (4I5,10A4)

Columns 1 - 5 : Number of input time-acceleration pairs defining ground motion in X direction (rotation about the X axis if KGRID= 1) (NPTH). Input zero or leave blank for no ground motion in this direction.

6 - 10 : Number of input time-acceleration pairs defining ground motion in Y direction (Z direction if KGRID= 1) (NPTV). Input zero or leave blank for no ground motion in this direction.

11 - 15 : Code for echo printing accelerations as input. Leave blank or zero for no output.

1 : print.

0 : do not print.

16 - 20 : Code for echo printing accelerations as interpolated at intervals of Δt.

1 : print.

0 : do not print.

21 - 60 : Title to identify the input deterministic acceleration record.

3.4.4.B Ground Acceleration Time History in X-Direction (rotation about X if KGRID= 1) (6(F6.3,F7.3))

Omit if NPTH is equal to zero. Otherwise, enter six pairs of time and acceleration records per card. The first time-acceleration pair has to be (0.0,0.0). Note that both the accelerations and time coordinates may be scaled if desired. See Section 3.4.1.

3.4.4.C Ground Acceleration Time History in Y-Direction (Z-direction if KGRID= 1)

(6(F6.3,F7.3))

Omit if NPTV is equal to zero. Otherwise, enter six pairs of time and acceleration records per card. The first time-acceleration pair has to be (0.0,0.0). Note that both the accelerations and time coordinates may be scaled if desired. See Section 3.4.1.

3.4.5 Quasi-Static Experimental Displacement Records

Omit this set of data if KQSTA is equal to zero (See Section 3.1.2).

3.4.5.A Control Information (4I5,10A4)

Columns 1 - 5 : Number of input controlled-displacement data (NPTH).

6 - 10 : Input zero or leave blank.

11 - 15 : Code for echo printing accelerations as input. Leave blank or zero for no output.

- 1 : print.
- 0 : do not print.

16 - 20 : Code for echo printing accelerations as interpolated at intervals of Δt.

- 1 : print.
- 0 : do not print.

21 - 60 : Title to identify the controlled-displacement record.

3.4.5.B Controlled-Displacement Records (I5,F10.4/8F10.4)

Columns 1 - 5 : Degree of freedom corresponding to the input displacement record.

6 - 15 : Arbitrarily assumed integration step size between adjacent controlled-displacement data. Note that this step size may be scaled down if desired. See Section 3.4.1.

1 - 80 : Enter eight values of the displacement records per card. The first data has to be 0.0. Note that this displacement data may be scaled if desired. See Section 3.4.1.

3.5 Analysis Information

3.5.1 Control Information for Eigenvalue Analysis(2I5)

If KQSTA is equal to one, only the natural frequency of the undamaged frame structure can be obtained.

Columns 1 - 5 : Code for natural frequencies.

1 : compute natural frequencies at specified time intervals.

0 : do not compute natural frequencies. If KQSTA=1, input zero.

6 - 10 : Time intervals, at which natural frequencies are to be computed, expressed as a multiple of the time step, Δt.

3.5.2 Control Information for Damage Indices (4I5)

Omit this card if KDAMAGE is equal to zero in Section 3.1.2. Otherwise, all nodal damage indices as well as global and story damage indices may be obtained at selected time intervals. If KDAMAGE is equal to one, all damage indices will be automatically computed at the end of the time history analysis.

Columns 1 - 5 : Code for time history of damage index.

1 : compute and print time history of damage indices.

0 : do not compute.

6 - 10 : Time interval for story damage indices to be computed, expressed as a multiple of the time step, Δt.

11 - 15 : Time interval for nodal damage indices to be computed, expressed as a multiple of the time step, Δt.

16 - 20 : Time interval for structural damage indices to be computed, expressed as a multiple of the time step, Δt.

3.5.3 Data for Automatic Design Procedure (5X,1I5,4F10.5)

Omit this card if KAUTO is equal to zero in Section 3.1.2, or if KQSTA is equal to one, i.e. for reproduction of the quasi-static experimental load-deformation curves.

Columns 6 - 10 : Maximum number of automated design iterations.

11 - 20 : Target mean value of beam damage indices.

21 - 30 : Tolerance by which the actual mean may deviate from the target mean value.

31 - 40 : Maximum tolerable deviation of individual beam damage indices from the actual mean value.

41 - 50 : Allowable damage index for beam-columns.

3.6 Time History Output Specifications

Omit all the cards for this section if KAUTO is equal to one, i.e. for an automated damage-controlled design analysis and, if KEARTH is equal to one and NEAR is greater than two, i.e. for more than two randomly generated earthquake data. However, envelope values of all nodal displacements and element results are automatically printed at the end of the computation for each randomly generated earthquake, except if the specified maximum displacement has been exceeded.

For the deterministic earthquake data, i.e. KEARTH equal to zero, printed time histories of selected nodal displacements and element results at selected time intervals may be obtained if desired. Similarly, envelope values of all nodal displacements and element results are printed at the end of the computation if the specified maximum displacement was not exceeded. Intermediate result envelopes are also printed at selected time intervals.

3.6.1 Control Information (13I5)

Columns 1 - 5 : Time interval for printout of nodal displacement time histories, expressed as a multiple of a time step Δt. Leave blank for no printout. The nodes for which time histories are required are specified in Sections 3.6.2, 3.6.3 and 3.6.4.

6 - 10 : Time interval for printout of time histories of element results, expressed as a multiple of the time step Δt. Leave blank for no printout. The elements for which time histories are required are specified in Section 3.3.8.

11 - 15 : Time interval for intermediate printout of envelope values, expressed as a multiple of the time step Δt. Leave blank for no intermediate printout. Envelope values are automatically printed at the end of the response period.

16 - 20 : Number of nodes (NHOUT) for which X displacement time histories are required (X rotation if KGRID is equal to 1).

21 - 25 : Number of nodes (NVOUT) for which Y displacement time histories are required. (Z displacement if KGRID is equal to 1).

26 - 30 : Number of nodes (NROUT) for which Z rotation time histories are required. (Y rotation if KGRID is equal to 1).

31 - 35 : Number of pairs of nodes (NHR) for which relative X displacement history is required (X rotation if KGRID is equal to one).

36 - 40 : Number of pairs of nodes (NVR) for which relative Y displacement history is required (Z displacement if KGRID is equal to one).

41 - 45 : Code for joint time history print (ITHPJ).

46 - 50 : Code for relative displacement time history print (ITHPR).

51 - 55 : Code for element time history print (ITHP).

56 - 60 : Code for saving displacement time history on tape (ISJ).

61 - 65 : Code for saving element time history on tape (ISE).

Note : All the codes above may have the following values,

0 : A printout is obtained for each time step.

2 : A printout is obtained at the end

1 : A printout is obtained both at the end and for each time step.

3.6.2 List of Nodes for X-Displacement Time Histories (10I5) (X-rotation if KGRID= 1).

As many cards as needed to specify NHOUT node numbers, with up to 10 nodes per card. Omit if NHOUT is equal to zero.

