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PROGRAM EXKAL2 FOR IDENTIFICATION OF STRUCTURAL DYNAMIC SYSTEMS

by

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16. Abstract (Limit: 200 words)

In this report, a computer program, EXKAL2, which has been developed for the identification of structural dynamic systems subjected to earthquake loading, is documented. The estimation of the structural parameters is carried out by using the extended Kalman filtering technique with a weighted global iteration procedure. The program can be used for the identification of the modal properties of a linear multi-degree-of-freedom structure and for the estimation of the structural parameters of a nonlinear single-degree-of-freedom system. The theoretical background, program descriptions and user's guide are given. Numerical analyses are given for five different example cases. Fortran listings of programs EXKAL2 and SRESP (for generating simulated records for response observations) are shown in the appendices. Example input and output data files are also listed in the appendices.

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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

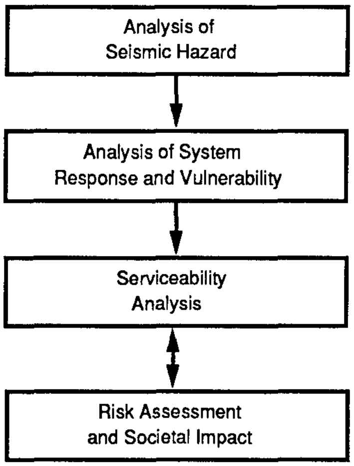
This technical report pertains to Program 3, Lifeline Systems, and more specifically to water delivery systems.

The safe and serviceable operation of lifeline systems such as gas, electricity, oil, water, communication and transportation networks, immediately after a severe earthquake, is of crucial importance to the welfare of the general public, and to the mitigation of seismic hazards upon society at large. The long-term goals of the lifeline study are to evaluate the seismic performance of lifeline systems in general, and to recommend measures for mitigating the societal risk arising from their failures.

From this point of view, Center researchers are concentrating on the study of specific existing lifeline systems, such as water delivery and crude oil transmission systems. The water delivery system study consists of two parts. The first studies the seismic performance of water delivery systems on the west coast, while the second addresses itself to the seismic performance of the water delivery system in Memphis, Tennessee. For both systems, post-earthquake fire fighting capabilities will be considered as a measure of seismic performance.

The components of the water delivery system study are shown in the accompanying figure.

Program Elements:



Tasks:

Wave Propagation, Fault Crossing
Liquefaction and Large Deformation
Above- and Under-ground Structure Interaction
Spatial Variability of Ground Motion

Soil-Structure Interaction, Pipe Response Analysis
Statistics of Repair/Damage
Post-Earthquake Data Gathering Procedure
Leakage Tests, Centrifuge Tests for Pipes

Post-Earthquake Firefighting Capability
System Reliability
Computer Code Development and Upgrading
Verification of Analytical Results

Mathematical Modeling
Socio-Economic Impact

This report documents a computer program which has been developed for identification of structural dynamic systems subjected to earthquake loading. The program, EXKAL2, can be used to estimate the modal properties of a linear multi-degree-of-freedom structure, and to determine the structural parameters of a nonlinear single-degree-of-freedom system. The program uses an extended Kalman filtering technique with a global iteration procedure.

ABSTRACT

In this report, a computer program, EXKAL2, which has been developed for the identification of structural dynamic systems subjected to earthquake loading, is documented. The estimation of the structural parameters is carried out by using the extended Kalman filtering technique with a weighted global iteration procedure. The program can be used for the identification of the modal properties of a linear multi-degree-of-freedom structure and for the estimation of the structural parameters of a nonlinear single-degree-of-freedom system. The theoretical background, program descriptions and user's guide are given. Numerical analyses are given for five different example cases. Fortran listings of programs EXKAL2 and SRESP (for generating simulated records for response observations) are shown in the appendices. Example input and output data files are also listed in the appendices.

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READERS' NOTE

The super- and subscripts are always not bold, although they are printed as bold. Otherwise, bold letters indicate vectors and matrices.

SECTION 1
INTRODUCTION

In this report, a computer program, EXKAL2, which has been developed for the identification of structural dynamic systems subjected to earthquake loading is documented. The program is based on the extended Kalman filtering technique with a weighted global iteration procedure (Hoshiya and Saito, 1983). It can be used for the estimation of the modal properties of a linear multi-degree-of-freedom (MDOF) structure as well as for the determination of the structural parameters of a nonlinear single-degree-of-freedom (SDOF) system.

The problem of system identification has become increasingly important in the area of structural engineering, particularly in connection with the prediction of structural response to adverse environmental loadings such as earthquakes, wind and wave forces [1–4] and also with respect to estimation of the existing conditions of structures for the assessment of damage and deterioration [5–8]. The general subject of system identification began in the area of electrical engineering and was later extended to the field of mechanical/control engineering. Various techniques have been developed. One can find general surveys on the subject in [9–11]. However, available methods may not be readily or directly applicable to problems of structural engineering systems for the following reasons: (i) these systems are generally much larger in size and much more complex in behavior so that accurate mathematical idealization is not easy, (ii) the availability of options for input-output observational data is usually very limited, (iii) observational data are in general heavily contaminated by measurement noise, and (iv) in the case of a damaged or deteriorated system, the behavior may be highly nonlinear. Therefore, for the purpose of effective structural engineering applications, specialized techniques of system identification need to be developed.

In the present study, the extended Kalman filtering technique is utilized for the purpose of parametric system identification and computer program EXKAL2 is developed for its implementation. The technique is particularly useful for structures experiencing nonlinear behavior under severe earthquake loading. The basic algorithm is a recursive procedure for estimating the conditional expectation of the state vector of a state equation which represents the structural system to be identified [12–14]. For the purpose of parameter estimation, the unknown parameters are included in the state vector as augmented state variables. Then the equation of motion is transformed into a state equation. The extended Kalman filtering algorithm was originally developed mainly for the signal processing and determination of the orbit of a spacecraft. Recently it has been applied to structural systems in connection with the estimation of structural parameters such as the nonlinear hydrodynamic coefficients of an offshore structure [2,4], the modal parameters of a MDOF structure [3] and parameters related to nonlinear hysteretic behavior [6]. Program EXKAL2 uses the weighted global iteration procedure recently developed in order to improve the estimation [3].

Program EXKAL2 can be used for the six different structural systems as listed below (see Table 1–I). The analysis option can be selected according to an input control parameter ICON as:

1. Linear MDOF system represented as continuous state equation (ICON=1);
2. Linear MDOF system represented as discrete state equation (ICON=2);
3. Linear MDOF system formulated in frequency domain (ICON=3);
4. Nonlinear SDOF system with nonparametric restoring force (ICON=4);
5. Nonlinear SDOF system with bilinear hysteresis (ICON=5); and
6. Nonlinear SDOF system with Bouc-Wen hysteretic model (ICON=6).

The program requires time histories of the observed ground acceleration and response components for the cases of ICON = 1, 2, 4, 5 and 6. However, for the case of ICON = 3, observation records for the frequency response function are required.

In Sections 2 and 3, the structural model and corresponding state equation are formulated for linear MDOF systems and nonlinear SDOF systems. In Section 4, the theory of the extended Kalman filter with weighted global iteration procedure is reviewed. In Section 5, Program EXKAL2 is detailed with emphasis on its applications. In Section 6, Program SRESP, which may be used for generating simulated observation records of ground acceleration and structural response for numerical simulation studies, is described. In Section 7, numerical examples are given for all the analysis options except for the case of ICON = 4. Fortran listings of Programs EXKAL2 and SRESP are shown in Appendices I and III. Examples of the input and output files used for the numerical analyses are listed in Appendices II and IV.

TABLE 1-I FEATURES OF PROGRAM EXKAL2

1. PURPOSE :

   Identification of Structural Parameters of a Linear Multi-Degree-of Freedom or a Nonlinear Single Degree of Freedom Structural System under Seismic Excitation by Extended Kalman Filter with Weighted Global Iteration Technique.

   It can be used for structural system with a general loading of single component.

2. AVAILABLE ANALYSIS OPTIONS :
   (a) Linear Multi-Degree of Freedom Structure for Time Domain Identification
   (b) Linear Multi-Degree of Freedom Structure for Frequency Domain Identification
   (c) Nonlinear Multi-Degree of Freedom Structure with Nonparametric Restoring Force Model
   (d) Nonlinear Multi-Degree of Freedom Structure with Bilinear Hysterteic Restoring Force Model
   (e) Nonlinear Multi-Degree of Freedom Structure with Bouc-Wen's Hysteretic Restoring Force Model

3. INPUT / OUTPUT FILES :
   (a) Input :

      Unit 5 : General Analysis Control Data

      Unit 8 : Observation Records for Ground Acceleration and Structural Response Components at a Node (It can be generated by using program SRESP for simulation studies.)

   (b) Output :

      Unit 6 : General Output

      Unit 22-30 : Estimated Parameters as Filtered State Variables

4. Required Subroutines :

   All subroutines are provided.

SECTION 2
LINEAR MULTI-DEGREE-OF-FREEDOM SYSTEM

2.1 Equation of Motion

Considering the horizontal response only, the governing equation of a linear multi-degree-of-freedom (MDOF) system subjected to a horizontal ground acceleration as in Fig. 2–1 may be represented by

$$\mathrm{M}\ddot{\mathrm{Z}} + \mathrm{C}\dot{\mathrm{Z}} + \mathrm{KZ} = -\mathrm{M}\{1\}\ddot{\mathrm{f}}(\mathrm{t}) \tag{2.1.1}$$

where $\mathbf{Z}, \dot{\mathbf{Z}}, \ddot{\mathbf{Z}}$ are the horizontal displacement, velocity and acceleration vectors of the structure all relative to the ground, $\ddot{f}(t)$ = the ground acceleration, M = mass matrix (diagonal), C = viscous damping matrix, K = stiffness matrix and $\{1\} = \{1\ 1\ \ldots\ 1\}^T$

Using mode superposition under the assumption that C is proportional damping,

$$\mathrm{Z} = \Phi\eta \tag{2.1.2}$$

where Φ is the modal matrix of the system which is normalized as $\Phi^{\mathrm{T}}\mathrm{M}\Phi = \mathrm{I}$ and η is the modal coordinate vector, Eq. 2.1.1 can be transformed into a set of uncoupled modal equations as

$$\ddot{\eta}_j + 2h_j\omega_j\dot{\eta}_j + \omega_j^2\eta_j = -\delta_j\ddot{f}(t) \tag{2.1.3}$$

with

$$\delta_j = \sum_{k=1}^{n} m_k\phi_{k_j} \tag{2.1.4}$$

In Eqs. 2.1.3 and 2.1.4, h_j, ω_j and δ_j are the modal damping ratio, natural circular frequency and mode participation factor for the j-th mode, and m_k is the mass of node k.

In most system identification problems, response measurements are available only at a limited number of locations of the structure. Hence, in this study, it is assumed that response observations are available only at a single node. Considering the response of the i-th node only, Eq. 2.1.3 can be rearranged into

$$\ddot{u}_{ij} + 2h_j\omega_j\dot{u}_{ij} + \omega_j^2u_{ij} = -p_{ij}\ddot{f}(t) \tag{2.1.5}$$

where $u_{ij} = \phi_{ij}\eta_j, \phi_{ij}$ = the element of Φ associated with the j-th mode and i-th node and p_{ij} = $\phi_{ij}\delta_j$. It is noted that u_{ij} is the j-th mode contribution to the displacement of the i-th node, and p_{ij} is the modal earthquake load factor associated with the j-th mode and displacement of the i-th node. Therefore, when the effects of all the modes are taken into account, the actual displacement of the i-th node is obtained by

$$Z_i = u_{i1} + u_{i2} + ... + u_{in} \tag{2.1.6}$$

2.2 Continuous State Equation (ICON=1)

In the present problem of system identification, the modal parameters, i.e., ω_j, h_j and p_{ij} in Eq. 2.1.5, are to be determined based on the observed response at node i and input ground acceleration. The extended Kalman filtering algorithm which is summarized in Section 4 is utilized for the parameter estimation. For this purpose, a continuous state equation is derived from the equation of motion as follows.

By introducing an extended state vector as

$$\mathrm{X} = \left\{\mathrm{X}_1^{\mathrm{T}}\ \mathrm{X}_2^{\mathrm{T}} \ldots \mathrm{X}_n^{\mathrm{T}}\right\}^T \tag{2.2.1}$$

where $\mathrm{X_j}$ contains the quantities corresponding to the j-th mode as

$$\begin{aligned} \mathrm{X_j} &= \{x_{1j} \quad x_{2j} \quad x_{3j} \quad x_{4j} \quad x_{5j}\}^T \\ &= \{u_{ij} \quad \dot{u}_{ij} \quad h_j \quad \omega_j \quad p_{ij}\}^T \end{aligned} \tag{2.2.2}$$

or $x_{1j} = u_{ij}$, $x_{2j} = \dot{u}_{ij}$, $x_{3j} = h_j$, $x_{4j} = \omega_j$ and $x_{5j} = p_{ij}$. Eq. 2.1.5 can be transformed into a continuous state vector representation as

$$\frac{d\mathrm{X_j}}{dt} = \begin{Bmatrix} \dot{x}_{1j} \\ \dot{x}_{2j} \\ \dot{x}_{3j} \\ \dot{x}_{4j} \\ \dot{x}_{5j} \end{Bmatrix} = \begin{Bmatrix} x_{2j} \\ -2x_{3j}x_{4j}x_{2j} - x_{4j}^2 x_{1j} - x_{5j}\ddot{f}(t) \\ 0 \\ 0 \\ 0 \end{Bmatrix} = \mathrm{g_j}(t) \qquad (2.2.3)$$

If several of the top l $(l < n)$ predominant modes are considered in the analysis, the state equation of the system becomes

$$\begin{Bmatrix} \dot{\mathbf{X}}_1 \\ \dot{\mathbf{X}}_2 \\ \cdot \\ \cdot \\ \cdot \\ \dot{\mathbf{X}}_l \end{Bmatrix} = \begin{Bmatrix} \mathrm{g}_1 \\ \mathrm{g}_2 \\ \cdot \\ \cdot \\ \cdot \\ \mathrm{g}_l \end{Bmatrix} + \mathbf{G}\mathrm{w}(t) \qquad (2.2.4)$$

where w(t) is the system noise vector with covariance matrix Q(t) and **G** is the coefficient matrix of the system noise. The system noise term may represent the error of the input ground acceleration record and the modelling error.

The observation equation can be obtained depending on the response observation data available. For instance, if the displacement and velocity response records at node i are available, the response observation vector **Y**(k) can be written as

$$\mathbf{Y}(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & \cdots \end{bmatrix} \begin{Bmatrix} \mathbf{X}_1(k) \\ \mathbf{X}_2(k) \\ \cdot \\ \cdot \\ \cdot \end{Bmatrix} + \mathbf{v}(k) \qquad (2.2.5)$$

where $\mathbf{Y}(k) = \mathbf{Y}(k\Delta t)$, with the same notation applicable to $\mathrm{X_j}(k)$ and $\mathbf{v}(k)$, and v(k) is the observational noise vector, with covariance matrix **R**(k).

<u>On Program EXKAL2</u>

If a continuous state equation is chosen (ICON=1) in Program EXKAL2, either one of two cases of response observation data is utilized depending on the input parameter (I2); i.e., the relative displacement record only or the relative displacement and velocity records (see Table

5–I in Section 5.2.1). If only the relative acceleration response record is available, one may use the other analysis option (ICON=2) described in Section 2.3. For computational efficiency of parameter estimation, a step by step approach is recommended as below.

1. First, approximate values of the first modal quantities are estimated by considering the system to have a single DOF.
2. The second modal quantities are identified by considering the system to have two DOF. In this case, the first modal quantities are set equal to the previously estimated values. This can be achieved by assigning these estimated values to the elements of the state vector corresponding to the first mode and setting corresponding diagonal elements of the error covariance matrix equal to zero.
3. The first and second modal quantities are usually revised by performing system identification again on the two DOF system with the initial values as described in Step 2.
4. Procedures similar to Steps 2 and 3 are applied to the third and higher modes, as necessary.

2.3 Discrete State Equation (ICON=2)

Applying the linear acceleration method, the velocity $\dot{Z}(k+1)$ and displacement $Z(k+1)$, at $t = (k+1)\Delta t$ can be approximated as [6]

$$\dot{Z}(k+1) = \dot{Z}(k) + \frac{\Delta t}{2}\ddot{Z}(k) + \frac{\Delta t}{2}\ddot{Z}(k+1) \tag{2.3.1}$$

$$Z(k+1) = Z(k) + (\Delta t)\dot{Z}(k) + \frac{(\Delta t)^2}{3}\ddot{Z}(k) + \frac{(\Delta t)^2}{6}\ddot{Z}(k+1) \tag{2.3.2}$$

Using Eqs. 2.3.1 and 2.3.2 and the state vector defined as

$$\mathrm{X} = \left\{\mathrm{X}_1^T \;\; \mathrm{X}_2^T \;\; \ldots \;\; \mathrm{X}_n^T\right\}^T \tag{2.3.3}$$

with

$$\begin{aligned} \mathrm{X_j} &= \{x_{1j} \;\; x_{2j} \;\; x_{3j} \;\; x_{4j} \;\; x_{5j} \;\; x_{6j}\}^T \\ &= \{u_{ij} \;\; \dot{u}_{ij} \;\; \ddot{u}_{ij} \;\; h_j \;\; w_j \;\; p_{ij}\}^T \end{aligned} \tag{2.3.4}$$

Equation 2.1.5 can be transformed into a discrete state vector representation as

$$X_j(k+1) = \begin{Bmatrix} x_{1j}(k+1) \\ x_{2j}(k+1) \\ x_{3j}(k+1) \\ x_{4j}(k+1) \\ x_{5j}(k+1) \\ x_{6j}(k+1) \end{Bmatrix} = \begin{Bmatrix} D_{11}x_{1j}(k) + D_{12}x_{2j}(k) + D_{13}x_{3j}(k) + D_{14}x_{6j}(k)\ddot{f}(k+1) \\ D_{21}x_{1j}(k) + D_{22}x_{2j}(k) + D_{23}x_{3j}(k) + D_{24}x_{6j}(k)\ddot{f}(k+1) \\ D_{31}x_{1j}(k) + D_{32}x_{2j}(k) + D_{33}x_{3j}(k) + D_{34}x_{6j}(k)\ddot{f}(k+1) \\ x_{4j}(k) \\ x_{5j}(k) \\ x_{6j}(k) \end{Bmatrix}$$

$$= \mathrm{g_j}(k) \tag{2.3.5}$$

where

$$D_{11} = 1 + (\Delta t)^2 D_2/6, \quad D_{12} = (\Delta t)(1 + (\Delta t) D_3/6), \quad D_{13} = (\Delta t)^2 (1 + D_4/2)/3,$$

$$D_{14} = (\Delta t)^2 D_1/6, \quad D_{21} = (\Delta t) D_2/2, \quad D_{22} = 1 + (\Delta t) D_3/2, \quad D_{23} = (\Delta t)(1 + D_4)/2,$$

$$D_{24} = (\Delta t) D_1/2, \quad D_{31} = D_2, \quad D_{32} = D_3, \quad D_{33} = D_4, \quad D_{34} = D_1,$$

with

$$D_1 = -\left(1 + (\Delta t) x_{4j}(k) x_{5j}(k) + (\Delta t)^2 x_{5j}^2(k)/6\right)^{-1}$$

$$D_2 = D_1 x_{5j}^2(k)$$

$$D_3 = D_1 \left(2x_{4j}(k) x_{5j}(k) + (\Delta t) x_{5j}^2(k)\right)$$

and

$$D_4 = D_1 \left((\Delta t) x_{4j}(k) x_{5j}(k) + (\Delta t)^2 x_{5j}^2(k)/3\right)$$

If one takes into account the first several predominant modes, then the state vector equation becomes

$$\begin{Bmatrix} X_1(k+1) \\ X_2(k+1) \\ \cdot \\ \cdot \\ X_l(k+1) \end{Bmatrix} = \begin{Bmatrix} g_1(k) \\ g_2(k) \\ \cdot \\ \cdot \\ g_l(k) \end{Bmatrix} + Gw(k) \tag{2.3.6}$$

If the displacement and velocity response records at node i are available, the observation equation is written as

$$Y(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & \cdots \end{bmatrix} \begin{Bmatrix} X_1(k) \\ X_2(k) \\ \cdot \\ \cdot \\ X_l(k) \end{Bmatrix} + v(k) \tag{2.3.7}$$

where v(k) is the observational noise vector whose covariance matrix is R(k). In this study, matrix R(k) is assumed to be constant for all k and diagonal.