3.6.3 List of Nodes for Y-Displacement Time Histories (10I5) (Z-displacement if KGRID= 1).

As many cards as needed to specify NVOUT node numbers, with up to 10 nodes per card. Omit if NVOUT is equal to zero.

3.6.4 List of Nodes for Z-Rotation Time Histories (10I5) (Y-rotation if KGRID= 1).

As many cards as needed to specify NROUT node numbers, with up to 10 nodes per card. Omit if NROUT = 0.

3.6.5 List of pairs of Nodes for relative X-Displacement Time Histories (10I5) (X-rotation if KGRID= 1).

As many cards as needed to specify NHR pairs of node numbers, with up to 10 nodes per card. Omit if NHR is equal to zero.

3.6.6 List of pairs of Nodes for relative Y-Displacement Time Histories (10I5) (Z-displacement if KGRID= 1).

As many cards as needed to specify NVR pairs of node numbers, with up to 10 nodes per card. Omit if NVR is equal to zero.

3.7 Termination

One card (A4) to terminate the complete data.

Columns 1 - 4 : Print the word "STOP".

SECTION 4

INSTALLATION AND EXECUTION

SARCF–II is written in Fortran-77 language for VAX computer systems and has been successfully installed on SUN micro-computer systems and on Silicon Graphics IRIS-4D workstations. All the calculations need to be performed in double precision. Otherwise, truncation errors would cause excessive errors in the solution, and numerical instabilities. The SARCF–II source consists of about 8500 statements,and is organized in a number of "base" subroutines. These subroutines read and print the structural and loading data, assemble the stiffness matrix and load vector, compute the displacement histories of the structure, eigenvalues, the statistics of damage indices; and perform automated damage-controlled design modifications of a preliminary frame design. It is particularly noted that SARCF–II calls some IMSL subroutines to generate random earthquakes Ref. [7] and to calculate the inverse stiffness matrix for reproduction of quasi-static experimental load-deformation curves. Because the IMSL library is proprietary, these subroutines are not provided. These subroutines are: DSCAL, FFTCC, GGNML, GGUBS, GGUD, LINV3F, LUDATN, LUELMN, MDNRIS, MERFI, UERTST, UGETIO and USPKD.

A typical procedure to execute SARCF–II on a Micro-Vax II or to execute the program on a SUN micro-computer, is listed below:

For Micro-Vax

```
% f77 -c -O -w sarcf.f
% f77 -o SARCF sarcf.o -limsl
% SARCF <Datafile >Outputfile
```

For SUN

```
% f77 -ffpa -w -O -o sarcf.f
% f77 -o SARCF sarcf.o -limsld
% SARCF <Datafile >Outputfile
```

After executing SARCF–II, the following output or scratch files will be generated on the Micro-Vax or SUN micro-computer:

fort.2 : scratch file for element information. This file is read before an analysis of a damaged structure is started.

fort.7 : scratch file for element information only if the automated damage-controlled design is required.

fort.8 : scratch file for time history of horizontal or vertical displacement if required (see Section 3.6.2 and 3.6.3).

fort.9 : scratch file for time history of rotational displacement if required (see Section 3.6.4).

fort.12 : scratch file for element stiffness information only if natural frequencies are required.

fort.13 : scratch file for element lumped mass information only if natural frequencies are required.

fort.14 : scratch file for modes shapes only if natural frequencies are required.

fort.16 : output file of the hysteretic curve information only for the element required (see Section 3.3.8).

fort.17 : scratch file for element information.

fort.20 : output file of time history of damage indices if damage analysis is required.

fort.33 : output file of mean values of all the element damage indices only if random earthquake analysis is required.

fort.34 : output file of shear forces of all columns only if KQSTA = 1 (See Section 3.1.2), i.e for reproduction of the quasi-static experimental load-deformation curves.

fort.59 : output file of displacements, damage indices and structure information to be used as input for the graphic postprocessor SARCF-G (see Section 3.1.2).

fort.60	output file of time and X displacements (Z displacements if KGRID= 1) pairs for node number one.
fort.70	output file of X acceleration (Z acceleration if KGRID= 1) values for node number one, one for each integration time step.
fort.71	output file of base X acceleration (Z acceleration if KGRID= 1) values, one for each integration time step.
fort.72	output file of base X acceleration (rotational acceleration about the X axis if KGRID= 1) values, one for each sample point. This file is read when the program is run with K2EARTH equal to two (see Section 3.1.2)
fort.73	output file of base Y acceleration (Z acceleration if KGRID= 1) values, one for each sample point. This is read when the program is run with K2EARTH equal to two (see Section 3.1.2)
fort.77	interactive earthquake data file if automated damage-controlled design option is required even for deterministic earthquake input data, i.e. KAUTO equal to one and KEARTH equal to zero
fort.80	output file of time-natural period pairs for each specified interval.

SECTION 5

EXAMPLES FOR INPUT DATA

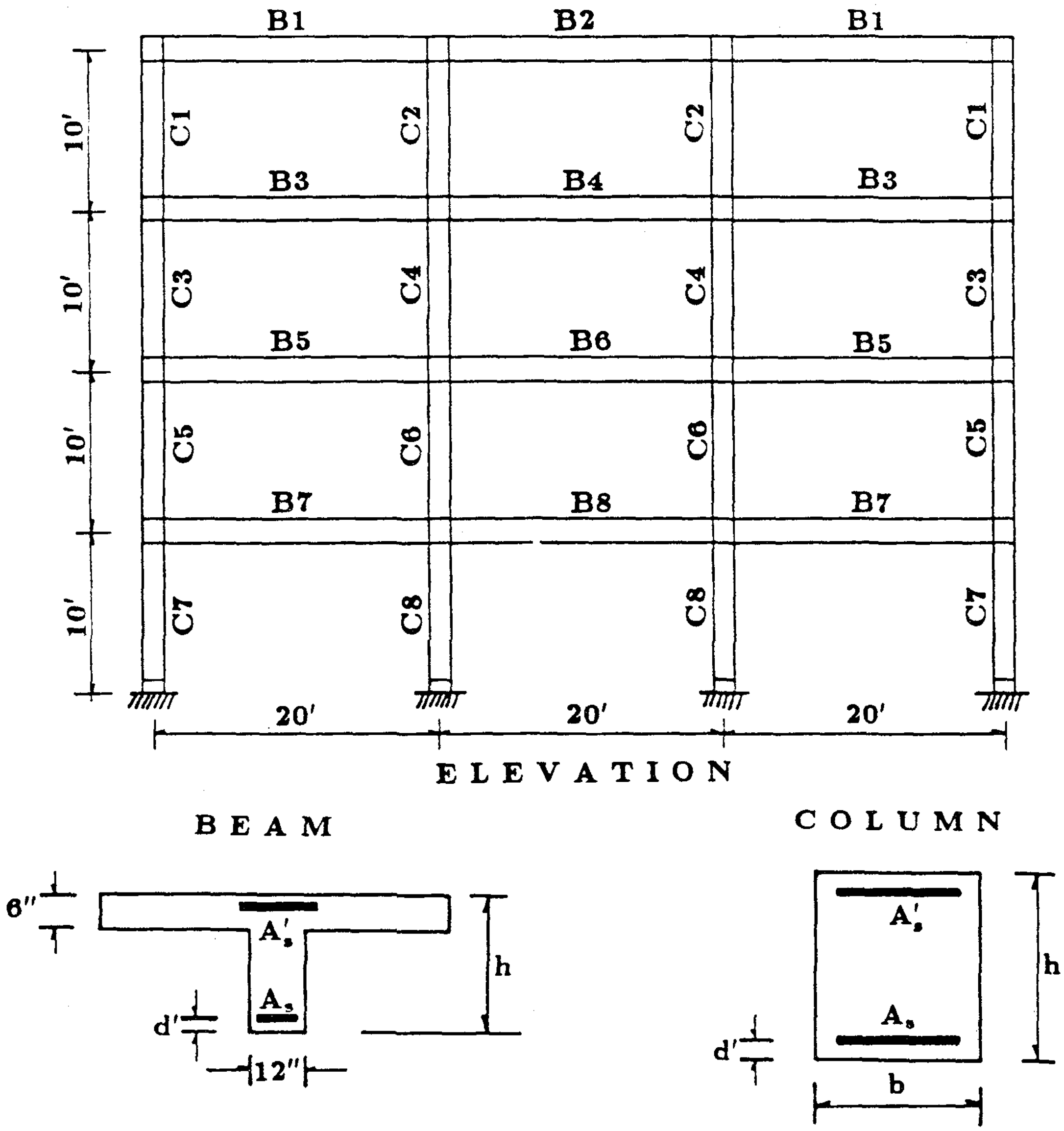
Six examples are provided to demonstrate the usage of the different analysis and design options of the program SARCF−II. The first example utilizes an artificially generated ground motion using an ARMA model. The second example utilizes a deterministic earthquake ground motion. In the third example the ground accelerations are artificially generated, using an envelope function of the exponential type. An automated damage-controlled design is presented in the the fourth example. The fifth example presents the quasi-static experimental load-deformation curve.Detailed input data and some basic output are included with further explanations. See Ref. [2] for more information.

5.1 Analysis of Four-Story Three-Bay Frame with ARMA Earthquake

This example illustrates the input for a four-story three-bay building frame shown in figure 5-1. The nonlinear response to an artificially generated earthquake using an ARMA model is to be computed. The earthquake magnitude is of 7 and the epicenter is assumed to be at 10 km. The fundamental natural frequency and the damage indices are requested. The input data are listed in table 5-I. The printout of the fundamental natural frequency and corresponding mode shape before the dynamic analysis are listed in table 5-II.

5.2 Deterministic Analysis of an Irregular Frame

The input data for the building frame shown in figure 5-2 are listed in table 5-III. The nonlinear response, fundamental natural frequency and the damage indices are to be computed for the El Centro Earthquake, North-South acceleration record.



	d'	A_s	A'_s	h
	(in)	(in^2)	(in^2)	(in)
B1,B2	2.0	1.596	1.596	18.0
B3,B4	2.0	2.400	2.400	20.0
B5,B6	2.0	2.622	2.622	22.0
B7,B8	2.0	2.736	2.736	22.0

	d'	A_s	A'_s	b	h
	(in)	(in^2)	(in^2)	(in)	(in)
C1	1.500	2.160	2.160	12.0	15.0
C2,C3	1.875	2.993	2.993	12.0	18.0
C4,C5,C7	1.875	3.135	3.135	12.0	18.0
C6,C8	1.875	3.260	3.260	12.0	18.0

FIGURE 5-1 Details of a Three Bay Four Story Building Frame
(1 in = 2.54 cm ; 1 kip = 4.448 kN)