<u>On Program EXKAL2</u>

If the discrete state equation is chosen (ICON=2), one or two response records among the displacement, velocity and acceleration can be used, depending on the input parameters ICON and MC2 (see Section 5.2.1).

For computational efficiency of parameter estimation, a step by step approach for each modal quantity similar to the one in Section 2.2 is recommended.

2.4 State Equation in Frequency Domain (ICON=3)

By taking the Fourier transform of Eqs. 2.1.5 and 2.1.6, one can evaluate the frequency response function of the displacement due to input ground acceleration $\ddot{f}(t)$ as

$$H_{ij}(\omega) = \frac{-p_{ij}}{\left(\omega_j^2 - \omega^2\right) + i(2h_j\omega_j\omega)} \tag{2.4.1}$$

and

$$H_i(\omega) = \sum_{j=1}^{n} H_{ij}(\omega) \tag{2.4.2}$$

where $H_{ij}(\omega)$ is the frequency response function of the displacement at the i-th node taking into account the j-th mode effect only, and $H_i(\omega)$ is the frequency response function at the i-th node including the effects of all the modes, and $\mathbf{i} = \sqrt{-1}$.

If the frequency response function is evaluated based on the observation data at the i-th node, then the state vector equation as well as the observation equation may be constructed as follows.

By defining the state vector as

$$\mathbf{X} = \left\{ \mathbf{X}_1^{\mathrm{T}} \;\; \mathbf{X}_2^{\mathrm{T}} \;\; \ldots \;\; \mathbf{X}_{\mathrm{n}}^{\mathrm{T}} \right\}^T \tag{2.4.3}$$

where $\mathbf{X}_{\mathrm{j}} = \{h_j, \omega_j, p_{ij}\}^T$, the discrete state vector equation for the j-th mode is obtained as

$$\begin{Bmatrix} x_{1j}(k+1) \\ x_{2j}(k+1) \\ x_{3j}(k+1) \end{Bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{Bmatrix} x_{1j}(k) \\ x_{2j}(k) \\ x_{3j}(k) \end{Bmatrix} \tag{2.4.4}$$

And the observation equation for the j-th mode contribution is written as

$$\mathbf{Y}_{\mathrm{j}}(k) = \begin{Bmatrix} Re\left[H_{ij}(k)\right] \\ Im\left[H_{ij}(k)\right] \end{Bmatrix} = \begin{Bmatrix} \dfrac{-x_{3j}(k)\left\{x_{2j}^2(k) - (k\Delta\omega)^2\right\}}{\left\{x_{2j}^2(k) - (k\Delta\omega)^2\right\}^2 + \left\{2x_{1j}(k)x_{2j}(k)(k\Delta\omega)\right\}^2} \\ \dfrac{2x_{3j}(k)x_{1j}(k)x_{2j}(k)(k\Delta\omega)}{\left\{x_{2j}^2(k) - k(\Delta\omega)^2\right\}^2 + \left\{2x_{1j}(k)x_{2j}(k)(k\Delta\omega)\right\}^2} \end{Bmatrix} + \mathbf{w}(k) \tag{2.4.5}$$

where the variable ω is discretized into $k\Delta\omega$. If one takes into account the first several predominant modes, then Eqs. 2.4.4 and 2.4.5 may be expanded into

$$\begin{Bmatrix} \mathbf{X}_1(k+1) \\ \mathbf{X}_2(k+1) \\ \cdot \\ \cdot \\ \mathbf{X}_l(k+1) \end{Bmatrix} = \begin{bmatrix} \mathbf{X}_1(k) \\ \mathbf{X}_2(k) \\ \cdot \\ \cdot \\ \mathbf{X}_l(k) \end{bmatrix} \tag{2.4.6}$$

and

$$\mathbf{Y}(k) = \begin{Bmatrix} Re\left[H_{i1}(k)\right] + Re\left[H_{i2}(k)\right] + \ldots \\ Im\left[H_{i1}(k)\right] + Im\left[H_{i2}(k)\right] + \ldots \end{Bmatrix} + \mathbf{w}(k) \tag{2.4.7}$$

It is noted that the state vector equations, Eqs. 2.4.4 and 2.4.6, are stationary linear equations since the elements of the state vector are constant parameters, whereas the observation equations, Eqs. 2.4.5 or 2.4.7, are nonlinear equations of the state vector.

On Program EXKAL2

In program EXKAL2, the frequency response data $H_i(\omega)$ at node i to the ground acceleration must be supplied as input data. The frequency response function can be obtained from the Fourier transforms of the ground acceleration and response as

$$H_i(\omega) = \frac{\widehat{Z}_i(\omega)}{\widehat{\ddot{f}}(\omega)} \tag{2.4.8}$$

$$H_i(\omega) = \frac{\widehat{\dot{Z}}(\omega)}{\mathrm{i}\left(\omega \widehat{\ddot{f}}(\omega)\right)} \tag{2.4.9}$$

$$H_i(\omega) = \frac{\widehat{\ddot{Z}}_i(\omega)}{-\omega^2 \widehat{\ddot{f}}(\omega)} \tag{2.4.10}$$

where $\widehat{Z}_i(\omega), \widehat{\dot{Z}}_i(\omega)$ and $\widehat{\ddot{Z}}_i(\omega)$ are Fourier transforms of response components $Z_i(t), \dot{Z}_i(t)$ and $\ddot{Z}_i(t)$ respectively and $\widehat{\ddot{f}}(\omega)$ is the Fourier transform of the ground acceleration $\ddot{f}(t)$.

A step by step approach for each modal quantity similar to the one in Section 2.2 is also recommended for computational efficiency of parameter estimation.

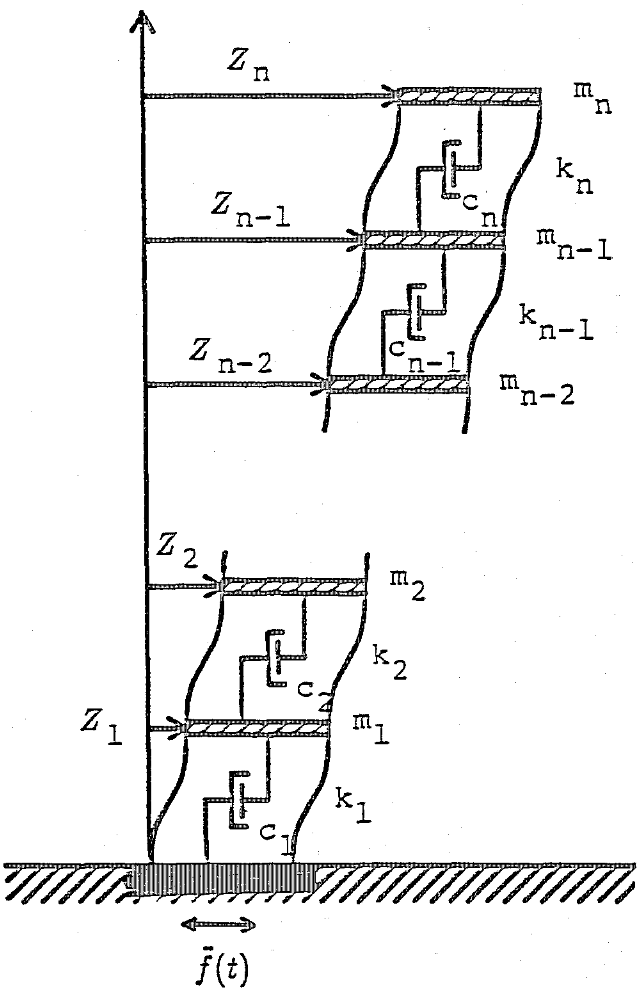

FIGURE 2-1 Example Structural Model for Linear MDOF System

SECTION 3
NONLINEAR SINGLE-DEGREE-OF-FREEDOM SYSTEM

3.1 Equation of Motion

The governing equation of a nonlinear single-degree-of-freedom system subjected to ground acceleration may be represented by

$$\ddot{Z}(t) + H\left(Z(t), \dot{Z}(t)\right) = -\ddot{f}(t) \tag{3.1.1}$$

where $Z, \dot{Z}, \ddot{Z}$ are the displacement, velocity and acceleration of the structure relative to the ground, $\ddot{f}(t)$ is the ground acceleration, and $H\left(Z, \dot{Z}\right)$ is the normalized nonlinear restoring force.

Three different kinds of nonlinear restoring force models are considered in this study. They are a nonparametric model with polynomial function of the structural response, bilinear hysteretic model and hysteresis model proposed by Bouc and Wen [15,16]. Detailed formulation for the system identification is given for each case in the following sections.

3.2 Nonparametric Model for Nonlinear Restoring Force (ICON=4)

For the identification of a nonlinear restoring force, the nonparametric model usually employs a polynomial function of the structural displacement $Z(t)$ and velocity $\dot{Z}(t)$. In this study, the following function with linear and cubic terms is used.

$$H\left(Z, \dot{Z}\right) = a_1 Z + a_2 Z^3 + a_3 \dot{Z} + a_4 \dot{Z}^3 \tag{3.2.1}$$

Then the equation of motion is obtained as

$$\ddot{Z} + a_1 Z + a_2 Z^3 + a_3 \dot{Z} + a_4 \dot{Z}^3 = -\ddot{f}(t) \tag{3.2.2}$$

By defining the state vector as

$$\mathrm{X} = \left\{Z, \dot{Z}, a_1, a_2, a_3, a_4\right\}^T \tag{3.2.3}$$

Equation 3.1.1 can be transformed into a continuous state vector representation as

$$\left\{\dot{\mathrm{X}}\right\} = \begin{Bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \dot{X}_4 \\ \dot{X}_5 \\ \dot{X}_6 \end{Bmatrix} = \begin{Bmatrix} X_2 \\ -\left(X_3 X_1 + X_4 X_1^3 + X_5 X_2 + X_6 X_4^3 + \ddot{f}(t)\right) \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} + \mathrm{Gw}(t) \qquad (3.2.4)$$

It is noted that the state variables X_3—X_6 in Eq. 3.2.3 are the parameters to be identified.

If observational data for the response displacement $Z(t)$ and response velocity $\dot{Z}(t)$ are available, the observational equation is given by

$$\mathbf{Y}(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \mathbf{X}(k) + \mathbf{v}(k) \qquad (3.25)$$

On Program EXKAL2

In this case (ICON=4), one or two response records of the displacement and velocity are utilized depending on the input parameter I2 (see Table 5–I in Section 5.2.1). However, better estimates can be obtained by using both the records.

If the early part of the response amplitude is small so that the response remains reasonably within the linear (elastic) range, an approach similar to the one in Section 2.2 may be employed for the identification of linear and nonlinear parameters:

1. The linear parameters a_1 and a_3 are estimated based on the early portion of the response data with small amplitude. In this case, the input data for the initial values of the nonlinear parameters must be set equal to zero and the corresponding values for the diagonal elements of the error covariance matrix must also be set equal to zero.
2. Then, the nonlinear parameters a_2 and a_4 are estimated based on the later portion of the response data with large amplitude.

3.3 Bilinear Hysteretic Model (ICON=5)

In this case, a bilinear hysteretic model is considered to represent the nonlinear behavior of a structure. The restoring force is modelled as

$$H\left(Z, \dot{Z}\right) = 2h\omega\dot{Z} + \omega^2\phi\left(Z, Z_e, \alpha\right) \tag{3.3.1}$$

where ω and h are the natural frequency and damping ratio of the structure before yielding, and $\phi(Z, Z_e, \alpha)$ represents the bilinear hysteretic characteristics as in Fig. 3–1. The function $\phi(Z, Z_e, \alpha)$ includes two parameters, i.e., the yielding displacement Z_e and ratio α of the post-yielding stiffness to pre-yielding stiffness.

By using Eq. 3.3.1, the governing equation becomes

$$\ddot{Z} + 2h\omega\dot{Z} + \omega^2\phi(Z, Z_e, \alpha) = -\ddot{f}(t) \tag{3.3.2}$$

Then, by using a state vector defined as

$$\mathbf{X} = \left\{Z, \dot{Z}, h, \omega, Z_e, \alpha\right\}^T \tag{3.3.3}$$

a continuous state equation is constructed from Eq. 3.3.2 as

$$\dot{\mathbf{X}} = \left\{\begin{array}{c} X_2 \\ -2X_3X_4X_2 - X_4^2\phi(X_1, X_2, X_5, X_6) - \ddot{f} \\ 0 \\ 0 \\ 0 \\ 0 \end{array}\right\} + \mathbf{G}\mathbf{w}(t) \tag{3.3.4}$$

If observational data for the structural displacement $Z(t)$ and velocity $\dot{Z}(t)$ are available, the observation equation is given by

$$\mathbf{Y}(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \mathbf{X}(k) + \mathbf{v}(k) \tag{3.3.5}$$

On Program EXKAL2

In this case (ICON=5), one or two response records of the displacement and velocity are utilized depending on the input parameter I2 (see Table 5–I in Section 5.2.1). However, better estimates can be obtained by using both of the records.

If the early part of the response amplitude is small so that the response remains reasonably within the linear (elastic) range, an approach similar to that in Section 3.2 may be employed for the identification of the linear and nonlinear parameters in two steps. For an approximate estimation of the linear parameters, Z_e may be set to a large value and α to unity. In this case, the corresponding diagonal elements of the error covariance matrix must be set to zero.

3.4 Bouc-Wen Hysteretic Model (ICON=6)

In this case, the nonlinear restoring force characteristics are represented by using Bouc and Wen's model [15–17]. So, the governing equations are obtained as

$$\ddot{Z}(t) + 2h\omega\dot{Z}(t) + \omega^2\phi(Z(t)) = -\ddot{f}(t) \tag{3.4.1}$$

$$\dot{\phi}(Z(t)) = \frac{A(t)\dot{Z}(t) - \nu(t)\left(\beta \mid \dot{Z}(t) \| \phi(Z(t)) \mid^{n-1} \phi(Z(t)) - \gamma\dot{Z}(t) \mid \phi(Z(t)) \mid^{n}\right)}{\eta(t)} \tag{3.4.2}$$

Equation 3.4.2 represents Bouc and Wen's hysteretic restoring force model which was first proposed by Bouc [15] and later generalized by Wen [16]. In Eq. 3.4.2, the parameters $\beta, \gamma, A(t), \nu(t), \eta(t)$ and n control the hysteretic shape and degree of system degradation.

The parameters A(t), $\nu(t)$ and $\eta(t)$ are functions of the dissipated hysteretic energy $\epsilon(t)$ given by

$$\dot{\epsilon}(t) = \omega^2 Z(t)\phi(Z(t)) \tag{3.4.3}$$

Then, the parameters A(t), $\nu(t)$ and $\eta(t)$ may be written as

$$A(t) = A_0 - \delta_A \epsilon(t)$$

$$\nu(t) = 1.0 + \delta_\nu \epsilon(t) \tag{3.4.4}$$

$$\eta(t) = 1.0 + \delta_\eta \epsilon(t)$$

where δ_A, δ_ν and δ_η are constants representing the degradation rate.

By defining a state vector as

$$\mathrm{X} = \left\{ Z \quad \dot{Z} \quad \phi \quad \epsilon \quad h \quad \omega \quad \beta \quad \gamma \quad A_0 \quad \delta_A \quad \delta_\nu \quad \delta\eta \right\}^T \tag{3.4.5}$$

a continuous state equation can be obtained from Eqs. 3.4.1 — 3.4.4 and

$$\frac{d\mathrm{X}}{dt} = \begin{Bmatrix} \dot{X}_1 \\ \dot{X}_2 \\ \dot{X}_3 \\ \dot{X}_4 \\ \dot{X}_5 \\ \dot{X}_6 \\ \dot{X}_7 \\ \dot{X}_8 \\ \dot{X}_9 \\ \dot{X}_{10} \\ \dot{X}_{11} \\ \dot{X}_{12} \end{Bmatrix} = \begin{Bmatrix} X_2 \\ -2X_5X_6X_2 - X_6^2X_3 - \ddot{f}(t) \\ \frac{\left[(X_9 - X_{10}X_4)X_2 - (1.0 + X_{11}X_4)\left(X_7|X_2||X_3|^{n-1}X_3 + X_8X_2|X_3|^n\right)\right]}{1.0 + X_{12}X_4} \\ X_6^2X_3X_2 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{Bmatrix} \tag{3.4.6}$$

It is noted that the state variables X_5 —X_{12} are the parameters to be identified. Regarding the parameter n appearing in Eq. 3.4.2, it is to be treated as a predetermined constant value n=1 in order to make the Kalman filtering technique tractable.

If observational data for the response displacement Z(t) and response velocity $\dot{Z}(t)$ are available, the observational vector equation is given by

$$\mathbf{Y}(k) = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \mathbf{X}(k) + \mathbf{v}(k) \qquad (3.4.7)$$

On Program EXKAL2

Similar comments to those appearing in Section 3.3 apply in this case. For an approximate estimation of the linear parameters, the values of the nonlinear parameters $\beta, \gamma, \delta_A, \delta_\nu, \delta_\eta$ and corresponding diagonal elements of the error covariance matrix may be set to zero.

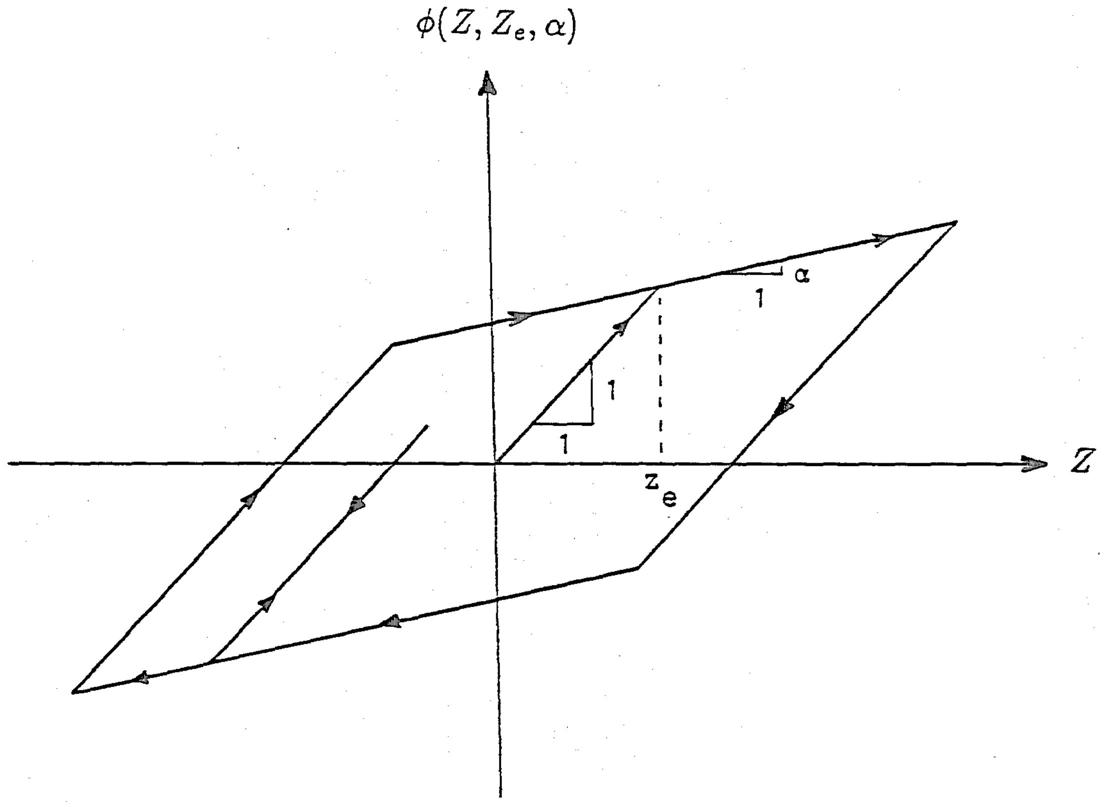

FIGURE 3-1 Bilinear Hysteresis

SECTION 4
SYSTEM IDENTIFICATION USING EXTENDED KALMAN FILTER

4.1 Extended Kalman Filter

As shown in preceding sections, the governing equation of a dynamic system can be transformed into a nonlinear state equation corresponding to an extended state vector, which contains the unknown parameters in the augmented state. Then, the estimated values for the system parameters can be obtained as part of the filtered state using the extended Kalman filter. The basic algorithm of the extended Kalman filter is a recursive process for estimating the optimal state vector of a nonlinear system based on observational data for the excitation and responses. It can be summarized as follows.