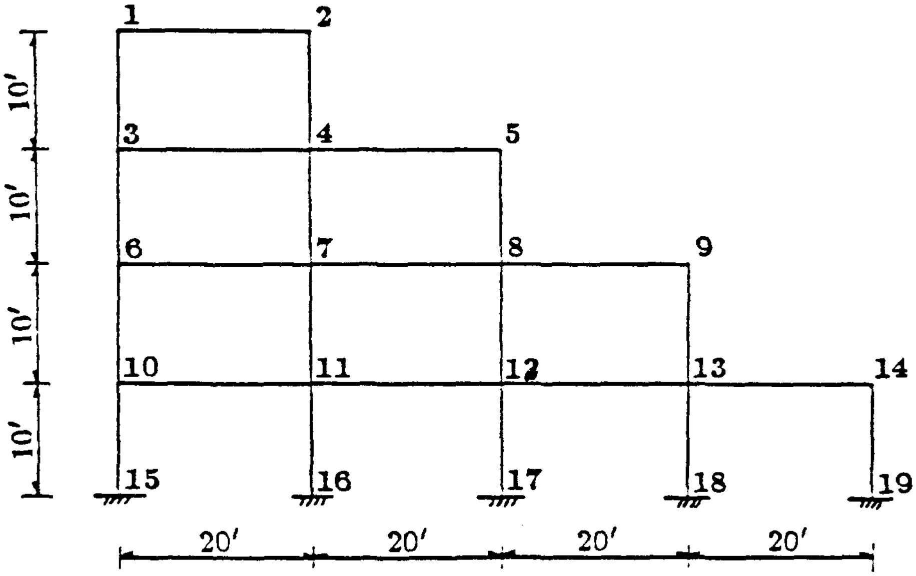


FIGURE 5-2 Irregular Building Frame

TABLE 5-I Analysis of Four-Story Three-Bay Frame with ARMA Earthquake

```
START 3 BAYS 4 STORIES (strong columns)  ARTIFICIAL QUAKE  (M 7.0 , D 10 km)
    0    1    1    0   -1    0
    4    3   20    8    4    1    4    8    2    0    0     50000
    10.0       480.0
    2240.0     480.0
    3480.0     480.0
    4720.0     480.0
   17  0.0     0.0
   18240.0     0.0
   19480.0     0.0
   20720.0     0.0
    1   17    3    4
    2   18    3    4
    3   19    3    4
    4   20    3    4
   17    1    1    1   20    1
    1    4    1    2    3    4
    1    4    5    6    7    8
    1    4    9   10   11   12
    1    4   13   14   15   16
   13  0.086060  0.086060       0.0   16     3  1.
   14  0.135240  0.135240       0.0   15     1  1.
    9  0.086060  0.086060       0.0   12     3  1.
   10  0.135240  0.135240       0.0   11     1  1.
    5  0.083690  0.083690       0.0    8     3  1.
    6  0.132780  0.132780       0.0    7     1  1.
    1  0.078810  0.078810       0.0    4     3  1.
    2  0.137560  0.137560       0.0    3     1  1.
    0.4305  0.00248       0.0       0.0
    1   12    1    2    4    4    9    0
    1    29000.000        0.01     60.00     0.100
    1       4.0  0.0030   0.024
    2       4.0  0.0030   0.030
    1      18.0     12.00 2.00      1.596 1.50 1.50       55.   2.1.596
    2      20.0     12.00 2.00      2.400 1.50 1.50       55.   2.2.400
    3      22.0     12.00 2.00      2.622 1.50 1.50       55.   2.2.622
    4      22.0     12.00 2.00      2.736 1.50 1.50       55.   2.2.736
    1       7.5      -7.5       0.0       0.0
    2       7.5      -9.0       0.0       0.0
    3       9.0      -9.0       0.0       0.0
    4       9.0      -7.5       0.0       0.0
    1    1        0.  32.5      1007.50        0.  32.5     -1007.50
    2    1        0.  32.8      1016.80        0.  32.8     -1016.80
    3    1        0.  33.       1023.          0.  33.      -1023.
    4    1        0.   4.        124.00        0.   4.       -124.00
    5    1        0.  10.        310.00        0.  10.       -310.00
    6    1        0.  32.5      1056.25        0.  32.5     -1007.50
    7    1        0.  32.5      1007.50        0.  32.5     -1056.25
    8    1        0.   4.        130.00        0.   4.       -124.00
    9    1        0.   4.        124.00        0.   4.       -130.00
```

TABLE 5-I Analysis of Four-Story Three-Bay Frame with ARMA Ear thquake (cont'd)

```
    1    1    2    0    1    1    1    2    0    0    0    6    8  1.0  0.0    0  0.0
    2    2    3    0    1    1    1    3    0    0    2    1    4  1.0  0.0    0  0.0
    3    3    4    0    1    1    1    4    0    0    0    7    9  1.0  0.0    0  0.0
    4    5    6    0    1    1    2    3    0    0    0    2    5  1.0  0.0    0  0.0
    5    6    7    0    1    1    2    3    0    0    0    2    5  1.0  0.0    0  0.0
    6    7    8    0    1    1    2    3    0    0    0    2    5  1.0  0.0    0  0.0
    7    9   10    0    2    1    3    3    0    0    0    3    5  1.0  0.0    0  0.0
    8   10   11    0    2    1    3    3    0    0    0    3    5  1.0  0.0    0  0.0
    9   11   12    0    2    1    3    3    0    0    0    3    5  1.0  0.0    0  0.0
   10   13   14    0    2    1    4    3    0    0    0    3    5  1.0  0.0    0  0.0
   11   14   15    0    2    1    4    3    0    0    0    3    5  1.0  0.0    0  0.0
   12   15   16    0    2    1    4    3    0    0    0    3    5  1.0  0.0    0  0.0
    2   16    1    3    4    4    0    0
    1   29000.000       0.01     60.00    0.100
    1       4.0   0.0030   0.012
    2       4.0   0.0030   0.010
    3       4.0   0.0030   0.008
   -1      15.0     12.00 1.50      2.160 1.50 1.50
   -2      18.0     12.001.875      2.993 1.50 1.50
   -3      18.0     12.001.875      3.135 1.50 1.50
   -4      18.0     12.001.875      3.260 1.50 1.50
    1       0.0        0.0     -11.0        0.0
    2       0.0        0.0     -11.0       11.0
    3       0.0        0.0     -10.0       11.0
    4       0.0        0.0     -09.0       10.0
    1    1    5    0    1    1    1    4    1    1    0    0    0  0.0  0.0    0  0.0
    2    2    6    0    1    1    2    4    1    1    0    0    0  0.0  0.0    0  0.0
    3    3    7    0    1    1    2    4    1    1    0    0    0  0.0  0.0    0  0.0
    4    4    8    0    1    1    1    4    1    1    0    0    0  0.0  0.0    0  0.0
    5    5    9    0    1    1    2    3    1    1    0    0    0  0.0  0.0    0  0.0
    6    6   10    0    2    1    3    3    1    1    0    0    0  0.0  0.0    0  0.0
    7    7   11    0    2    1    3    3    1    1    0    0    0  0.0  0.0    0  0.0
    8    8   12    0    1    1    2    3    1    1    0    0    0  0.0  0.0    0  0.0
    9    9   13    0    2    1    3    2    1    1    0    0    0  0.0  0.0    0  0.0
   10   10   14    0    3    1    4    2    1    1    0    0    0  0.0  0.0    0  0.0
   11   11   15    0    3    1    4    2    1    1    0    0    0  0.0  0.0    0  0.0
   12   12   16    0    2    1    3    2    1    1    0    0    0  0.0  0.0    0  0.0
   13   13   17    0    3    1    3    1    1    1    0    0    0  0.0  0.0    0  0.0
   14   14   18    0    3    1    4    1    1    1    0    0    0  0.0  0.0    0  0.0
   15   15   19    0    3    1    4    1    1    1    0    0    0  0.0  0.0    0  0.0
   16   16   20    0    3    1    3    1    1    1    0    0    0  0.0  0.0    0  0.0
    1    8     12500    00.002     .39370        1.0       1.0        0.0     100.0
    1.000000000000
    1         0.      -3.94         0.    4    3
    2         0.      -4.13         0.    3    1
    5         0.      -9.66         0.    8    3
    6         0.      -5.85         0.    7    1
    9         0.     -10.25         0.   12    3
   10         0.      -6.25         0.   11    1
   13         0.     -10.25         0.   16    3
   14         0.      -6.25         0.   15    1
    1    3    2.   20.   10.   7.0           .10
 1000 0000    0    0    ARTIFICIAL EARTHQUAKE M 7.0 D 10
    1    1
    120000   50020000
    012500    0    0
STOP
```

TABLE 5-II Example 1. Output for Natural Frequency and Mode Shape

```
FIRST NATURAL FREQUENCY =    0.11849e+01
FIRST MODE SHAPE:
    NODE             X                Y                R
      1         0.1000e+01       0.5097e-02      -0.1017e-02
      2         0.1000e+01      -0.5969e-02      -0.1071e-02
      3         0.1000e+01      -0.5184e-02      -0.1068e-02
      4         0.1000e+01      -0.1102e-01      -0.1009e-02
      5         0.7990e+00       0.4714e-02      -0.1587e-02
      6         0.7990e+00      -0.5992e-02      -0.1386e-02
      7         0.7990e+00      -0.5154e-02      -0.1383e-02
      8         0.7990e+00      -0.1062e-01      -0.1582e-02
      9         0.5430e+00       0.3995e-02      -0.1865e-02
     10         0.5430e+00      -0.5175e-02      -0.1544e-02
     11         0.5430e+00      -0.4355e-02      -0.1540e-02
     12         0.5430e+00      -0.9092e-02      -0.1861e-02
     13         0.2484e+00       0.2630e-02      -0.2098e-02
     14         0.2484e+00      -0.3205e-02      -0.1610e-02
     15         0.2484e+00      -0.2594e-02      -0.1607e-02
     16         0.2484e+00      -0.5756e-02      -0.2096e-02
     17         0.0000e+00       0.0000e+00       0.0000e+00
     18         0.0000e+00       0.0000e+00       0.0000e+00
     19         0.0000e+00       0.0000e+00       0.0000e+00
     20         0.0000e+00       0.0000e+00       0.0000e+00
```