Consider the general dynamic system described by a continuous state equation as

$$\dot{\mathbf{X}} = \mathbf{g}\left(\mathbf{X}, \mathbf{f}; t\right) + \mathbf{G}\mathbf{w}\left(t\right) \tag{4.1.1}$$

with observation at $t = k\Delta t$

$$\mathbf{Y}\left(k\right) = \mathbf{h}\left(\mathbf{X}\left(k\right); k\right) + \mathbf{v}\left(k\right) \tag{4.1.2}$$

in which $\mathbf{X}\left(k\right)$ = state vector at $t = k\Delta t$, $\mathbf{Y}\left(k\right)$ = observational vector at $t = k\Delta t$, $\mathbf{f}\left(t\right)$ = input excitation, $\mathbf{v}\left(k\right)$ = observational noise vector with covariance matrix $\mathbf{R}\left(k\right)$ and $\mathbf{w}\left(k\right)$ = system noise vector with covariance matrix $\mathbf{Q_k}$.

The predicted state $\hat{\mathbf{X}}\left(k+1/k\right)$ and its error covariance matrix P(k+1/k) can be evaluated as

$$\hat{\mathbf{X}}(k+1/k) = E\{\mathbf{X}(k+1) \mid \mathbf{Y}(1), \mathbf{Y}(2), ..., \mathbf{Y}(k)\} \qquad (4.1.3)$$
$$= \hat{\mathbf{X}}(k/k) + \int_{k\Delta t}^{(k+1)\Delta t} \mathbf{g}(\mathbf{X}(t/k), f; t)\, dt$$

where

$$\mathbf{P}(k+1/k) = \mathbf{\Phi}(k+1,k)\,\mathbf{P}(k/k)\,\mathbf{\Phi}^{\mathrm{T}}(k+1,k) + \mathbf{Q_k} \qquad (4.1.4)$$

and $E\{A \mid B\}$ is the expected value of A conditional to B and $\mathbf{\Phi}(k+1,k)$ is the state transition matrix which can be approximately obtained as

$$\mathbf{\Phi}(k+1,k) \simeq \mathbf{I} + \Delta t \left[\frac{\partial g_i(\mathbf{X}, f; t)}{\partial X_j}\right]_{X(t)=X(\hat{k}/k)} \qquad (4.1.5)$$

for small Δt.

Then, the filtered state $\hat{\mathbf{X}}(k+1/k+1)$ and its error covariance matrix P(k+1/k+1) can be estimated as

$$\hat{\mathbf{X}}(k+1/k+1) = E\{\mathbf{X}(k+1) \mid \mathbf{Y}(1), \mathbf{Y}(2), ..., \mathbf{Y}(k+1)\} \qquad (4.1.6)$$
$$= \hat{\mathbf{X}}(k+1/k) + \mathbf{K}(k+1)\left[\mathbf{Y}(k+1) - \mathbf{h}\left(\hat{\mathbf{X}}(k+1/k); k\right)\right]$$

$$\mathbf{P}(k+1/k+1) = [\mathbf{I} - \mathbf{K}(k+1)\,\mathbf{M}(k+1)]\,\mathbf{P}(k+1/k)\,[\mathbf{I} - \mathbf{K}(k+1)\,\mathbf{M}(k+1)]^{T}$$
$$+ \mathbf{K}(k+1)\,\mathbf{R_k}\mathbf{K}^{\mathrm{T}}(k+1) \qquad (4.1.7)$$

and $\mathbf{K}(k+1)$ is the Kalman gain matrix which is defined as

$$\mathbf{K}(k+1) = \mathbf{P}(k+1/k)\,\mathbf{M}(k+1)^{T}\left[\mathbf{M}(k+1)\,\mathbf{P}(k+1/k)\,\mathbf{M}(k+1)^{T} + \mathbf{R_k}\right]^{-1} \qquad (4.1.8)$$

and $\mathbf{M}(k)$ is the linearized coefficient matrix of the observation equation as

$$\mathbf{M}(k) = \left[\frac{\partial h_i(\mathbf{X}(k), k)}{\partial X_j}\right]_{X_k=\hat{X}(k/k)} \qquad (4.1.9)$$

For parameter identification by using the extended Kalman filter, the initial state $\hat{\mathbf{X}}(0/0)$ and its error covariance matrix $\mathbf{P}(0/0)$ are required. However, these are unknown, particularly because the state vector $\mathbf{X}(t)$ contains unknown parameters as its augmented variables. Hence, the uncertainty in the initial values $X(\hat{0}/0)$ and $P(0/0)$ may cause divergence of the filtering algorithm. In essence, the problem is this. The filter is capable of tracking the state very well, so that the estimated error covariance matrices $P(k+1/k)$ and $P(k+1/k+1)$ approach zero as the filtering proceeds. Hence, the Kalman gain $K(k+1)$ becomes small and the subsequent observations have little effect on the filtered state $\hat{X}(k+1/k+1)$ (see Eq. 4.1.6). The system model in the filter may, however, be quite different from the actual system, due to improper initial values for the system parameters, so that the estimates may converge to incorrect values or else diverge. Many remedial schemes were developed. These were mainly accomplished by increasing the error covariance matrix during the filtering process by providing a fictitious noise input [18], by using the limited memory filter [19] or by overweighting the most recent data [20]. Recently, a weighted global iteration was proposed and successfully applied to the identification of many structural dynamic systems [3], In program EXKAL2, this weighted global iteration algorithm described in the next section is used.

4.2 Weighted Global Iteration Procedure

In this procedure, global iterations of the extended Kalman filter are carried out by overweighting the error covariance matrix at each global iteration. At first, the filtering is performed with initial guesses of $\hat{X}_{(1)}(0/0)$ and $P_{(1)}(0/0)$ to obtain $\hat{X}_{(1)}(N/N)$ and $P_{(1)}(N/N)$ where N represents the discrete time t_N for the last datum and the subscript (1) denotes the first global iteration. Then the second iteration is carried out utilizing the estimates of $\hat{X}_{(1)}(N/N)$ and $P_{(1)}(N/N)$. The initial value for $\hat{X}_{(2)}(0/0)$ and $P_{(2)}(0/0)$ are constructed as

$$\hat{X}_{(2)}(0/0) = \left\{ \begin{matrix} \xi_{(1)}(0/0) \\ \theta_{(1)}(N/N) \end{matrix} \right\} \tag{4.2.1}$$

$$P_{(2)}(0/0) = \begin{bmatrix} I & 0 \\ 0 & wP_{\theta\theta(1)}(N/N) \end{bmatrix} \tag{4.2.2}$$

where $\xi_{(1)}(0/0)$ represents the initial values of the state variables related to the response components, $\theta_{(1)}(N/N)$ the estimated parameters at $t = t_N$, $P_{\theta\theta(1)}(N/N)$ is the error covariance matrix associated with the parameters at $t = t_N$ and w is the weight used for the iteration. Subsequent iterations are to be performed until convergence can be achieved in the system parameters $\theta_{(J)}(N/N)$.

The theoretical background of the weighted global iterative procedure was demonstrated by Maruyama using the following special case for a constant state vector, which can be represented as

$$\mathrm{X}(k+1) = \mathrm{X}(k) \tag{4.2.3}$$

$$\mathrm{Y}(k) = \mathrm{M}(k)\,\mathrm{X}(k) + \mathbf{v}(k) \tag{4.2.4}$$

where $\mathbf{X}(k)$ is a state vector with constant values, $\mathbf{Y}(k)$ is an observation vector, $\mathrm{M}(k)$ is the coefficient matrix of the observation and $\mathbf{v}(k)$ is an observational noise vector with covariance matrix $\mathbf{R_k}$.

From the first iteration, the filtered state $\hat{\mathrm{X}}_{(1)}(N/N)$ and the error covariance matrix $\mathbf{P}_{(1)}(N/N)$ at t = t_N can be obtained as

$$\hat{\mathbf{X}}_{(1)}(N/N) = \mathbf{P}_{(1)}^{-1}(N/N)\left[\sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{Y}(i) + \mathbf{P}_{(1)}^{-1}(0/0)\,\hat{\mathbf{X}}_{(1)}(0/0)\right] \tag{4.2.5}$$

$$\mathbf{P}_{(1)}(N/N) = \left[\mathbf{P}_{(1)}^{-1}(0/0) + \sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{M}(i)\right]^{-1} \tag{4.2.6}$$

Then, performing weighted global iteration J times, one obtains

$$\hat{\mathbf{X}}_{(J)}(N/N) = [\left(\frac{1+w+w^2+...+w^{J-1}}{w^{J-1}}\right)\sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{Y}(i) + \frac{1}{w^{J-1}}\mathbf{P}_{(1)}^{-1}(0/0)\,\hat{\mathbf{X}}_{(1)}(0/0)] \tag{4.2.7}$$

$$\mathbf{P}_{(\mathrm{J})}(N/N) = [\left(\frac{1+w+w^2+...+w^{J-1}}{w^{J-1}}\right)\sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{Y}(i) + \frac{1}{w^{J-1}}\mathbf{P}_{(1)}^{-1}(0/0)] \tag{4.2.8}$$

From Eqs. 4.2.7 and 4.2.8, it is apparent that the effect of the initial conditions (i.e., initial uncertainties) for $\hat{\mathbf{X}}_{(1)}(0/0)$ and $\mathbf{P}_{(1)}(0/0)$ disappears as the iteration proceeds if $w \geq 1$. Finally, it can be shown that the estimated state converges as

$$\lim_{j \to \infty} \hat{X}_{(J)}(N/N) = \left[\sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{M}(i)\right]^{-1}\left[\sum_{i=1}^{N} \mathbf{M}^{\mathrm{T}}(i)\,\mathbf{R}_{\mathrm{i}}^{-1}\mathbf{Y}(i)\right] \tag{4.2.9}$$

It is worthwhile to note that in this example, the estimated value in Eq. 4.2.9 converges to the least square estimate, which minimizes the following error criterion function:

$$J = \frac{1}{N} \sum_{i=1}^{N} \frac{1}{2} [\mathbf{Y}(i) - \mathbf{M}(i)\,\mathbf{X}(i)]^T \, \mathbf{R}_i^{-1} \, [\mathbf{Y}(i) - \mathbf{M}(i)\,\mathbf{X}(i)] \qquad (4.2.10)$$

SECTION 5
PROGRAM EXKAL2

5.1 Program Structures

Program EXKAL2 can be used for the identification of system parameters for the six different structural systems subjected to ground excitation discussed in Sections 2 and 3. The analysis option can be selected according to the input control parameter ICON as

1. Linear MDOF system represented as continuous state equation (ICON=1);
2. Linear MDOF system represented as discrete state equation (ICON=2);
3. Linear MDOF system formulated in frequency domain (ICON=3);
4. Nonlinear SDOF system with nonparametric restoring force (ICON=4);
5. Nonlinear SDOF system with bilinear hysteresis (ICON=5); and
6. Nonlinear SDOF system with Bouc-Wen hysteresis (ICON=6)

The program requires time histories of the observed ground acceleration and response components as input. The input observation data may be obtained from experiments or generated artificially for numerical simulation studies by using Program SRESP described in Section 6. Estimated system parameters and responses will be obtained as output.

The subroutine tree of Program EXKAL2 is shown in Fig. 5–1. The fortran listing of the program is given in Appendix I-1.

5.2 Description of Input Data Files

5.2.1 General Input Data: UNIT=3

This data file contains general control input data. The data format is free. Descriptions of the input data are given in Appendix I-2. Example input data files used for the numerical analysis are shown in Appendix II-1.

5.2.2 Observation Data for Excitation and Responses: UNIT=8

This data file contains observed time histories of input excitation and output response. The data may be obtained from experiments or generated by Program SRESP in Section 6 for numerical simulation studies. Descriptions of data are given in Appendix I-3. Part of the example data files used for the numerical analysis is shown in Appendix II-2.

5.3 Output Files

The following output files are to be generated by Program EXKAL2.

1. General Output: UNIT=6

   Contains the control input data, estimated parameters and estimation error. Part of the example data files generated from the numerical analysis is given in Appendix II-3.

2. Estimated Hysteresis and Convergence Process of Parameters: UNIT=22–30

   If input parameter ICON is greater than or equal to 4 and NCON is equal to 1, the data files described in Table 5–II are to be generated for plotting the estimated hysteresis and convergency process of the parameters.

Table 5-I Response Observations Used

ICON	I2	MC2	RESPONSE COMPONENTS USED
1	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
2	1	1	DISPLACEMENT RESPONSE
	1	2	VELOCITY RESPONSE
	1	3	ACCELERATION RESPONSE
	2	1	DISPLACEMENT AND VELOCITY RESPONSES
	2	2	ACCELERATION AND VELOCITY RESPONSES
3	2		REAL PART OF FREQUENCY FUNCTION AND IMAGINARY PART OF FREQUENCY FUNCTION
4	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
5	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
6	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY

Note : For earthquake ground excitation, relative responses to the ground must be used.

Table 5-II Output Files Generated for Plotting

File Unit	ICON 4	ICON 5	ICON 6
22	$H(Z,\dot{Z})$	$\phi(Z,Z_e,\alpha)$	$\phi(Z)$
23	a_1	h	h
24	a_2	ω	ω
25	a_3	Z_e	β
26	a_4	α	γ
27	–	–	A_0
28	–	–	δ_A
29	–	–	δ_ν
30	–	–	δ_η
Remarks	Eq.(3.2.1)	Eq.(3.3.2)	Eq.(3.4.2)

Note :

1. File 22 contains two sets of records. The first one is for Z−axis data and the other is for $H(Z,\dot{Z})$, $\phi(Z,Z_e,\alpha)$ or $\phi(Z)$.
2. Each of files 23-30 also contains two sets of records. One is for time-axis data and the other is for estimated parameter as filtered states.

PROGRAM EXKAL2

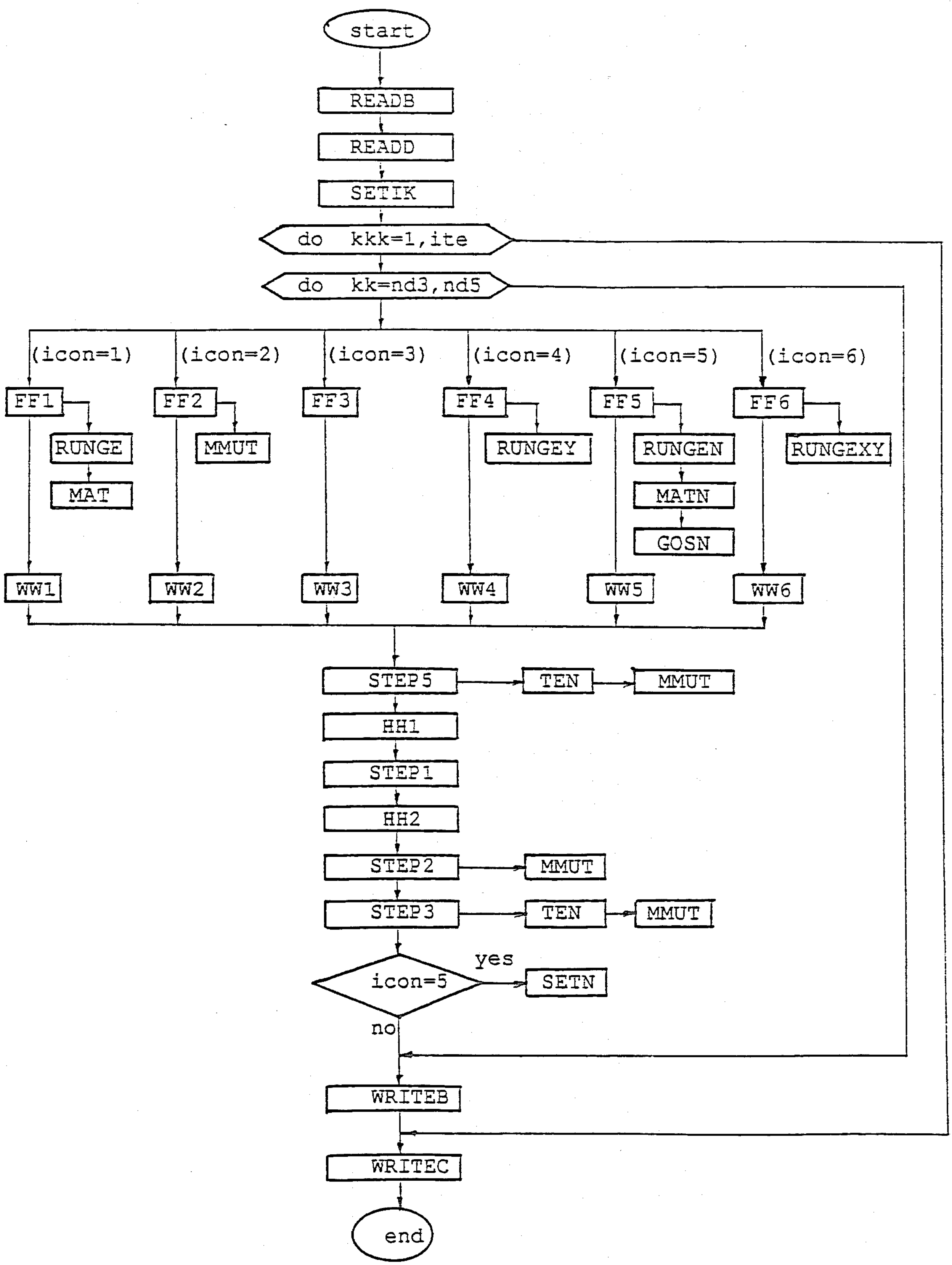

FIGURE 5-1 Subroutine Tree of Program EXKAL2

SECTION 6
PROGRAM SRESP

6.1 Program Structures

Program SRESP is for generating time histories of input excitation and output response for numerical simulation studies. The analysis case can be selected according to the input control parameter ICOM as:

1. Linear MDOF system for identification in time domain (ICOM=1);
2. Nonlinear SDOF system with bilinear non-hysteretic spring (ICOM=2);
3. Nonlinear SDOF system with bilinear hysteretic spring (ICOM=3);
4. Nonlinear SDOF system with Bouc-Wen hysteresis (ICOM=4).

The program requires time histories of ground acceleration. Data files for ground acceleration and response records will be obtained as output files (UNIT=8 and UNIT=31–35). The subroutine tree of Program SRESP is shown in Fig. 6–1. Fortran listing of the program is given in Appendix III-1.

6.2 Description of Input Data Files

6.2.1 General Input Data: UNIT=2

This data file contains general control input data. The data format has been chosen as free. Descriptions of the input data are given in Appendix III-2. The example input files used for the numerical analysis are shown in Appendix IV-1.

6.2.2 Ground Acceleration Data: UNIT=7

The input data must be furnished as below:

1. Title card of input ground acceleration.
2. Ground acceleration record with format of 8 (1PE10.3). The number of data points of the record must be greater than or equal to the one (NN) in the data file UNIT=2. The time interval Δt must be the same as the one in the data file UNIT=2.