TABLE 5-III Deterministic Analysis of an Irregular Frame

```
START    NONSYMMETRIC FOUR-STORY FRAME
    0    0    1    0   -1
    4    0   19   10    4    1    4    7    2    0    0       30000
    4    3    2    1
    10.         480.
    2240.       480.
    30.         360.
    5480.       360.
    60.         240.
    9720.       240.
   100.         120.
   14960.       120.
   150.         0.
   19960.       0.
    3    5    1    1
    6    9    2    1
   10   14    3    1
   15   19    3    1
   15    1    1    1   19    1
    1    2    1    2
    1    3    3    4    5
    1    4    6    7    8    9
    1    5   10   11   12   13   14
    1  0.072733  0.072733      0.0    2    0  1.
    3  0.069094  0.069094      0.0    5    2  1.
    4  0.138188  0.138188      0.0    0    0  1.
    6  0.071251  0.071251      0.0    9    3  1.
    7  0.142501  0.142501      0.0    8    0  1.
   10  0.068474  0.068474      0.0   14    4  1.
   11  0.136948  0.136948      0.0   13    1  1.
    0.075      0.004       0.0       0.0
    1   10    1    2    4    2    0    0
    1    29000.000       0.01      60.00      0.100
    1       4.0    0.0030   0.024
    2       4.0    0.0030   0.030
   -1      18.0     12.00      2.00      1.596 1.50
   -2      20.0     12.00      2.00      2.400 1.50
   -3      22.0     12.00      2.00      2.622 1.50
   -4      22.0     12.00      2.00      2.736 1.50
    1       7.5     -7.5       0.0        0.0
    2       9.0     -9.0       0.0        0.0
    1    1    2    0    1    1    1    1   0   0   0   0   0  0.0  0.0    0  0.0
    2    3    4    0    1    1    2    2   0   0   0   0   0  0.0  0.0    0  0.0
    3    4    5    0    1    1    2    2   0   0   0   0   0  0.0  0.0    0  0.0
    4    6    7    0    2    1    3    2   0   0   0   0   0  0.0  0.0    0  0.0
    5    7    8    0    2    1    3    2   0   0   0   0   0  0.0  0.0    0  0.0
    6    8    9    0    2    1    3    2   0   0   0   0   0  0.0  0.0    0  0.0
    7   10   11    0    2    1    4    2   0   0   0   0   0  0.0  0.0    0  0.0
    8   11   12    0    2    1    4    2   0   0   0   0   0  0.0  0.0    0  0.0
    9   12   13    0    2    1    4    2   0   0   0   0   0  0.0  0.0    0  0.0
   10   13   14    0    2    1    4    2   0   0   0   0   0  0.0  0.0    0  0.0
    2   14    1    3    4    4    7    0
    1    29000.000       0.01      60.00    0.100
```

TABLE 5-III Deterministic Analysis of an Irregular Frame (cont'd)

```
    1       4.0    0.0030   0.012
    2       4.0    0.0030   0.010
    3       4.0    0.0030   0.008
   -1      15.0     12.00     1.50      2.160 1.50
   -2      18.0     12.00     1.875     2.993 1.50
   -3      18.0     15.00     1.875     3.135 1.50
   -4      18.0     15.00     1.875     3.260 1.50
    1       0.0       0.0    -11.0       0.0
    2       0.0       0.0    -11.0      11.0
    3       0.0       0.0    -10.0      11.0
    4       0.0       0.0    -9.00      10.0
    1    0  26.250         0.0       0.0  -26.250        0.0       0.0
    2    0  52.792         0.0       0.0  -52.792        0.0       0.0
    3    0 105.583         0.0       0.0 -105.583        0.0       0.0
    4    0  80.229         0.0       0.0  -80.229        0.0       0.0
    5    0 160.458         0.0       0.0 -160.458        0.0       0.0
    6    0 107.854         0.0       0.0 -107.854        0.0       0.0
    7    0 215.708         0.0       0.0 -215.708        0.0       0.0
    1    1    3    0    1    1    1    4   0   0   0   1   0  1.0  0.0    0  0.0
    2    2    4    0    1    1    1    4   0   0   0   1   0  1.0  0.0    0  0.0
    3    3    6    0    1    1    2    3   0   0   0   2   0  1.0  0.0    0  0.0
    4    4    7    0    2    1    3    3   0   0   0   3   0  1.0  0.0    0  0.0
    5    5    8    0    1    1    2    3   0   0   0   2   0  1.0  0.0    0  0.0
    6    6   10    0    2    1    3    2   0   0   0   4   0  1.0  0.0    0  0.0
    7    7   11    0    2    1    4    2   0   0   0   5   0  1.0  0.0    0  0.0
    8    8   12    0    2    1    4    2   0   0   0   5   0  1.0  0.0    0  0.0
    9    9   13    0    2    1    3    2   0   0   0   4   0  1.0  0.0    0  0.0
   10   10   15    0    2    1    3    1   0   0   0   6   0  1.0  0.0    0  0.0
   11   11   16    0    3    1    4    1   0   0   0   7   0  1.0  0.0    0  0.0
   12   12   17    0    3    1    4    1   0   0   0   7   0  1.0  0.0    0  0.0
   13   13   18    0    3    1    4    1   0   0   0   7   0  1.0  0.0    0  0.0
   14   14   19    0    2    1    3    1   0   0   0   6   0  1.0  0.0    0  0.0
    0    0       7680.010          38.64       1.0       1.0       0.0     300.0
  384    0    0    0   El CENTRO NORTH-SOUTH EARTHQUAKES
 0.000  0.000 0.020 -0.014 0.040 -0.110 0.060 -0.103 0.080 -0.090 0.100 -0.097
 0.120 -0.122 0.140 -0.145 0.160 -0.130 0.180 -0.112 0.200 -0.087 0.220 -0.087
   *      *     *      *     *      *     *      *     *      *     *      *
   *      *     *      *     *      *     *      *     *      *     *      *
   *      *     *      *     *      *     *      *     *      *     *      *
 7.440  0.204 7.460  0.443 7.480  0.501 7.500  0.195 7.520  0.094 7.540 -0.022
 7.560 -0.021 7.580  0.053 7.600  0.095 7.620  0.260 7.640  0.375 7.660  0.535
    1    0
    0  400  400  400
    0    0    0    0    0    0    0    0    0    0    0    0    0
STOP
```