The example input data file used in the numerical analysis is shown in Appendix IV-2.

6.3 Output Files

The following output files are to be generated by Program SRESP.

1. General Output: UNIT=6

   It contains the control input data.

2. Data File for System Identification: UNIT=8

   If input parameter NCOM in the general input data file (UNIT=2) is 1, a data file (UNIT=8) will be generated for system identification. It includes simulated time history observations for input excitation and displacement, velocity and acceleration response (see Section 5.2.2). Part of the example data files used for the numerical analysis is shown in Appendix II-2.

3. Data files for Plotting Excitation/Response Observation

   If NCOM=2, the following data files will be generated: UNIT 31: input ground acceleration; UNIT 32: displacement response; UNIT 33: velocity response; UNIT 34: acceleration response. If NCOM=3, a data file (Unit 35) will be generated for hysteretic behavior.

Each of the files (UNITS 31–34) contains two sets of records. The first is for time-axis data and the second for excitation or response component. However, for the case of UNIT 35, the first record is for structural displacement (Z) and the second is for $H\left(Z,\dot{Z}\right)$, $\phi(Z, Z_e, \alpha)$ or $\phi(Z)$ (see Eqs. 3.2.1, 3.3.2 and 3.4.2).

PROGRAM SRESP

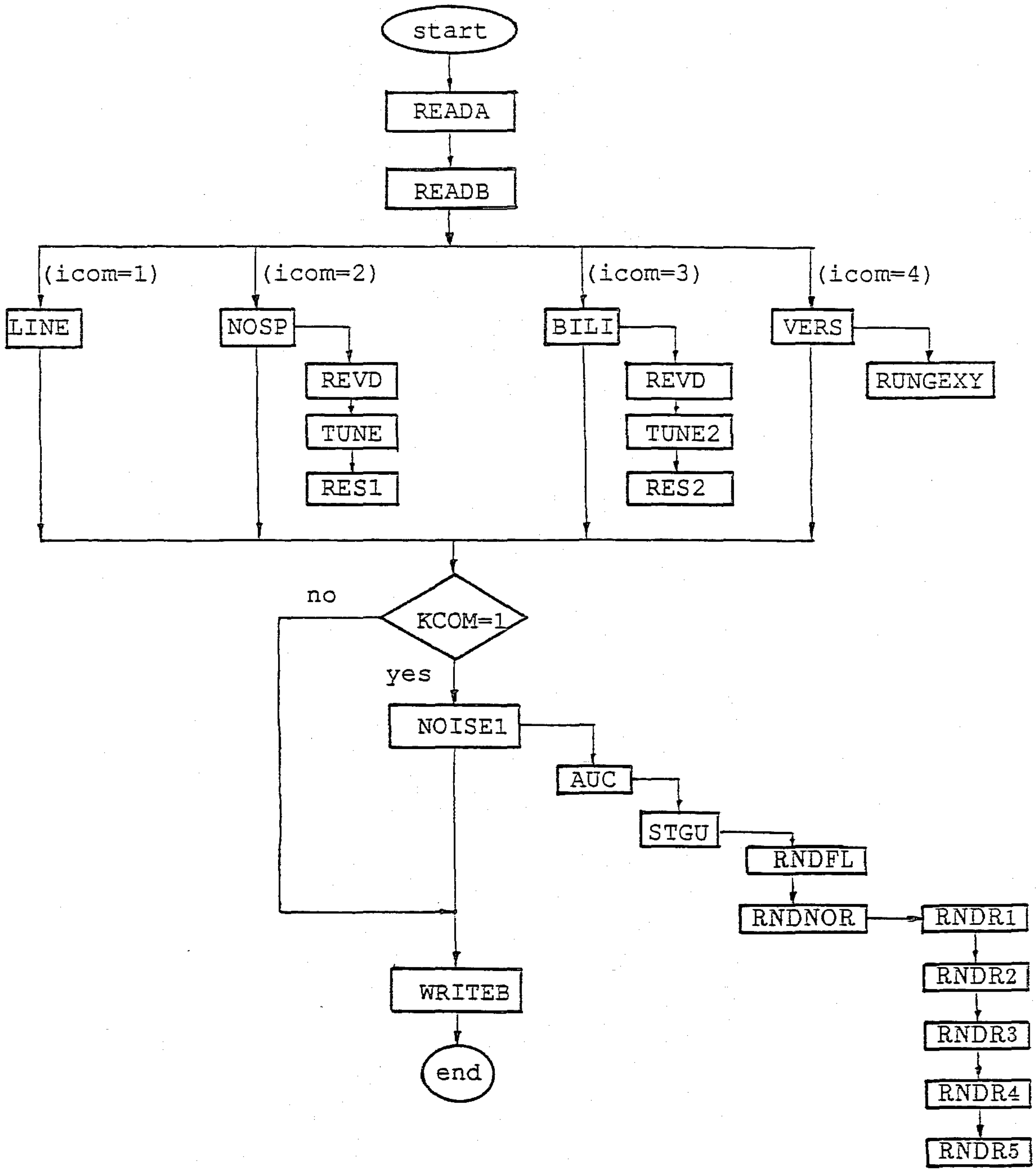

FIGURE 6-1 Subroutine Tree of Program SRESP

SECTION 7
NUMERICAL EXAMPLES AND DISCUSSION

7.1 Linear Multi-Degree-of-Freedom System

7.1.1 System Used for Numerical Simulation Study

Identification of the first two modes of an MDOF system is carried out utilizing the observation records for ground acceleration and response (at node i) simulated by Program SRESP. The modal properties to be estimated are the natural frequencies (ω_j), modal damping ratios (h_j) and modal earthquake load factor (p_{ij}) for mode j and node i. The time history of the input ground acceleration is shown in Fig. 5 and listed in Appendix IV–2. The exact values of the parameters assumed for simulation of the response observations are shown in Table 7–I. Two cases of observational noise levels are considered: i.e., 0 and 10% of the response in root mean square (RMS) values. Time histories of the simulated response observations for two observational noise conditions are shown in Fig. 7–2. The general control inpout data file (UNIT 2) for generating observation records by Program SRESP is listed in Appendix IV–1–1.

7.1.2 Identification Using Continuous State Equation (ICON=1)

In the present example, identification of the modal parameters is carried out based on the ground acceleration record (Fig. 7–1) and relative displacement and velocity records of node i to the ground motion (Fig. 7–2). As discussed in Section 2.2, modal quantities for two modes are obtained by a step-by-step approach. At first, approximate values of the first modal quantities are estimated by considering the system to be a single DOF system. Then the second modal quantities are evaluated, while the first modal properties are assumed to be the previously estimated ones. Finally, the first and second modal parameters are revised by reperforming the identification using the previous estimates as the initial values. Three sets of general control input data files (File 3) for the parameter estimation are shown in Appendix II–1–1. An example of a general output data file (File 6) is shown in Appendix II–3–1. The parameters estimated at each step are summarized in Table 7–I. The results in Table 7–I indicate that the identified parameters agree exceptionally well with the assumed exact values for the two cases of observational noise conditions: i.e., 0 and 10% of the response in RMS values. Figure 7–3 shows the structural displacement and velocity recalculated using the estimated parameters. Comparison between the results in Figs. 7–2 and 7–3 shows that the estimated response is virtually identical to the response observation without measurement noise.

7.1.3 Identification Using Discrete State Equation (ICON=2)

In this example, modal parameters are identified based on the ground acceleration record (Fig. 7–1) and relative acceleration records of node i to the ground motion (Fig. 7–2). Parameter estimation is carried out by a step-by-step approach similar to the case of ICON=1. Three sets of general control input data files (File 3) for parameter estimation are listed in Appendix II–1–2. The estimated values for modal parameters are summarized in Table 7–II. Excellent agreement between the exact and estimated parameters can be observed. Figure 7–4 shows the relative acceleration of the structure (at node i) recomputed by using the estimated parameters. It is found that the estimated response agrees extremely well with the observed if there is no observation error (Fig. 7–2).

It is noted that in actual applications, estimation of parameters may be more conveniently, but not necessarily more accurately, carried out by using the observation data for structural acceleration rather than those for structural displacement and/or velocity, since acceleration records are more commonly available than other records. In this regard, identification using the present discrete state equation may be more useful than that using the continuous state equation (ICON=1).

7.1.4 Identification Using State Equation in Frequency Domain (ICON=3)

In this example, modal parameters are identified based on the frequency response function $H_i(\omega)$ at node i (Eq. 2.4.2). The frequency response function is evaluated by two different methods: one based on the Fourier transforms of the ground acceleration and structural displacement records using Eq. 2.4.8, and the other based on those of the ground acceleration and structural acceleration records using Eq. 2.4.10. Figure 7–5 shows $H_i(\omega)$ obtained by the two different methods. It can be observed that both $H_i(\omega)'s$ are very close to each other at most of the frequency values. However, large discrepancies between the two $H_i(\omega)'s$ are observed at frequency values near zero. It is noted, however, that for the purpose of parameter estimation, the data for $H_i(\omega)$ at small frequency values may be disregarded, as demonstrated by the following numerical examples.

Parameter identification is carried out by a step-by-step approach similar to the one in the case of ICON=1. At first, approximate values for the first modal properties are evaluated by utilizing the data of $H_i(\omega)$ in the vicinity of the first natural frequency (i.e., 3.0–7.0 rad/sec). Then the second modal parameters are estimated by using the data of $H_i(\omega)$ in the wider frequency range (i.e., 3.0–17.0 rad/sec). The estimated parameters are summarized in Table 7–III. Results indicate that the modal parameters are successfully identified by using either method for evaluating $H_i(\omega)$. It is noted that in actual application, $H_i(\omega)$ may be more conveniently evaluated from the ground acceleration and structural acceleration records, since structural response observations are more commonly available in terms of acceleration rather than displacement.

7.2 Nonlinear Single Degree-of-Freedom System

7.2.1 Nonparametric Model for Nonlinear Restoring Force (ICON=4)

The present analysis option may be used for systems with nonlinearity of the nonhysteretic type; for example, geometric nonlinearity, nonlinear interactive force, etc. At the time of the present report, no numerical example is given for this analysis option.

7.2.2 System with Bilinear Hysteresis (ICON=5)

In this example, identification is carried out for the parameters of the bilinear hysteresis model, i.e., h, ω, Z_e, α in Eq. 3.3.1 and Fig. 3–1. Response observation records are artificially generated by using Program SRESP. The same ground acceleration record used in the previous examples is utilized (Fig. 7–1 and Appendix IV–2). The general control input data file (UNIT 2) for Program SRESP is listed in Appendix IV-2–2. The exact parameters assumed for simulating the response observation are shown in Table 7–IV. Figure 7–6 shows the simulated time histories of the relative displacement and velocity of the structure to the ground motion, which are utilized for parameter identification. In the present example, observational noise is not included. Figure 7–8a also shows the true hysteretic behavior computed by Program SRESP for the purpose of comparison with the estimated one.

As discussed in Section 3.3, a step-by-step approach is employed to obtain the linear and nonlinear parameters. The estimated parameters in each step are summarized and compared with the exact in Table 7–IV. From the numerical results in Table 7–IV, it can be seen that the estimates at the last step agree very well with the exact values. Figures 7–7 and 7–8b show the structural displacement and velocity and the hysteresis recomputed by using the estimated parameters. Comparison between the observed and estimated quantities in Figs. 7–6, 7–7 and 7–8 indicates that parameter identification has been successfully carried out in the present case of very severe material nonlinearity as shown in Fig. 7–8. by using the extended Kalman filtering technique. Figure 7–9 shows the convergence process of several parameters during two different global iterations, i.e., first and fifth. The results in Fig. 7–9 indicate that the estimated values for the system parameters converge at fairly reasonable values at the end of the first iteration. However, it is observed that more accurate values have been estimated at the end of the fifth iteration.

7.2.3 System with Bouc-Wen Hysteresis (ICON=6)

Identification is performed for the parameters of Bouc-Wen's hysteresis model. In this example, parameters related to structural degradation are assumed to be predetermined to zero: $\delta_A = \delta\nu = \delta\eta = 0$ in Eq. 3.4.4. The value of A_0 is also assumed to be known as unity. Hence, the parameters to be identified are h, ω, β and γ in Eq. 3.4.2. Exact values of the parameters used for simulating the response observation are shown in Table 7–V. The same ground acceleration value used in previous examples is utilized (Fig. 7–1 and Appendix IV–2). Figure 7–10 shows the time histories of the displacement and velocity of the structure relative to the ground which have been simulated using Program SRESP and utilized for parameter identification. In this example, it is assumed that the response observation is noise-free.The general control input data file (UNIT 2) used for Program SRESP is listed in Appendix IV-1–3. Figure 7–12a shows the true hysteretic curve obtained during the response calculation using Program SRESP.

As discussed in Section 3.4, a step-by-step approach is employed to estimate the linear and nonlinear parameters. The estimated parameters are compared with the exact in Table 7–V. Figures 7–11 and 7–12b show the structural displacement and velocity and the hysteretic curve recomputed using the estimated parameters. Comparison between the results in Table 7–V and Figs. 7–10, 7–11 and 7–12 shows that the parameters and structural response have been successfully identified for the present example of severe material nonlinearity as shown in Fig. 7–12. Figure 7–13 shows the covergence process of several parameters during the first and fifth global iterations. The results indicate that the estimated parameters converge to fairly reasonable values at the end of each iteration. In this example case, the estimates from the two iterations are found to be almost identical.

Table 7-I. Exact and Estimated Parameters (ICON = 1)

a. Without Observational Noise

Cases	Exact Values	Estimated Values					
		Step I		Step II		Step III	
		θ_0^*	$\bar{\theta}_5^*$	θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$
h_1	0.05	0.5	0.09	0.09	0.09	0.09	0.05
ω_1	6.28	5.0	6.38	6.38	6.38	6.38	6.28
p_{i1}	0.724	0.5	1.029	1.029	1.029	1.029	0.724
h_2	0.05	–		0.5	0.03	0.03	0.05
ω_2	9.42	–		5.0	9.50	9.50	9.41
p_{i2}	0.276	–		0.5	0.142	0.142	0.276

b. With Observational Noise = 10% of Response in RMS

Cases	Exact Values	Estimated Values					
		Step I		Step II		Step III	
		θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$
h_1	0.05	0.5	0.075	0.075	0.075	0.075	0.051
ω_1	6.28	5.0	6.302	6.302	6.302	6.302	6.279
p_{i1}	0.724	0.5	0.959	0.959	0.959	0.978	0.722
h_2	0.05	–		0.5	0.071	0.071	0.054
ω_2	9.42	–		15.0	9.517	9.517	9.376
p_{i2}	0.276	–		0.5	0.326	0.326	0.294

Note :

θ_0 = initial guesses
$\bar{\theta}_5$ = estimates after the fifth iteration
unit of ω_1 and ω_2 = rad/sec

Table 7-II. Exact and Estimated Parameters (ICON = 2)

a. Without Observational Noise

Cases	Exact Values	Estimated Values: Step I θ_0	Step I $\bar{\theta}_5$	Step II θ_0	Step II $\bar{\theta}_5$	Step III θ_0	Step III $\bar{\theta}_5$
h_1	0.05	0.5	0.18	0.18	0.18	0.18	0.05
ω_1	6.28	5.0	6.61	6.61	6.61	6.61	6.28
p_{i1}	0.724	0.5	1.125	1.125	1.125	1.125	0.724
h_2	0.05	—		0.5	-0.53	-0.53	0.05
ω_2	9.42	—		10.0	3.52	3.52	9.42
p_{i2}	0.276	—		0.5	0.219	0.219	0.276

b. With Observational Noise = 10% of Response in RMS

Cases	Exact Values	Estimated Values: Step I θ_0	Step I $\bar{\theta}_5$	Step II θ_0	Step II $\bar{\theta}_5$	Step III θ_0	Step III $\bar{\theta}_5$
h_1	0.05	0.5	0.175	0.175	0.175	0.175	0.05
ω_1	6.28	5.0	6.615	6.615	6.615	6.615	6.282
p_{i1}	0.724	0.5	1.121	1.121	1.121	1.121	0.721
h_2	0.05	—		0.5	0.021	0.021	0.05
ω_2	9.42	—		15.0	9.562	9.562	9.42
p_{i2}	0.276	—		0.5	0.078	0.078	0.275

Note :

θ_0 = initial guesses
$\bar{\theta}_5$, $\bar{\theta}_{10}$ = estimates after the fifth and tenth iterations
unit of ω_1 and ω_2 = rad/sec

Table 7-III. Exact and Estimated Parameters (ICON = 3)

a. By Using Structural Displacement Observation

Cases	Exact Values	Initial Guesses θ_0	Estimated Values Step I $\bar{\theta}_{10}$	Step II $\bar{\theta}_{10}$	Step III $\bar{\theta}_{10}$	Step I $\bar{\theta}_{10}$	Step II $\bar{\theta}_{10}$	Step III $\bar{\theta}_{10}$
h_1	0.05	0.5	0.056	0.056	0.054	0.056	0.056	0.054
ω_1	6.28	10.0	6.188	6.188	6.182	6.186	6.186	6.181
p_{i1}	0.724	0.5	0.765	0.765	0.732	0.766	0.766	0.733
h_2	0.05	0.5	–	0.050	0.052	–	0.051	0.053
ω_2	9.42	15.0	–	9.309	9.305	–	9.313	9.307
p_{i2}	0.276	0.5	–	0.262	0.271	–	0.268	0.278
Observational Noise				No			10 % in RMS	

b. By Using Structural Acceleration Observation

Cases	Exact Values	Initial Guesses θ_0	Estimated Values Step I $\bar{\theta}_{10}$	Step II $\bar{\theta}_{10}$	Step III $\bar{\theta}_{10}$	Step I $\bar{\theta}_{10}$	Step II $\bar{\theta}_{10}$	Step III $\bar{\theta}_{10}$
h_1	0.05	0.5	0.056	0.056	0.054	0.056	0.056	0.054
ω_1	6.28	10.0	6.186	6.186	6.180	6.189	6.189	6.183
p_{i1}	0.724	0.5	0.762	0.762	0.735	0.766	0.766	0.737
h_2	0.05	0.5	–	0.049	0.050	–	0.048	0.050
ω_2	9.42	15.0	–	9.314	9.311	–	9.311	9.309
p_{i2}	0.276	0.5	–	0.260	0.266	–	0.256	0.262
Observational Noise				No			10 % in RMS	

Note :

$\bar{\theta}_{10}$ = estimates after the tenth iteration
unit of ω_1 and ω_2 = rad/sec

Table 7-IV. Exact and Estimated Parameters (ICON = 5)

Cases	Exact Values	Estimated Values					
		Step I		Step II		Step III	
		θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$
h	0.10	0.5	0.098	0.098	0.098	0.098	0.109
ω	3.14	5.0	3.16	3.16	3.145	3.16	3.14
Z_e	3.00	100.0	100.0	1.0	2.960	3.04	2.95
α	0.10	1.0	1.0	0.5	0.1	0.10	0.103

Note : (1) No observational noise is included.
(2) θ_0 = initial guess
$\bar{\theta}_5$ = estimates after the fifth iteration.
(3) Units : ω is in rad/sec and Z_e is in cm.

Table 7-V. Exact and Estimated Parameters (ICON = 6)

Cases	Exact Values	Estimated Values					
		Step I		Step II		Step III	
		θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$	θ_0	$\bar{\theta}_5$
h	0.10	0.5	0.105	0.105	0.105	0.105	0.108
ω	3.14	5.0	3.177	3.177	3.177	3.177	3.151
β	0.10	0.0	0.0	0.0	0.072	0.074	0.096
γ	0.20	0.0	0.0	0.0	0.259	0.245	0.211

Note : (1) No observational noise is included.
(2) θ_0 = initial guess
$\bar{\theta}_5$ = estimates after the fifth iteration.
(3) It is assumed that $\delta_A = \delta_\nu = \delta_\eta = 0.0$ and $A_0 = 1.0$.
(4) Units : ω is in rad/sec and β and γ are in $1/cm$.

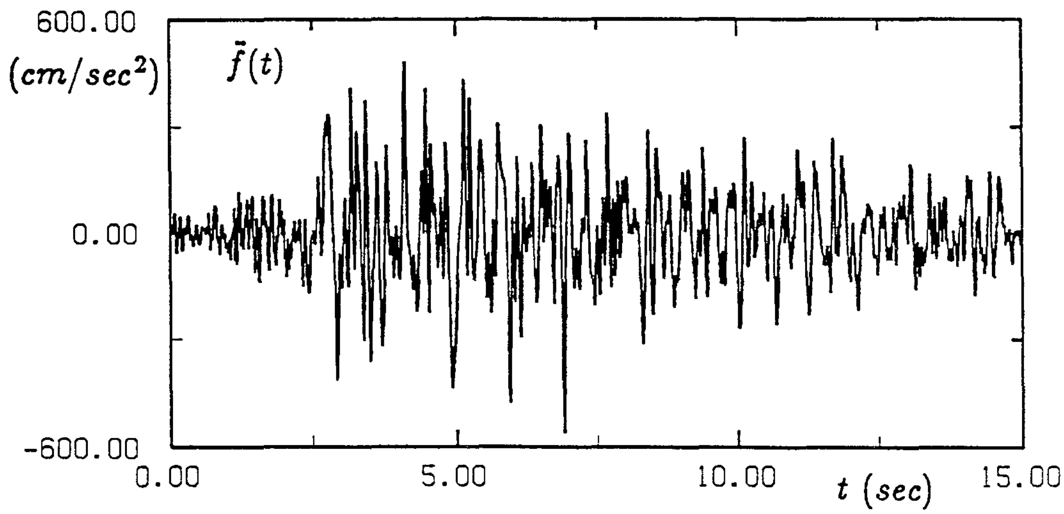

FIGURE 7-1 Input Ground Acceleration

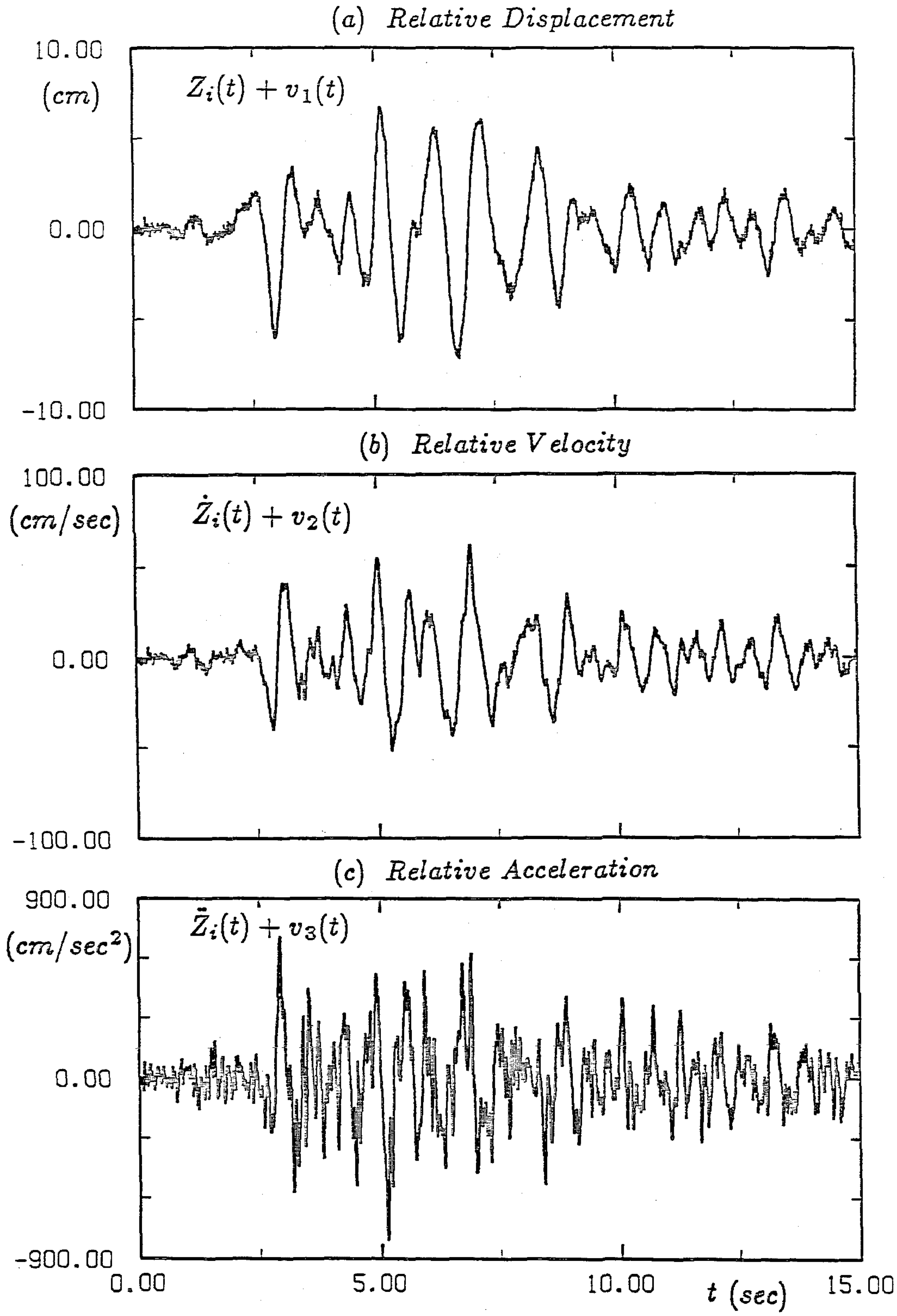

FIGURE 7-2 Response Observations of Linear MDOF Structure (at Node i; ICON=1,2 and 3; 10% Observational Noise in RMS)

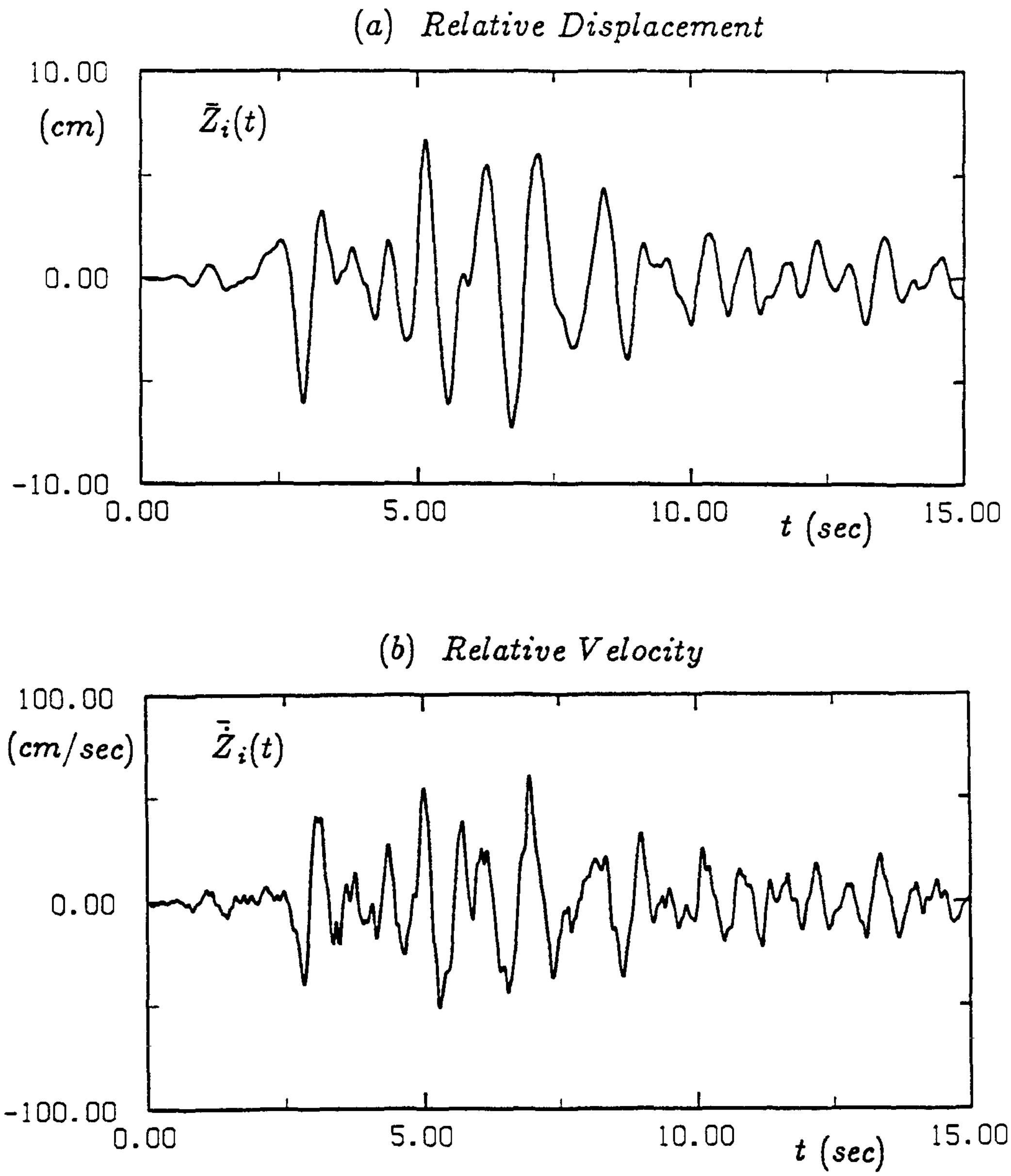

FIGURE 7-3 Estimated Response Based on the Identified Parameters (ICON=1; 10% Observational Noise in RMS)

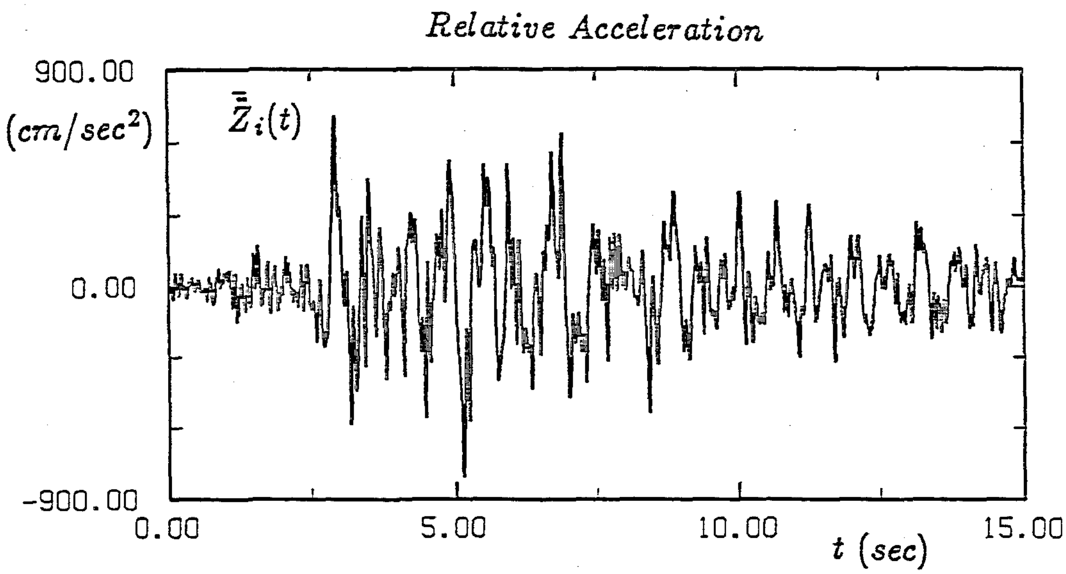

FIGURE 7-4 Estimated Acceleration Based on the Identified Parameters (ICON=2; 10% Observational Noise in RMS)

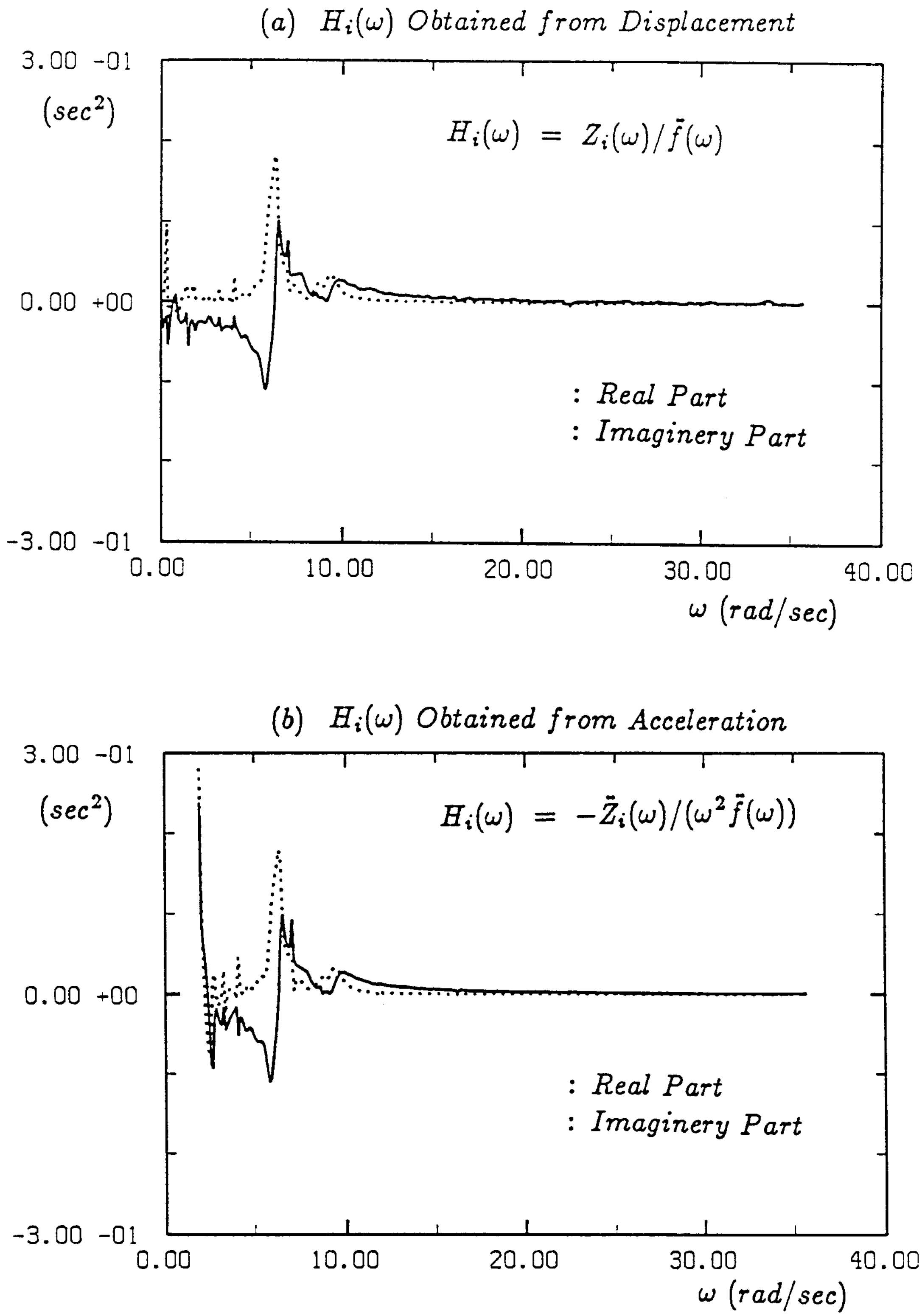

FIGURE 7-5 Frequency Response Function Used for Parameter Estimation in Frequency Domain (ICON=3; 10% Observational Noise in RMS)

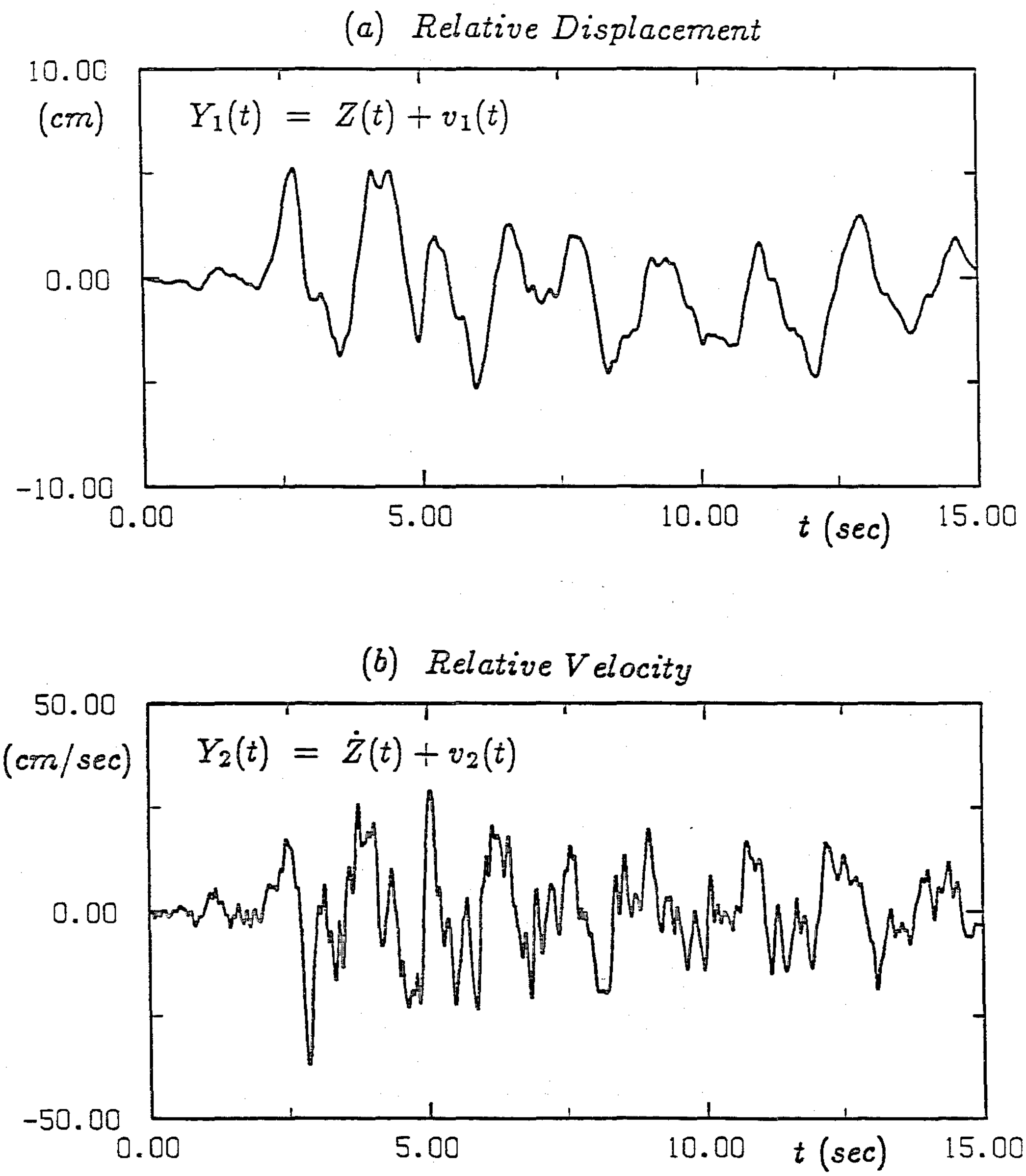

FIGURE 7-6 Response Observations of Nonlinear SDOF Structure with Bilinear Hysteresis (ICON=5; No Observational Noise Condition)