TABLE 5-IV Random Vibration Analysis of Four-Story Three-Bay Frame

```
START   RANDOM VIBRATION ANALYSIS FOR FOUR STORY - THREE BAY FRAME
    0    1    1    0   -1
    4    3   14    6    3    2    4    8    2    0    1     30000
    10.0       480.0
    2240.0     480.0
    3360.0     480.0
   12360.0     120.0
   130.0       0.0
   14240.0     0.0
    1   13    3    3
    2   14    3    3
    3   12    2    3
   13    1    1    1   14    1
    3    0    1    0   12    3
    1    3    1    2    3
    1    3    4    5    6
    1    3    7    8    9
    1    3   10   11   12
   10  0.067638  0.067638       0.0    0    0  1.
   11  0.135276  0.135276       0.0    0    0  1.
    7  0.070280  0.070280       0.0    0    0  1.
    8  0.140560  0.140560       0.0    0    0  1.
    4  0.068366  0.068366       0.0    0    0  1.
    5  0.136732  0.136732       0.0    0    0  1.
    1  0.074081  0.074081       0.0    0    0  1.
    2  0.148163  0.148163       0.0    0    0  1.
    0.075     0.004       0.0       0.0
    1    8    1    2    4    5    0    0
    1    29000.000       0.01     60.00     0.100
    1       4.0  0.0030   0.024
    2       4.0  0.0030   0.030
   -1      20.0     12.00 2.00      2.280 1.50 1.50
   -2      20.0     12.00 2.00      2.622 1.50 1.50
   -3      22.0     12.00 2.00      2.622 1.50 1.50
   -4      22.0     12.00 2.00      2.736 1.50 1.50
    1       7.5      -7.5       0.0       0.0
    2       7.5      -9.0       0.0       0.0
    3       9.0      -9.0       0.0       0.0
    4       7.5       0.0       0.0       0.0
    5       9.0       0.0       0.0       0.0
    1    1    2    0    1    1    1    1   0   0   0   0   0  0.0  0.0    0  0.0
   -2    2    3    0    1    1    1    4   0   0   0   0   0  0.0  0.0    0  0.0
    3    4    5    0    1    1    2    1   0   0   0   0   0  0.0  0.0    0  0.0
   -4    5    6    0    1    1    2    4   0   0   0   0   0  0.0  0.0    0  0.0
    5    7    8    0    2    1    3    2   0   0   0   0   0  0.0  0.0    0  0.0
   -6    8    9    0    2    1    3    5   0   0   0   0   0  0.0  0.0    0  0.0
    7   10   11    0    2    1    4    3   0   0   0   0   0  0.0  0.0    0  0.0
   -8   11   12    0    2    1    4    5   0   0   0   0   0  0.0  0.0    0  0.0
    2    8    1    3    4    4    8    0
    1    29000.000       0.01     60.00   0.100
```

TABLE 5-IV Random Vibration Analysis of Four-Story Three-Bay Frame (cont'd)

```
    1       4.0    0.0030   0.012
    2       4.0    0.0030   0.010
    3       4.0    0.0030   0.008
   -1      15.0     12.00 1.50     1.800 1.50 1.50
   -2      15.0     12.00 1.50     2.850 1.50 1.50
   -3      18.0     15.001.875     2.850 1.50 1.50
   -4      18.0     15.001.875     2.964 1.50 1.50
    1       0.0       0.0    -11.0        0.0
    2       0.0       0.0    -11.0       11.0
    3       0.0       0.0    -10.0       11.0
    4       0.0       0.0    -10.0       10.0
    1    0  26.833         0.0       0.0  -26.833        0.0       0.0
    2    0  53.667         0.0       0.0  -53.667        0.0       0.0
    3    0  53.250         0.0       0.0  -53.250        0.0       0.0
    4    0 106.500         0.0       0.0 -106.500        0.0       0.0
    5    0  80.250         0.0       0.0  -80.250        0.0       0.0
    6    0 160.500         0.0       0.0 -160.500        0.0       0.0
    7    0 107.563         0.0       0.0 -107.563        0.0       0.0
    8    0 215.125         0.0       0.0 -215.125        0.0       0.0
    1    1    4    0    1    1    1    4   0   0   0   1   0  1.0  0.0     0  0.0
    2    2    5    0    1    1    1    4   0   0   0   2   0  1.0  0.0     0  0.0
    3    4    7    0    1    1    1    3   0   0   0   3   0  1.0  0.0     0  0.0
    4    5    8    0    2    1    2    3   0   0   0   4   0  1.0  0.0     0  0.0
    5    7   10    0    2    1    2    2   0   0   0   5   0  1.0  0.0     0  0.0
    6    8   11    0    3    1    3    2   0   0   0   6   0  1.0  0.0     0  0.0
    7   10   13    0    3    1    3    1   0   0   0   7   0  1.0  0.0     0  0.0
    8   11   14    0    3    1    4    1   0   0   0   8   0  1.0  0.0     0  0.0
    0    0      12000.010           1.00       1.0       1.0       0.0    300.0
   10    1  1.5 11.5 13.0  386.4000   28.2743 0.6 300.0  3.0  1.0
  512    0    0    0INPUT ARTIFICIAL GROUND MOTIONS
    1    0
    0  400  400  400
STOP
```

5.3 Random Vibration Analysis of a Four-Story Three-Bay Frame

This example illustrates the input for one-half of a four-story and three-bay building frame shown in figure 5-3, by making use of symmetry. Ten artificial earthquake ground motions are now to be generated. After the ten analyses, the mean and the standard deviation of the beam damage indices will be computed. The input data for this case can be seen in table 5-IV.

5.4 Automated Design Example for Deterministic Earthquake

Input data for this example are almost the same as those for the third example, except that deterministic earthquake data are now to be input instead of the randomly generated ground motions in the third example, and the automated design option is utilized. The input data for this case are identical to those for the third example, except for the following:

The two first lines are now:

```
START   AUTOMATIC DESIGN FOR 4 STORY-3 BAY FRAME ON DETERMINISTIC EARTHQUAKE
    0    0    1    1   -1
```

instead of:

```
START   RANDOM VIBRATION ANALYSIS FOR FOUR STORY - THREE BAY FRAME
    0    1    1    0   -1
```

The input ground acceleration is El Centro Earthquake, therefore the following lines are introduced:

```
START   AUTOMATIC DESIGN FOR 4 STORY-3 BAY FRAME ON DETERMINISTIC EARTHQUAKE
    0    0    1    1   -1
```