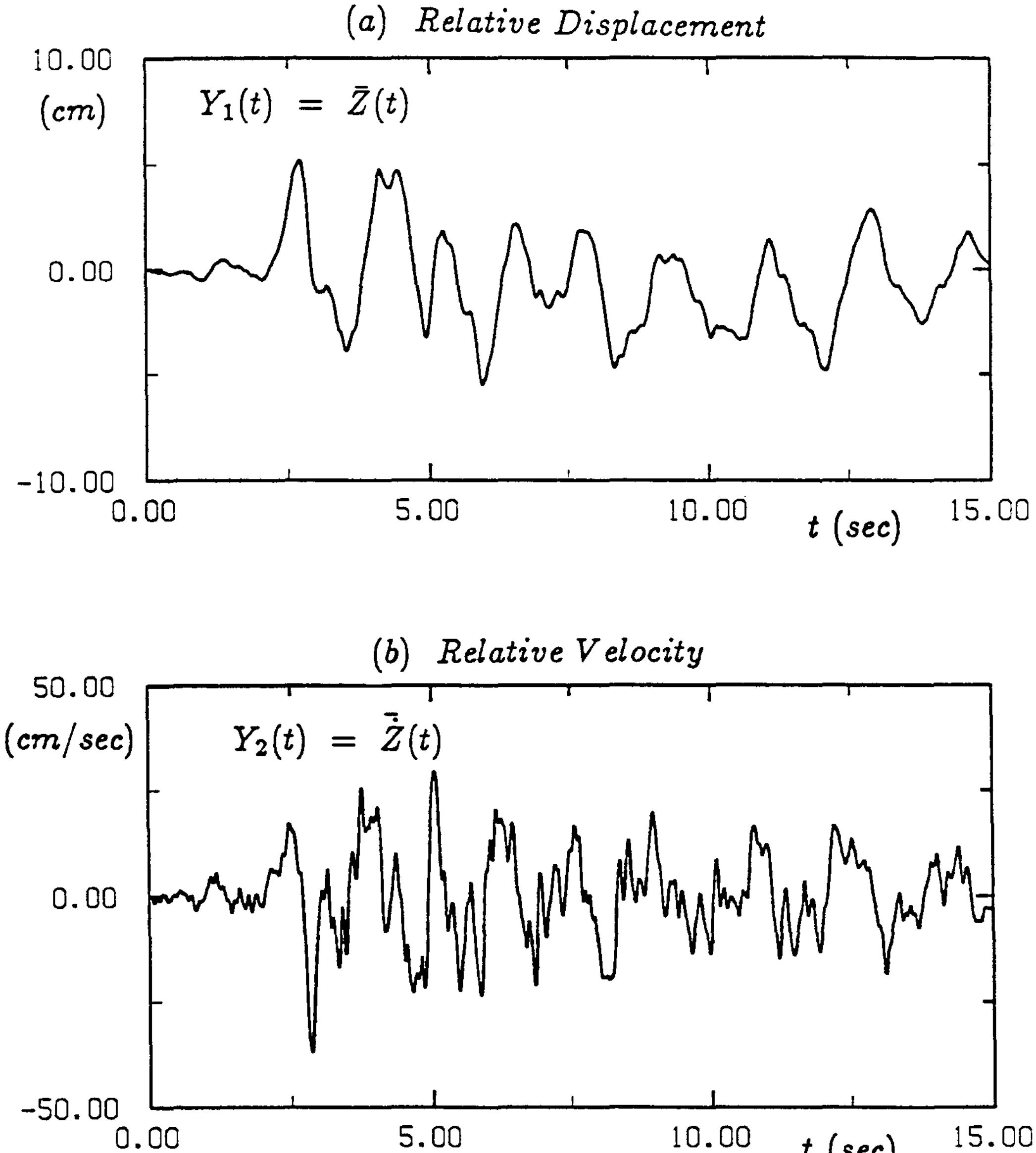

FIGURE 7-7 Estimated Response Based on the Identified Parameters (ICON=5; No Observational Noise Condition)

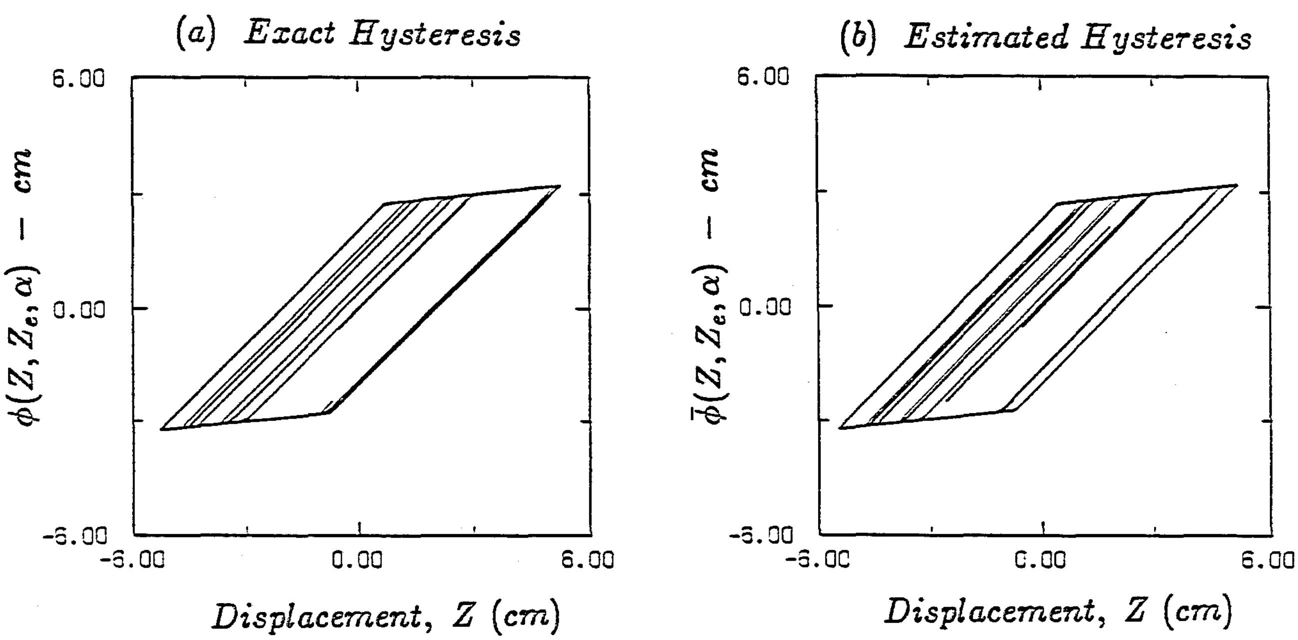

FIGURE 7-8 Exact and Estimated Bilinear Hystereses
(ICON=5; No Observational Noise Condition)

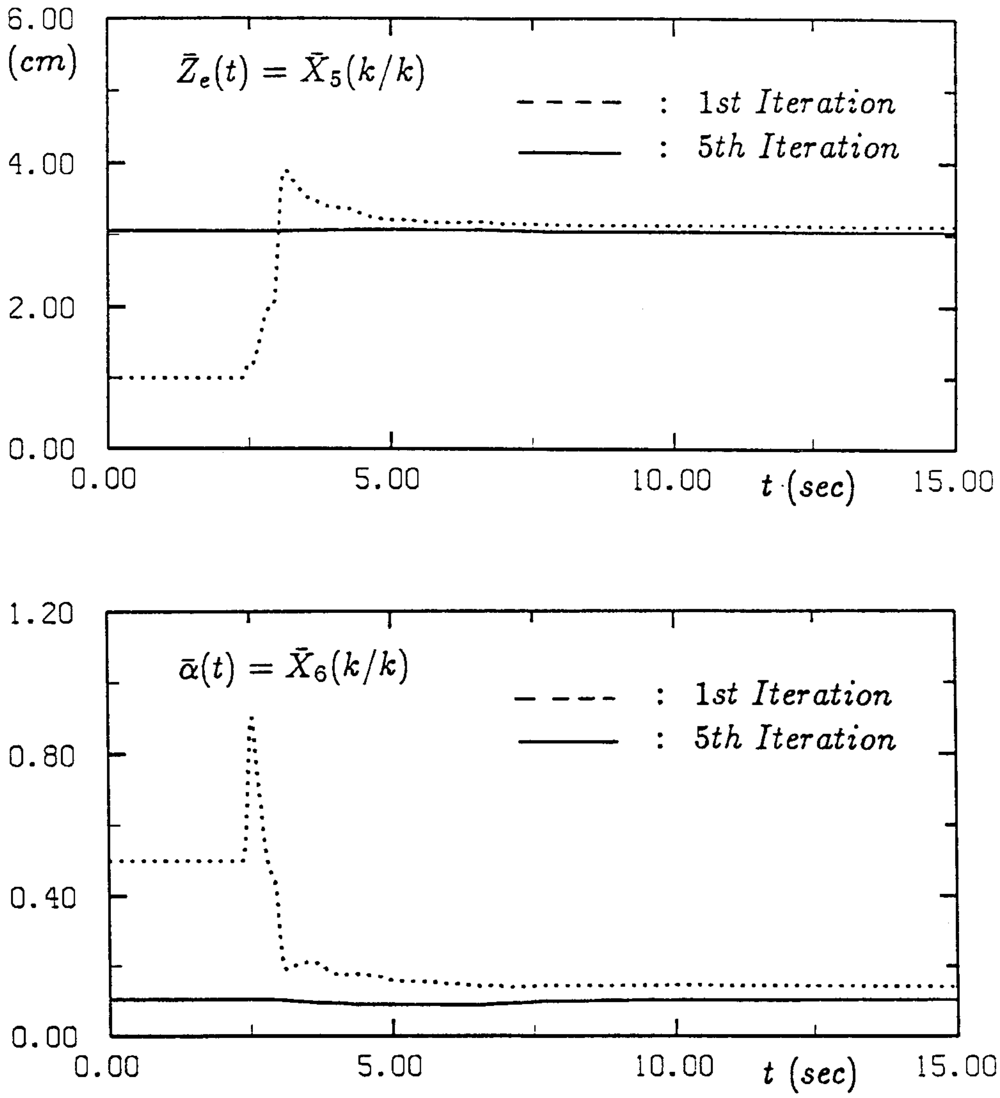

FIGURE 7-9 Convergency Processes of Estimated Parameters as Augmented State Variables (ICON=5; Step II in Table 7-IV)

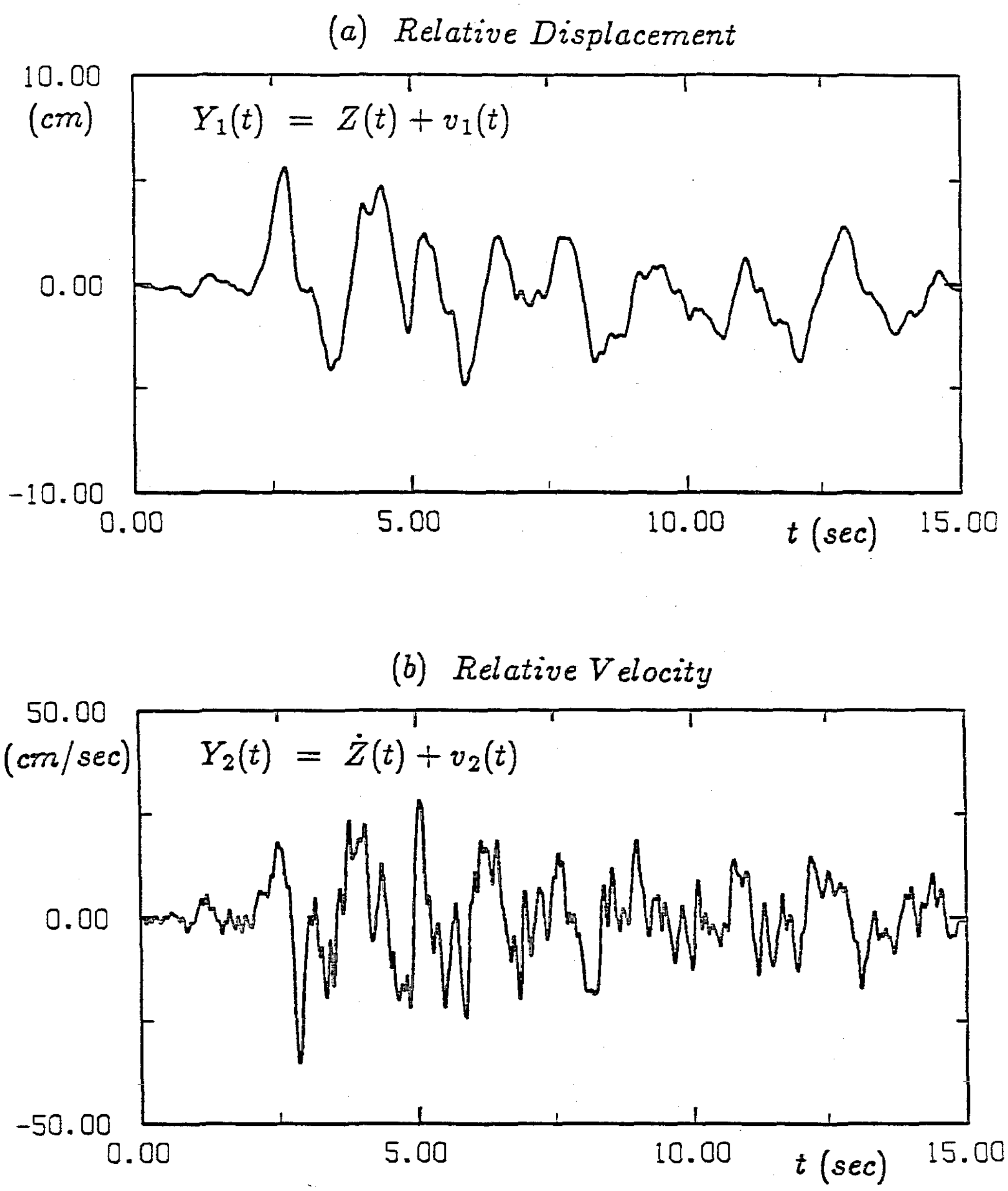

FIGURE 7-10 Response Observations of Nonlinear SDOF Structure with Bouc-Wen's Hysteresis (ICON=6; No Observational Noise Condition)

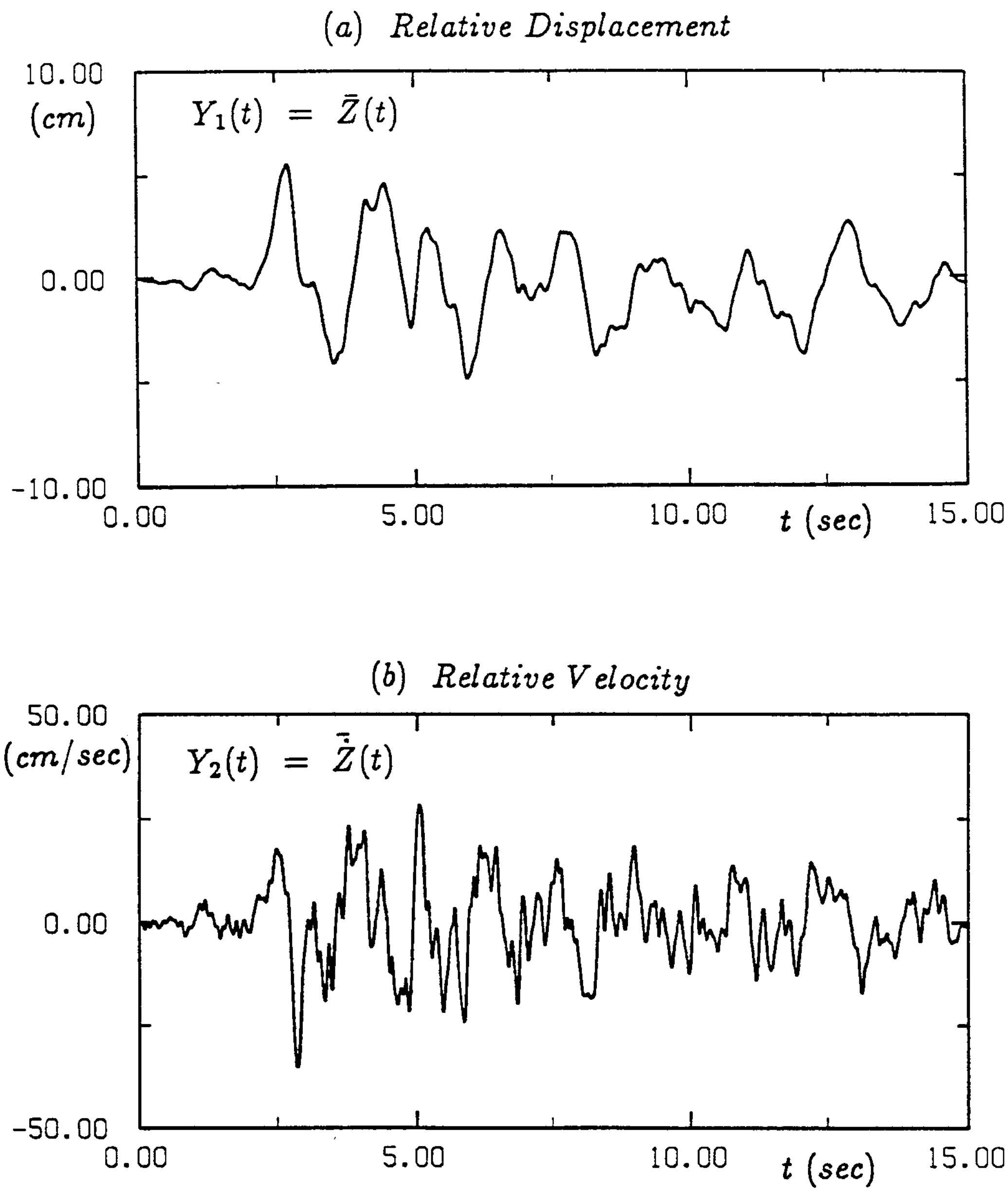

FIGURE 7-11 Estimated Response Based on the Identified Parameters (ICON=6; No Observational Noise Condition)

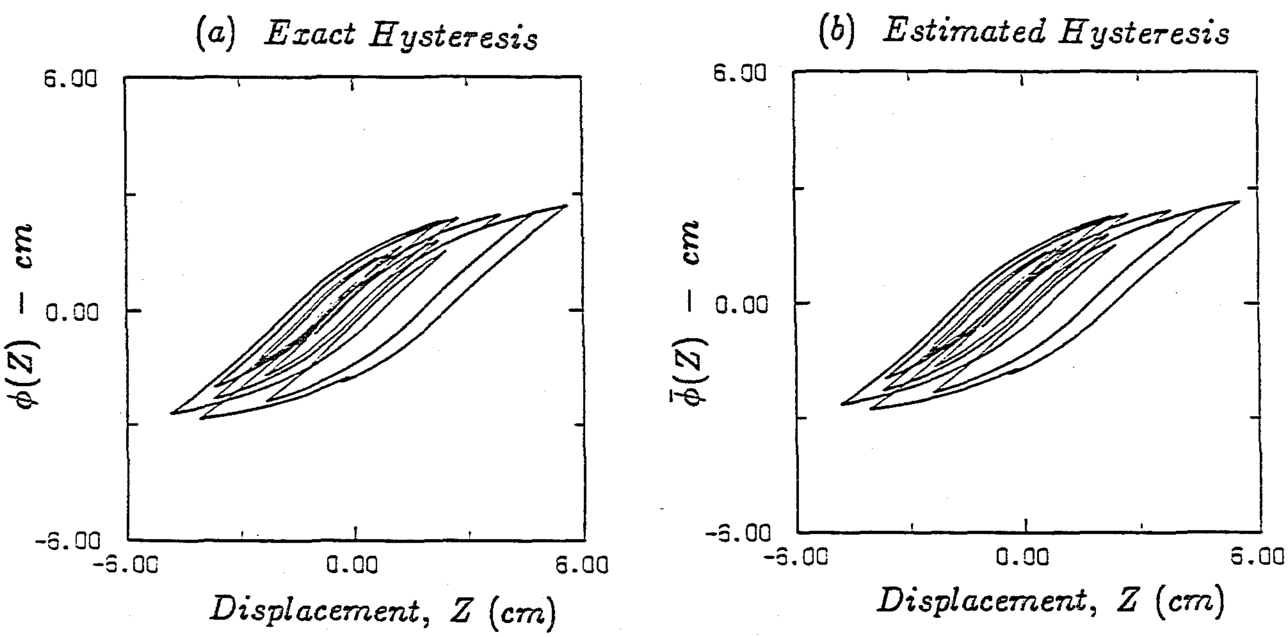

FIGURE 7-12 Exact and Estimated Hystereses of Bouc-Wen's Model (ICON=6; No Observational Noise Condition)

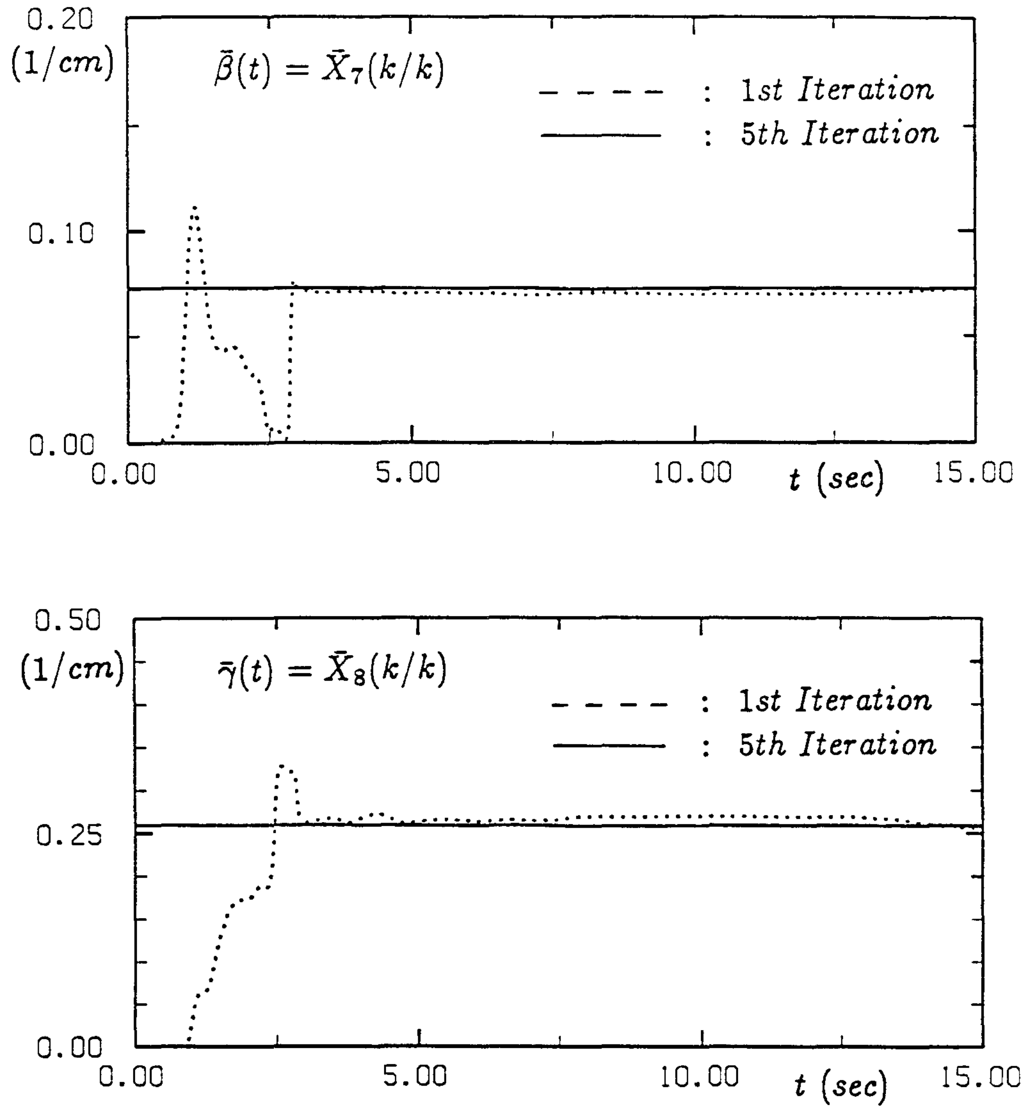

FIGURE 7-13 Convergency Processes of Estimated Parameters as Augmented State Variables (ICON=6; Step II in Table 7-V)

SECTION 8
CONCLUDING REMARKS

In this study, a computer program, EXKAL2, is developed for the identification of the unknown parameters of a linear or nonlinear structure by using the extended Kalman filtering technique with a global iteration procedure. Numerical example analyses are carried out for five different cases of structural systems subjected to earthquake loading. Observational data generated by Program SRESP are used for this purpose. From the numerical results, it has been found that Program EXKAL2 yields excellent estimations of the unknown parameters.

From the numerical investigation, it was observed that for a case with a high level of observational noise and/or severe nonlinearity, proper assignment of the input values for the initial estimates of the unknown parameters and corresponding error covariance matrix are very important to assure good estimation results. It is also noted that proper evaluation of the observational noise level is also very important to obtain better estimation. For the purpose of preliminary estimation of the system parameters, development of an estimation procedure, possibly in the context of expert systems, with the aid of simple and conventional methods such as those based on Fourier analysis will be useful. Presently, an experimental study is being carried out using laboratory models in order to verify the validity of the identification techniques developed in this study. The preliminary results indicate that Kalman filtering with weighted global iterative procedure gives good estimation for support excitation as well as for impulsive load applied at a structural node. Upon completion of such verification, field experiments will follow. The results of these experimental studies will also be reported in the near future.