instead of:

```
START   RANDOM VIBRATION ANALYSIS FOR FOUR STORY - THREE BAY FRAME
    0    1    1    0   -1
```

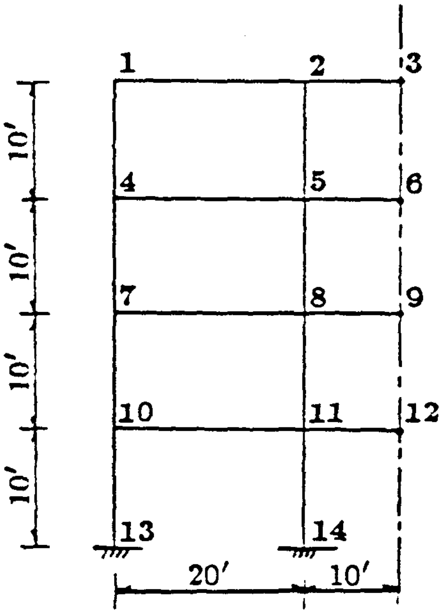


FIGURE 5-3 Half of Four Story Three Bay Building Frame

The input ground acceleration is El Centro Earthquake, therefore the following lines are introduced:

```
  0     0     384  0.020          40.000        1.0        1.0        0.0    300.0
 384    0     0     0   El CENTRO N-S EARTHQUAKES
 0.000  0.000 0.020 -0.014 0.040 -0.110 0.060 -0.103 0.080 -0.090 0.100 -0.097
 0.120 -0.122 0.140 -0.145 0.160 -0.130 0.180 -0.112 0.200 -0.087 0.220 -0.087
 7.440  0.204 7.460  0.443 7.480  0.501 7.500  0.195 7.520  0.094 7.540 -0.022
 7.560 -0.021 7.580  0.053 7.600  0.095 7.620  0.260 7.640  0.375 7.660  0.535
```

instead of:

```
  0     0     1200  0.010             1.00        1.0        1.0        0.0    300.0
  10    1   1.5 11.5 13.0  386.4000   28.2743 0.6 300.0  3.0  1.0
 512    0     0     OINPUT ARTIFICIAL GROUND MOTIONS
```

This input specifies a target mean value of 0.15 for the beam damage indices, with tolerance 0.05, and maximum deviation of 0.1. For columns, the maximum allowable damage index is specified to be 0.01. This is expressed in the following new line:

```
0  20  0.1500   0.05   0.10   0.01
```

5.5 Quasi-Static Load-Deformation Curve

Ohno's quasi-static experimental load-deformation curves [9] have been simulated numerically. The input data for the experimental one-bay one-story frame of figure 5-4 are listed in table 5-V.

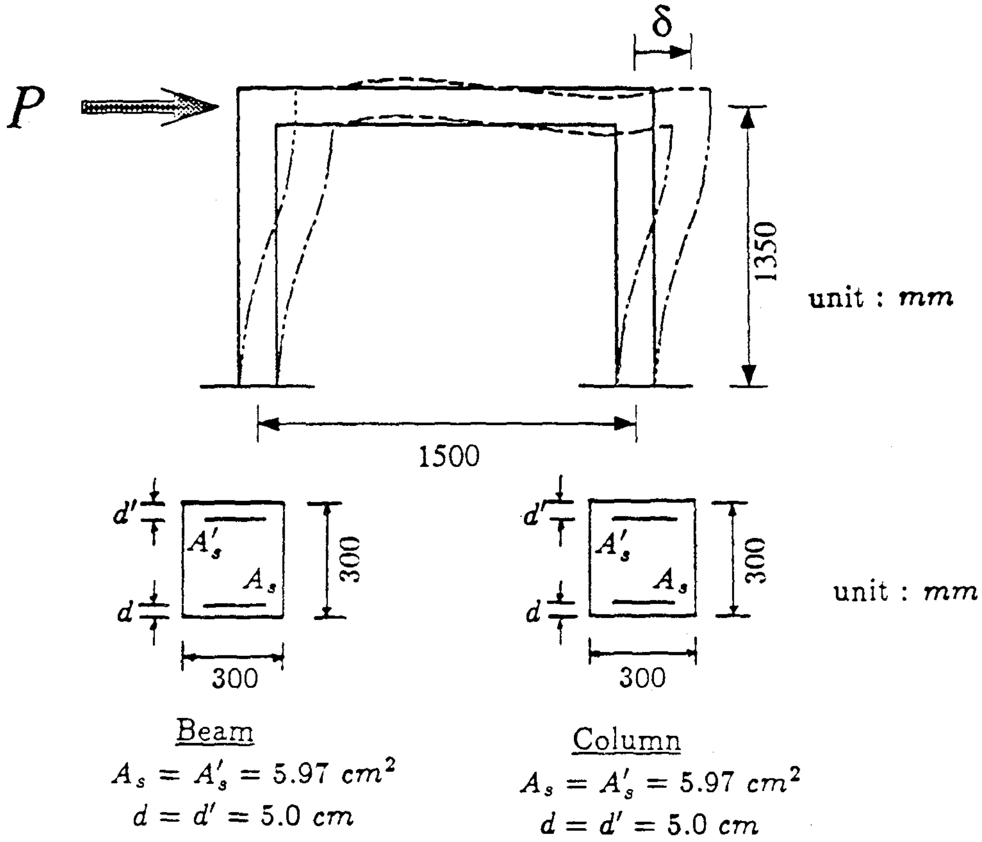


FIGURE 5-4 Details of Ohno's Experimental Frame

TABLE 5-V Quasi-Static Load-Deformation Curve

```
START     OHNO'S EXPERIMENT NO. 3,  ONE STORY - ONE BAY FRAME
    0    1    0   -1    1
    1    1    4    4    0    1    1    2    2    0    1     30000
    10.0       135.0
    2150.0     135.0
    30.0         0.0
    4150.0       0.0
    3    1    1    1    4    1
    1    2    1    2
    1  0.000000  0.000000       0.0            1.
    2  0.000000  0.000000       0.0            1.
    0.000     0.000       0.0       0.0
    1    1    1    1    1    1    0    0
    1     1561.400     0.00785     3.535     0.150
    1     0.260    0.0030   0.030
   -1      30.0     30.00 5.00     5.970 2.50 2.50
    1      15.0     -15.0       0.0       0.0
    1    1    2    0    1    1    1    1   0   0   0   0   0  0.0  0.0    0  0.0
    2    2    1    1    1    1    1    0
    1     1561.400     0.00785     3.535     0.150
    1     0.260    0.0030   0.010
   -1      30.0     30.00 5.00     5.970 2.50 2.50
    1       0.0       0.0     -15.0       0.0
    1    0  9.0000         0.0       0.0  -9.0000       0.0       0.0
    1    1    3    0    1    1    1    1   0   0   1   1   0  1.0  0.0    0  0.0
    2    2    4    0    1    1    1    1   0   0   0   1   0  1.0  0.0    0  0.0
    0    0      24750.100         0.1000      1.0       1.0       0.0    300.0
  496    0    0    0   QUASI-STATIC EXPERIMENTAL RECORDS
    10.500
    0.0050   -0.0300    0.1950    0.5850    1.6550    2.5250    3.6750    5.0250
    6.1050    7.0600    8.0400    7.7450    5.9850    3.9500    1.9100    0.9800
   -0.1650   -1.3700   -2.7000   -4.3250   -5.9000   -6.9950   -8.1050   -7.2850
   -4.9850   -2.0000   -0.2150    1.1700    3.8100    6.0050    8.5150    0.6050
   -3.1550   -7.4400   -8.1250   -7.2550   -4.8700   -1.5950    2.4950    5.4250
    6.8100    8.0500    7.5350    0.5850   -7.5900   -7.8800   -8.0100   -7.2600
   -1.4500    2.7500    6.0400    8.1200    7.4900    0.4250   -3.8600   -6.9250
   -7.9000   -7.9750   -7.3200   -1.2850    2.7800    5.6950    7.9850    7.0950
    0.3650   -3.9450   -7.5100   -8.0050   -7.4250   -1.3950    2.5250    6.9100
    8.0700    9.9450   12.1650   15.0050   15.9650   15.5950   14.9400   12.6700
   10.0900    6.7400    4.3450    1.5900   -1.0800   -3.4850   -5.5000   -7.8600
  -10.6100  -13.9500  -16.0300  -15.1900  -13.5000  -10.6000   -6.5350   -2.0850
    0.3850    7.0550   10.1500   14.2350   16.2600   15.6300   13.4550   10.4500
    5.4800   -2.9950   -9.8550  -12.0550  -15.0350  -16.0000  -15.3600  -14.3950
  -11.2750   -5.4500    0.7950    6.4700    9.7300   14.0400   16.1050   15.6400
   13.4000   10.2750    4.9050    1.7750   -7.1250  -11.9500  -15.7900  -15.9450
  -15.3150  -13.2700  -10.2450   -4.9200   -0.8750    7.1700   11.3450   15.0150
   16.1050   15.7150   13.4350   10.2000    4.6950    1.8000   -7.5750  -13.4600
  -15.8900  -16.0400  -15.4850  -13.4000  -10.3450   -4.9550    0.0400    7.3500
   12.1900   16.0800   15.7850   13.4850   10.2600    4.6200    1.8850   -7.9250
  -14.2250  -15.8700  -16.1250  -15.5100  -13.4850  -10.3650   -4.8250    0.1450
    7.6950   12.9850   16.0600   18.5300   22.1800   23.9900   23.0400   20.6950
   17.5700   12.4200    8.2850   -0.5400   -5.4050   -9.0900  -13.8750  -16.1150
```

Table 5-V Quasi-Static Load-Deformation Curve (cont'd)

```
  -18.1100  -20.8500  -24.1150  -23.2200  -20.9250  -17.6700  -12.2600   -7.2650
   -0.6500    9.6550   13.4400   16.6100   19.6250   22.0650   24.0400   23.1850
   20.9000   17.3300   11.2350    6.4050    1.2750   -8.2400  -15.7600  -20.0150
  -23.9700  -23.1250  -20.7250  -17.2250  -11.3800   -1.9150    2.2900    6.9450
   18.3200   22.0800   23.9900   23.2400   20.9400   17.2900   10.8700    5.4200
    0.1350   -9.3800  -17.8800  -22.1550  -24.0350  -23.2450  -20.8350  -17.2800
  -11.2150   -1.3900    7.5400   18.9350   21.9050   24.1150   23.1850   21.1250
   17.4000   10.8600   -0.2900  -10.0300  -18.6550  -22.8400  -24.4250  -23.6600
  -21.3350  -17.6850  -11.4000   -1.0150    7.9150   15.9600   22.3300   24.0400
   23.2050   21.1500   17.3550   10.6600   -0.8750  -10.3950  -18.9950  -22.3150
  -23.9250  -23.2350  -20.9000  -17.1950  -10.8950   -0.2600    8.6850   16.5150
   22.6400   23.9500   28.0300   31.9600   31.4850   28.5750   24.8550   18.7200
    5.9150   -5.9500  -17.3300  -22.6800  -26.5950  -30.1700  -31.8400  -32.0050
  -31.0300  -28.4200  -24.5950  -18.3450   -6.1150    5.7900   17.6400   22.7350
   27.6750   30.3850   32.0900   31.5250   28.8150   24.9300   18.3150    4.8350
   -8.1100  -20.4950  -27.3750  -32.1250  -30.9900  -28.2300  -24.0900  -17.2650
   -4.0900    8.2350   20.0150   28.6900   32.1200   31.4400   29.2350   25.1050
   17.9450    3.0750   -9.9700  -22.4900  -29.4900  -32.0800  -31.2200  -28.5250
  -24.4400  -17.6000   -3.6400    8.8400   20.7450   27.6600   32.1100   31.4400
   29.2350   25.1050   17.9450    3.0750   -9.9700  -22.4900  -29.4900  -32.0800
  -31.2200  -28.5250  -24.4400  -17.6000   -3.6400    8.8400   20.7450   27.6600
   32.0450   31.4050   29.1050   24.9450   17.5450    1.3800  -11.7450  -23.9150
  -29.0750  -31.8900  -31.2600  -28.5350  -24.3800  -17.2600   10.6950   22.4850
   29.1650   32.9700   36.6300   40.0050   39.2350   36.4000   32.3200   25.1250
    7.7800   -7.7100  -21.9850  -30.1550  -33.6350  -39.8000  -38.6600  -35.8800
  -31.6850  -24.5650    7.9850   23.6900   36.5450   40.1800   39.2950   36.8750
   32.5150   24.8300  -10.1750  -25.4750  -36.9600  -40.0550  -39.0500  -36.2250
  -31.8900  -24.4900    9.7700   25.3300   38.7850   40.0400   38.4100   32.6050
   24.5450  -12.0500  -27.6200  -36.2650  -39.9250  -37.7400  -33.1250  -24.1850
   11.7450   27.7950   38.4450   40.0600   37.2950   32.7250   24.4200  -13.8700
  -28.6300  -38.6050  -40.0150  -37.7750  -33.2250  -24.2950   13.0250   29.2600
   39.4750   40.1200   37.2750   32.3100   24.1500  -15.0450  -29.9700  -40.1150
  -38.1250  -33.5200  -24.5800   14.9400   30.9800   41.0400   48.1200   46.6150
   40.8350   32.7250  -11.1600  -29.1750  -40.4050  -47.9350  -45.7650  -41.3250
  -37.0900  -32.7500   13.3650   34.6950   48.6850   46.4100   41.8200   33.1600
    3.4850  -25.6000  -48.1150  -46.3850  -41.4850  -33.3300   20.0700   26.2200
   31.9950   42.1000   48.3650   42.5550   34.2350    3.8050  -25.9700  -48.0750
  -42.2750  -33.7050    6.4050   16.5650   30.1300   49.6450   44.7050   36.2050
    0.3750  -25.9750  -45.1200  -47.8450  -42.1500  -33.1450   -1.5350    7.2900
    0    0
    0  400  400  400
    1    1    0    1    0    0    0    0    1    0    0    0
    1
STOP
```

SECTION 6

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