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APPENDIX I–1

FORTRAN LISTING OF PROGRAM EXKAL2

```
      PROGRAM EXKAL2
C ***********************************************************************
C                              PROGRAM  EXKAL2
C ***********************************************************************
C   A COMPUTER PROGRAM FOR SYSTEM IDENTIFICATION UNDER SEISMIC EXCIATION
C     BY THE EXTENDED KALMAN FILTERING WITH WEIGHTED GLOBAL ITERATION.
C                               (EK-WGI PROCEDURE)
C ***********************************************************************
C     EACH PROGRAM IS  ORIGINALLY CODED BY DR.E.SAITO AND O.MARUYAMA
C               UNDER THE GUIDANCE OF PROF. M.HOSHIYA
C                  DEPARTMENT OF CIVIL ENGINEERING
C                  MUSASHI INSTITUTE OF TECHNOLOGY
C                  1-28-1, TAMAZUTSUMI SETAGAYA-KU,
C                        TOKYO 158,JAPAN
C -----------------------------------------------------------------------
C                 LATER SUMMARIZED BY DR.O.MARUYAMA
C             UNDER THE SUPERVISION OF PROF. M.SHINOZUKA
C         DEPARTMENT OF CIVIL ENGINEERING AND OPERATIONS RESEARCH
C         SCHOOL OF ENGINEERING/APPLIED SCIENCE
C         PRINCETON UNIVERSITY PRINCETON, N.J. 08544, U.S.A.
C
C                  THIS IS VERSION *** EXKAL2 *******
C                         (04, JANUARY 1989)
C ***********************************************************************
C   THIS PROGRAM IS FOR IDENTIFICATION OF
C  (1) LINEAR MULTI-DEGREE OF FREEDOM SYSTEM IN TIME DOMAIN.
C  (2) LINEAR MULTI-DEGREE OF FREEDOM SYSTEM IN FREQUENCY DOMAIN.
C  (3) NONLINEAR SINGLE DEGREE OF FREEDOM SYSTEM IN TIME DOMAIN.
C
C ************************************************************************
C
C  INPUT DATA FILES:
C
C      GENERAL INPUT DATA: UNIT=3
C            SEE THE DESCRIPTION  OF INPUT DATA IN UNIT 3
C
C      EXCITATION/RESPONSE OBSERVATIONS: UNIT=8
C            SEE THE DESCRIPTION  OF INPUT DATA IN UNIT 8
C
C  OUTPUT DATA FILES:
C
C      GENERAL OUTPUT: UNIT=6
C
C      ESTIMATED HYSTERESIS AND CONVERGENCY PROCESS OF PARAMETERS:
C                      UNIT=22-30
C
C ***********************************************************************
C              <  DESCRIPTION OF INPUT DATA IN UNIT 3  >
C                       ***  FREE  FORMAT  ***
C ***********************************************************************
C
C  1. HEADING CARD
C
C  2. MASTER CONTROL CARD; ICON,NCON,ITE,PITE
C
C      ICON:  ANALYSIS CASE
C         ICON=1 : LINEAR (MDOF) RUNGE-KUTTA METHOD
C         ICON=2 : LINEAR (MDOF) LINEAR ACCLERATION METHOD
C         ICON=3 : LINEAR (MDOF) FREQUENCY DOMAIN
C         ICON=4 : NONLINEAR (SDOF) NONPARAMETRIC MODEL
```

```
C          ICON=5 : NONLINEAR (SDOF) BILINEAR HYSTRESIS
C          ICON=6 : NONLINEAR (SDOF) BOUC-WEN'S MODEL
C
C      NCON : OUTPUT COTROL
C
C          IF(ICON.LE.3), NO OUTPUT DATA FILES EXCEPT UNIT 6 ARE GENERATED AND
C                         ANY POSITIVE INTEGER VALUE MAY BE INPUT FOR NCON.
C
C          IF(ICON.GE.4 AND NCON=1), UNIT 22-30 ARE GENERATED FOR PLOTTING.
C               UNIT=22 : ESTIMATED HYSTERESIS
C               UNIT=23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
C
C      ITE : TOTAL NUMBER OF GLOBAL ITERATIONS (ITE.GE.1)
C
C      PITE : WEIGHT FOR EK-WGI PROCEDURE  (PITE.GT.1.0)
C
C  3. CONTROL CARD; N,I1,I2,MC2
C
C      N  : NUMBER OF DEGREES OF FREEDOM(OR MODES) TO BE IDENTIFIED
C
C      I1 : DIMENSION OF EXTENDED STATE VECTOR (I1.LE.30)
C
C                 TABLE 5-I  COMPONENTS OF STATE VECTOR
C         +-------------------------------------------------------------+
C         |ICON |  I1  |          COMPONENTS  OF STATE VECTOR            |
C         |-----|------|-----------------------------------------------|
C         |  1  |  5*N | Uij, dUij/dt, hj, wj, Pij                      |
C         |     |      |             for each mode j=1,..,N             |
C         |-----|------|-----------------------------------------------|
C         |  2  |  6*N | Uij, dUij/dt, ddUij/dtdt, hj, wi, Pij          |
C         |     |      |             for each mode j=1,...,N            |
C         |-----|------|-----------------------------------------------|
C         |  3  |  3*N | hj, wj, Pij     for each mode j=1,...,N        |
C         |-----|------|-----------------------------------------------|
C         |  4  |   6  | Z, dZ/dt, a1, a2, a3, a4                       |
C         |-----|------|-----------------------------------------------|
C         |  5  |   6  | Z, dZ/dt, h, w, Ze, alfa                       |
C         |-----|------|-----------------------------------------------|
C         |  6  |  12  | Z, dZ/dt, phi, e, h, w, be, ga, A0, ca, cv, cn |
C         +-------------------------------------------------------------+
C
C       NOTE :
c          FOR ICON=6, (SEE SECTION 3.4)
C            phi = hysteretic function,
C            e   = dissipated hysteretic energy,
C            h   = damping ratio,   w = natural frequency,
C            be  = beta,  ga = gamma,
C            A0  = A0, ca = delta A, cv = delta nu, cn = delta eta
C
C      I2  : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING
C              IF ICON IS 1,4,5 OR 6,  I2 IS RECOMMENED AS 2.
C              IF ICON IS 3,  I2 MUST BE 2.
C
C      MC2 : CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED
C               (REQUIRED ONLY FOR ICON=2)
C
C                 TABLE 5-II  RESPONSE OBSERVATIONS* USED
C          +--------------------------------------------------------+
C          |ICON | I2 | MC2 |         RESPONSE COMPONENTS USED       |
C          |-----|----|-----|---------------------------------------|
```

```
C          |  1   | 1  |      | DISPLACEMENT ONLY                        |
C          |      | 2  |      | DISPLACEMENT AND VELOCITY                |
C          |---------------------------------------------------------------|
C          |  2   | 1  |  1   | DISPLACEMENT RESPONSE                    |
C          |      |    |  2   | VELOCITY RESPONSE                        |
C          |      |    |  3   | ACCELERATION RESPONSE                    |
C          |      |----|------|------------------------------------------|
C          |      | 2  |  1   | DISPLACEMENT AND VELOCITY RESPONSE       |
C          |      |    |  2   | ACCELERATION AND VELOCITY RESPONSE       |
C          |---------------------------------------------------------------|
C          |  3   | 2  |      | REAL AND IMAGINERY PARTS OF FREQUENCY    |
C          |      |    |      | RESPONSE FUNCTION  WILL BE USED.         |
C          |---------------------------------------------------------------|
C          |  4   | 1  |      | DISPLACEMENT ONLY                        |
C          |      | 2  |      | DISPLACEMENT AND VELOCITY                |
C          |---------------------------------------------------------------|
C          |  5   | 1  |      | DISPLACEMENT ONLY                        |
C          |      | 2  |      | DISPLACEMENT AND VELOCITY                |
C          |---------------------------------------------------------------|
C          |  6   | 1  |      | DISPLACEMENT ONLY                        |
C          |      | 2  |      | DISPLACEMENT AND VELOCITY                |
C          +---------------------------------------------------------------+
C       NOTE : FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE TO THE
C              GROUND MUST BE USED.
C
C  4. OBSERVATION DATA CARD; NN,DT,NM1,NM2
C
C       NN  : TOTAL NUMBER OF OBSERVATION DATA POINTS OF EACH RECORD
C       DT  : TIME INCREMENT(SEC) OR FREQUENCY INCREMENT(RAD/SEC) IN DATA
C       NM1 : STRATING DATA POINT USED FOR FILTERING
C       NM2 : ENDING DATA POINT USED FOR FILTERING
C
C  5. INITIAL GUESS FOR FILTERED STATE VECTOR; Y2(I,1), I=1,I1
C
C         DATA MUST BE SUPPLIED FOR Y2(I,1), I=1,I1.
C         FOR DEFINITION OF STATE VECTOR Y2(I),  SEE TABLE 5-I.
C
C  6. INITIAL GUESS FOR ERROR COVARIANCE MATRIX OF THE FILTERED STATE;
C               P11(I), I=1,I1
C
C         INITIAL VALUES FOR THE ERROR COVARIANCE MATRIX OF THE FILTERED
C         STATE VECTOR IS ASSUMED AS DIAGONAL.   INITIAL VALUES OF THE
C         DIAGONAL MEMBERS MUST BE SUPPIED;  P11(I), I=1,I1.
C
C  7. SYSTEM NOISE COVARIANCE MATRIX;  QR1(I), I=1,I1
C
C         COVARIANCE MATRIX OF SYSTEM NOISE IS ASSUMED TO BE DIAGONAL.
C         VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPLIED;  QR1(I), I=1,I1
C
C  8. SYSTEM NOISE COEFFICIENT MATRIX; G11(I), I=1,I1
C
C         COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
C         DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
C         MUST BE PROVIDED;  G11(I), I=1,I1
C
C  9. OBSERVATION NOISE COVARIANCE MATRIX; QR2(I),I=1,I2
C
C         COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
C         DIAGONAL.  DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
C               QR2(I),  I=1,I2.
```

```
C
C **********************************************************************
C **********************************************************************
C                    < DESCRIPTION OF INPUT DATA IN UNIT 8 >
C **********************************************************************
C
C  ******    IF ICON = 1,2,4,5 AND 6    ******
C
C  1. HEADING CARD   (72A)
C
C  2. MASTER CONTROL DATA ;   NRSP   (I5)
C
C       NRSP : NUMBER OF RESPONSE COMPONENT RECORDS AT A CERTAIN NODE
C              TO BE SUPPLIED IN THIS DATA FILE (NRSP.LE.3)
C
C  3. GROUND ACCELERATION DATA
C
C    3-A.  TITLE CARD   (72A)
C
C    3-B.  GROUND ACCELERATION DATA   ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C  4. RESPONSE OBSERVATION DATA
C
C       NRSP COMPONENTS OF RESPONSE OBSERVATIONS MUST BE PROVIDED.
C          (FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
C           TO THE GROUND MOTION MUST BE USED.)
C
C       FOR EACH COMPONENT, FOLLOWING SET OF DATA MUST BE SUPPLIED.
C
C    4-A.  TITLE OF RESPONSE COMPONENT ( 72A )
C
C    4-B.  RESPONSE COMPONENT INDICATOR   ( I5 )
C                   = 1,  FOR DISPLACEMANT
C                     2,  FOR VELOCITY
C                     3,  FOR ACCELERATION
C
C    4-C.  OBSERVED RESPONSE DATA   ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C  ******   IF ICON = 3    ******
C
C  1. HEADING CARD ( 72A )
C
C  2. MASTER CONTROL CARD ;  NRSP ( I5 )
C       NRSP = 2 (REAL & IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION)
C
C  3. REAL PARTS OF FREQUENCY RESPONSE FUNCTION
C
C    3-A.  TITLE CARD   ( 72A )
C
C    3-B   RESPONSE COMPONENT INDICATOR   ( I5 )
C                 =  1   (REAL PARTS)
C
C    3-C.  REAL PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
```

```
C  4. IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION
C
C     4-A.  TITLE CARD   ( 72A )
C
C     4-B   RESPONSE COMPONENT INDICATOR ( I5 )
C                   =  2  (IMAGINERY PARTS)
C
C     4-C.  IMAGINERY PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
C              NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
C              SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C *******************************************************************
C
      PARAMETER (J1=30,J2=10,J3=3000,J5=3)
      DIMENSION AK(J1,J2),P1(J1,J1),H1(J2,J1),H2(J1,J2),
     *          R(J2,J2),P2(J1,J1),W1(J1,J1),W2(J1,J1),
     *          G1(J1,J1),G2(J1,J1),Q(J1,J1),P11(J1),
     *          G11(J1),DY(J3),Y(J2,J3),Z(J2,1),Y3(J1,J3),
     *          Y1(J1,1),Y2(J1,1),QR1(J1),QR2(J2),AHH(J2,1),
     *          F(J1,1),GG1(J3),Y4(J1,J3),P3(J1,J1),YC(J2,J3),
     *          DYC(J3),MC(J5)
C
C     ---- READ GENERAL INPUT AND
C           INITIAL GUESS FOR EK-WGI METHOD (UNIT=3)--------
      CALL READB(QR1,QR2,Y2,P11,G11,N,NN,I1,I2,
     *    DT,J1,J2,J5,ITE,PITE,NM1,NM2,MC,ICON,NCON,AAZ)
C
C     ----   OBSERVATION DATA FOR INPUT EXCITATION
C                 AND OUTPUT RESPONSE       (UNIT=8)--------
      CALL READD(DY,Y,NN,I2,J2,J3,ICON,MC)
C
      ND=NM2-NM1+1
      ND3=NM1
      ND5=NM2
      CALL SETIK(ICON,IK1,Y,NM1,J2,J3)
C
C     -------- SET INITIAL GUESS FOR EK-WGI METHOD ---------
      CALL INIT(Q,P2,G1,R,H1,QR1,QR2,P11,G11,I1,I2,J1,J2,F)
C
C     ----- START WITH THE FILTERED STATE VECTOR [Y2]
C            AND ITS ERROR COVARIANCE MATRIX [P2] ----------
      WRITE(6,1200)  (Y2(I,1),I=1,I1)
      WRITE(6,1200)  (P2(I,I),I=1,I1)
 1200 FORMAT(1H ,6(1X,E11.5))
C
C   **************************************************************
C   *  EXTENDED KALMAN FILTER WEIGHTED GLOBAL ITERATION METHOD   *
C   **************************************************************
C
                         DO 9500 KKK=1,ITE
C
      WRITE(6,8000)
 8000 FORMAT(1H ,' ')
      WRITE(6,1300) KKK
 1300 FORMAT(1H ,3X,'***** NUMBER OF ITERATIONS=',I5,'************')
C
C
      IF(ICON.NE.3) THEN
      IF(ICON.EQ.1.OR.ICON.EQ.2) THEN
      IF(ICON.EQ.1) IQ=5
```

```
      IF(ICON.EQ.2) IQ=6
      DO 131 I=1,N
      II=IQ*(I-1)
      DO 132 IK=1,IK1
      Y2(II+IK,1)=0.0
  132 CONTINUE
  131 CONTINUE
      ELSE
      DO 130 IK=1,IK1
      Y2(IK,1)=0.0
  130 CONTINUE
      END IF
      END IF
C
      DO 135 I=1,I1
      DO 135 J=1,I1
  135 P3(I,J)=0.0
C
      IF(KKK.EQ.1) GO TO 140
C     -------  WEIGHTED GLOBAL ITERATIONS ------------------
C           *PITE=WEIGHT OF GLOBAL ITERATIONS
C
      DO 150 I=1,I1
      DO 160 J=1,I1
      P3(I,J)=P2(I,J)*PITE
      P2(I,J)=P3(I,J)
  160 CONTINUE
  150 CONTINUE
C     -------------------------------------------------------
  140 CONTINUE
C
      WRITE(6,8000)
      WRITE(6,1800)
 1800 FORMAT(1H ,'INITIAL GUESS OF THE STATE VECTOR =')
      WRITE(6,1400) (Y2(I,1),I=1,I1)
 1400 FORMAT(1H ,6(1X,F11.5))
C
      NZ=1
      XX=0.0
      XXX=0.0
C
      WRITE(6,8000)
      WRITE(6,1500) ND3,ND5
 1500 FORMAT(1H ,'ND3=',I5,5X,'ND5=',I5)
C
C    ******************************
C    *  EXTENDED KALMAN FILTER    *
C    ******************************
C
      DO 9000 KK=ND3,ND5
C
      KQ=KK-ND3+1
C
C     -----  COMPUTE THE PREDICTED STATE VECTOR [Y1]
C                 AND ITS STATE TRANSITION MATRIX [W1] -----
      IF(ICON.EQ.1) GO TO 3100
      IF(ICON.EQ.2) GO TO 3200
      IF(ICON.EQ.3) GO TO 3300
      IF(ICON.EQ.4) GO TO 3400
      IF(ICON.EQ.5) GO TO 3500
```

```
      IF(ICON.EQ.6) GO TO 3600
C
 3100 CONTINUE
C
C     ***********    LINEAR-MDOF   (ICON=1)      **************
C       (CONTINUOUS STATE EQUATION WITH RUNGE-KUTTA METHOD)
C
      CALL FF1(N,F,Y2,Y1,I1,DY,DT,J1,J3,KK)
      CALL WW1(N,W1,Y2,I1,J1,J3,DT,DY,KK)
      GO TO 4000
C
 3200 CONTINUE
C
C     ***********    LINEAR-MDOF (ICON=2)      ****************
C     (DISCRETE STATE EQUATION WITH LINEAR ACCELERATION METHOD)
C
      CALL FF2(F,Y2,Y1,I1,DY,DT,J1,J3,KK,N,MC)
      CALL WW2(W1,Y2,DY,I1,J1,DT,KK,J3,N,MC)
      GO TO 4000
C
 3300 CONTINUE
C
C     ***********    LINEAR-MDOF (ICON=3)      ***************
C                (FREQUENCY DOMAIN FORMULATION)
C
      CALL FF3(F,Y2,Y1,J1,I1)
      CALL WW3(W1,Y2,I1,J1)
      GO TO 4000
C
 3400 CONTINUE
C
C     **********    NONLINEAR-SDOF (ICON=4)    ***************
C             (NONPARAMETRIC RESTORING FORCE MODEL)
C
      CALL FF4(F,Y2,Y1,DY,DT,J1,J3,KK,NM1)
      CALL WW4(W1,Y2,I1,J1,DT)
      BB1=Y2(3,1)*Y2(1,1)+Y2(4,1)*Y2(1,1)*Y2(1,1)*Y2(1,1)
      BB2=Y2(5,1)*Y2(2,1)+Y2(6,1)*Y2(2,1)*Y2(2,1)*Y2(2,1)
C     *****  GG1: ESTIMATED HYSTRESIS *******************
      GG1(KQ)=BB1+BB2
      GO TO 4000
C
 3500 CONTINUE
C
C     ***********    NONLINEAR-SDOF (ICON=5)    **************
C           (BILINEAR HYSTERETIC RESTORING FORCE MODEL)
C
      CALL FF5(F,Y2,Y1,DY,DT,J1,J3,KK,NZ,XX,XXX,AK1)
      CALL WW5(W1,Y2,DT,I1,J1,XX,NZ,XXX)
C     ****** GG1: ESTIMATED HYSTERESIS *******************
      GG1(KQ)=AK1
      GO TO 4000
C
 3600 CONTINUE
C
C     ***********      NONLINEAR-SDOF (ICON=6)    **************
C            (BOUC-WEN'S HYSTERETIC RESTORING FORCE MODEL)
C
      CALL FF6(F,Y2,Y1,DY,DT,J1,J3,KK,AAZ,NM1)
      CALL WW6(W1,Y2,I1,J1,DT,KK,AAZ,NM1)
```

```
C      ******* GG1: ESTIMATED HYSTERESIS ******************
       GG1(KQ)=Y2(3,1)
C
  4000 CONTINUE
C
       DYC(KQ)=DY(KK)
       DO 170 JC=1,I2
   170 YC(JC,KQ)=Y(JC,KK)
C
       DO 180 I=1,I1
   180 Y4(I,KQ)=P2(I,I)
C
C      --- COMPUTE THE ERROR COVARIANCE MATRIX
C                        OF THE PREDICTED STATE   [P1]------
       CALL STEP5(P1,W1,P2,W2,G1,Q,G2,I1,J1)
C
       DO 190 I=1,I1
   190 Y3(I,KQ)=Y2(I,1)
C
C
       IF(KK.EQ.ND5) GO TO 9000
       CALL HH1(H1,I2,DT,J1,J2,KK,ICON,Y1,N)
C
C      --- COMPUTE THE KALMAN GAIN MATRIX [AK] -----------
       CALL STEP1(AK,P1,H1,H2,R,I1,I2,J1,J2)
C
       DO 100 I=1,I2
       Z(I,1)=Y(I,KK+1)
   100 CONTINUE
C
       CALL HH2(N,AHH,Y1,KK,DT,I2,J1,J2,ICON)
C
C      --- COMPUTE THE FILTERED STATE VECTOR [Y2] --------
       CALL STEP2(Y2,Y1,AK,Z,AHH,I1,I2,J1,J2)
C
C      --- COMPUTE THE ERROR COVARIANCE MATRIX
C                       OF THE FILTERED STATE [P2] ----------
       CALL STEP3(P2,AK,H1,P1,R,I1,I2,J1,J2)
C
       IF(ICON.EQ.5.AND.KK.NE.1) THEN
       CALL SETN(Y3,J1,J3,KK,NZ,XX,XXX)
       END IF
C
  9000 CONTINUE
C
C
C*************************************************************
C
       IF(ICON.EQ.1.OR.ICON.EQ.2) THEN
       DO 510 J=1,I2
       DO 520 JJ=1,KQ
       AA=0.0
       DO 530 I=1,N
       IF(ICON.EQ.1) IQ=5
       IF(ICON.EQ.2) IQ=6
       II=IQ*(I-1)
       AA=AA+Y3(J+II,JJ)
   530 CONTINUE
       Y3(J,JJ)=AA
   520 CONTINUE
```

```
  510 CONTINUE
      END IF
C*********************************************************
C     PRINT GENERAL OUTPUT (UNIT=6)
      CALL WRITEB(YC,DYC,Y3,I2,I1,J1,J2,J3,ND,Y4)
C**********************************************************
C
 9500 CONTINUE
C
C
C     ***************************************************
C     GENERATE OUTPUT FILE (UNIT=22-UNIT=30) FOR PLOTTING
      CALL WRITEC(ICON,NCON,DT,N,ND,Y3,GG1,J1,J3)
C*********************************************************
      STOP
      END
C
C   ***************** SUBROUTINE READB ************************
C   *                                                         *
C   *  SUBROUTINE FOR  READING GENERAL INPUT DATA FROM UNIT 3 *
C   *              CALLED BY THE MAIN PROGRAM                 *
C   ***********************************************************
C
C     PURPOSE:
C       TO READ GENERAL INPUT DATA AND INITIAL GUESS FROM UNIT=3
C
C     USAGE:
C       CALL READB(QR1,QR2,Y2,P11,G11,N,NN,I1,I2,DT,
C      *   J1,J2,J5,ITE,PITE,NM1,NM2,MC,ICON,NCON,AAZ)
C
C ***********************************************************************
C           < DESCRIPTION OF INPUT DATA IN UNIT 3  >
C                    ***  FREE FORMAT  ***
C ***********************************************************************
C
C  1. HEADING CARD
C
C  2. MASTER CONTROL CARD; ICON,NCON,ITE,PITE
C
C      ICON:  ANALYSIS CASE
C         ICON=1 : LINEAR (MDOF) RUNGE-KUTTA METHOD
C         ICON=2 : LINEAR (MDOF) LINEAR ACCLERATION METHOD
C         ICON=3 : LINEAR (MDOF) FREQUENCY DOMAIN
C         ICON=4 : NONLINEAR (SDOF) NONPARAMETRIC MODEL
C         ICON=5 : NONLINEAR (SDOF) BILINEAR HYSTRESIS
C         ICON=6 : NONLINEAR (SDOF) BOUC-WEN'S MODEL
C
C      NCON : OUTPUT COTROL
C
C         IF(ICON.LE.3), NO OUTPUT DATA FILES EXCEPT UNIT 6 ARE GENERATED AND
C                         ANY POSITIVE INTEGER VALUE MAY BE INPUT FOR NCON.
C
C         IF(ICON.GE.4 AND NCON=1), UNIT 22-30 ARE GENERATED FOR PLOTTING.
C              UNIT=22 : ESTIMATED HYSTERESIS
C              UNIT=23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
C
C      ITE : TOTAL NUMBER OF GLOBAL ITERATIONS (ITE.GE.1)
C
C      PITE : WEIGHT FOR EK-WGI PROCEDURE  (PITE.GT.1.0)
C
```

```
C  3. CONTROL CARD; N,I1,I2,MC2
C
C      N  : NUMBER OF DEGREES OF FREEDOM(OR MODES) TO BE IDENTIFIED
C
C      I1 : DIMENSION OF EXTENDED STATE VECTOR (I1.LE.30)
C
C                   TABLE 5-I  COMPONENTS OF STATE VECTOR
C         +--------------------------------------------------------------+
C         |ICON |  I1  |          COMPONENTS  OF STATE VECTOR            |
C         |-----|------|-------------------------------------------------|
C         |  1  |  5*N |  Uij, dUij/dt, hj, wj, Pij                      |
C         |     |      |              for each mode j=1,..,N             |
C         |-----|------|-------------------------------------------------|
C         |  2  |  6*N |  Uij, dUij/dt, ddUij/dtdt, hj, wi, Pij         |
C         |     |      |              for each mode j=1,...,N            |
C         |-----|------|-------------------------------------------------|
C         |  3  |  3*N |  hj, wj, Pij     for each mode j=1,...,N        |
C         |-----|------|-------------------------------------------------|
C         |  4  |   6  |  Z, dZ/dt, a1, a2, a3, a4                       |
C         |-----|------|-------------------------------------------------|
C         |  5  |   6  |  Z, dZ/dt, h, w, Ze, alfa                       |
C         |-----|------|-------------------------------------------------|
C         |  6  |  12  |  Z, dZ/dt, phi, e, h, w, be, ga, A0, ca, cv, cn |
C         +--------------------------------------------------------------+
C
C       NOTE :
c          FOR ICON=6, (SEE SECTION 3.4)
C            phi = hysteretic function,
C            e   = dissipated hysteretic energy,
C            h   = damping ratio,  w = natural frequency,
C            be  = beta,  ga = gamma,
C            A0  = A0, ca = delta A, cv = delta nu, cn = delta eta
C
C      I2  : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING
C              IF ICON IS 1,4,5 OR 6,  I2 IS RECOMMENED AS 2.
C              IF ICON IS 3,  I2 MUST BE 2.
C
C      MC2 : CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED
C               (REQUIRED ONLY FOR ICON=2)
C
C                    TABLE 5-II  RESPONSE OBSERVATIONS USED
C          +--------------------------------------------------------+
C          |ICON | I2 | MC2 |        RESPONSE COMPONENTS USED       |
C          |-----|----|-----|---------------------------------------|
C          |  1  | 1  |     | DISPLACEMENT ONLY                     |
C          |     | 2  |     | DISPLACEMENT AND VELOCITY             |
C          |--------------------------------------------------------|
C          |  2  | 1  |  1  | DISPLACEMENT RESPONSE                 |
C          |     |    |  2  | VELOCITY RESPONSE                     |
C          |     |    |  3  | ACCELERATION RESPONSE                 |
C          |     |----|-----|---------------------------------------|
C          |     | 2  |  1  | DISPLACEMENT AND VELOCITY RESPONSE    |
C          |     |    |  2  | ACCELERATION AND VELOCITY RESPONSE    |
C          |--------------------------------------------------------|
C          |  3  | 2  |     | REAL AND IMAGINERY PARTS OF FREQUENCY |
C          |     |    |     | RESPONSE FUNCTION  WILL BE USED.      |
C          |--------------------------------------------------------|
C          |  4  | 1  |     | DISPLACEMENT ONLY                     |
C          |     | 2  |     | DISPLACEMENT AND VELOCITY             |
C          |--------------------------------------------------------|
```

```
C           |  5  | 1  |      | DISPLACEMENT ONLY                          |
C           |     | 2  |      | DISPLACEMENT AND VELOCITY                  |
C           |-----------------------------------------------------------|
C           |  6  | 1  |      | DISPLACEMENT ONLY                          |
C           |     | 2  |      | DISPLACEMENT AND VELOCITY                  |
C           +-----------------------------------------------------------+
C       NOTE :
C              FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
C              TO THE GROUND MOTION MUST BE USED.
C
C  4. OBSERVATION DATA CARD; NN,DT,NM1,NM2
C
C       NN  : TOTAL NUMBER OF OBSERVATION DATA POINTS OF EACH RECORD
C       DT  : TIME INCREMENT(SEC) OR FREQUENCY INCREMENT(RAD/SEC) IN DATA
C       NM1 : STRATING DATA POINT USED FOR FILTERING
C       NM2 : ENDING DATA POINT USED FOR FILTERING
C
C  5. INITIAL GUESS FOR FILTERED STATE VECTOR; Y2(I,1), I=1,I1
C
C         DATA MUST BE SUPPLIED FOR Y2(I,1), I=1,I1.
C         FOR DEFINITION OF STATE VECTOR Y2(I),  SEE TABLE 5-I.
C
C  6. INITIAL GUESS FOR ERROR COVARIANCE MATRIX OF THE FILTERED STATE;
C               P11(I), I=1,I1
C
C         INITIAL VALUES FOR THE ERROR COVARIANCE MATRIX OF THE FILTERED
C         STATE VECTOR IS ASSUMED AS DIAGONAL.   INITIAL VALUES OF THE
C         DIAGONAL MEMBERS MUST BE SUPPIED;  P11(I), I=1,I1.
C
C  7. SYSTEM NOISE COVARIANCE MATRIX;  QR1(I), I=1,I1
C
C         COVARIANCE MATRIX OF SYSTEM NOISE IS ASSUMED TO BE DIAGONAL.
C         VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPLIED;  QR1(I), I=1,I1
C
C  8. SYSTEM NOISE COEFFICIENT MATRIX; G11(I), I=1,I1
C
C         COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
C         DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
C         MUST BE PROVIDED;  G11(I), I=1,I1
C
C  9. OBSERVATION NOISE COVARIANCE MATRIX; QR2(I),I=1,I2
C
C         COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
C         DIAGONAL.  DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
C               QR2(I),  I=1,I2.
C
C ***********************************************************************
C
C      REMARKS:
C        (1) PARAMETER I1 MUST BE LESS THAN 30
C        (2) PARAMETER I2 MUST BE LESS THAN 10
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        NONE
C************************************************************************
C
      SUBROUTINE READB(QR1,QR2,Y2,P11,G11,N,NN,I1,I2,DT,
     *    J1,J2,J5,ITE,PITE,NM1,NM2,MC,ICON,NCON,AAZ)
      CHARACTER*72 TEXT
      DIMENSION QR1(J1),QR2(J2),Y2(J1,1)
```

```
      DIMENSION MC(J5),P11(J1),G11(J1)
C
      READ(3,1200) TEXT
 1200 FORMAT(72A)
C
      READ(3,*) ICON,NCON,ITE,PITE
C
      IF(ICON.NE.2) READ(3,*) N,I1,I2
      IF(ICON.EQ.2) READ(3,*) N,I1,I2,MC2
C
      READ(3,*) NN,DT,NM1,NM2
C
      READ(3,*) (Y2(I,1),I=1,I1)
C
      READ(3,*) (P11(I),I=1,I1)
C
      READ(3,*) (QR1(I),I=1,I1)
C
      READ(3,*) (G11(I),I=1,I1)
C
      READ(3,*) (QR2(I),I=1,I2)
C
C
      AAZ=1.0
      MC(1)=1
      MC(2)=MC2
      IF(I2.EQ.2.AND.MC(2).EQ.2) MC(2)=3
C
      WRITE(6,1210) TEXT
 1210 FORMAT(2X,72A/)
C
      WRITE(6,8000)
      WRITE(6,1201) ICON
 1201 FORMAT(1H ,'ANALYSIS CASE : ICON====>',I5)
C
      WRITE(6,8000)
      WRITE(6,1202) NCON
 1202 FORMAT(1H ,'OUTPUT CONTROL : NCON====>',I5)
C
      WRITE(6,8000)
      WRITE(6,1203) ITE
 1203 FORMAT(1H ,'NO. OF GLOBAL ITERATIONS : ITE ====>',I5)
C
      WRITE(6,8000)
      WRITE(6,1204) PITE
 1204 FORMAT(1H ,'WEIGHT FOR GLOBAL ITERATION : PITE===>',2X,E15.4)
C
      WRITE(6,8000)
      WRITE(6,1205) N
 1205 FORMAT(1H ,'NO. OF DOF OF SYSTEM : N===>',I5)
C
      WRITE(6,8000)
      WRITE(6,1206) I1
 1206 FORMAT(1H ,'DIMENSION OF STATE VECTOR : I1===>',I5)
C
      WRITE(6,8000)
      WRITE(6,1207) I2
 1207 FORMAT(1H ,'NO. OF RESPONSE OBSERVATIONS USED : I2===>',I5)
C
      IF(ICON.EQ.2) THEN
```

```
      WRITE(6,8000)
      WRITE(6,1208) MC2
 1208 FORMAT(1H ,'CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED '
     1          ,': MC2 ====>',2X,I5)
      END IF
C
      WRITE(6,8000)
      WRITE(6,1020) NN,DT,NM1,NM2
 1020 FORMAT(1H ,'DATA OF OBSERVED RECORDS TO BE USED :'/
     1   1H ,'  NN=',I5,'     DT=',F10.4,'     NM1=',I5,'    NM2=',I5)
C
      WRITE(6,8000)
      WRITE(6,1041)
 1041 FORMAT(1H ,'INITIAL GUESS OF STATE VECTOR : Y2===>')
      WRITE(6,1040) (Y2(I,1),I=1,I1)
 1040 FORMAT(1H ,6(2X,E10.3))
C
      WRITE(6,8000)
      WRITE(6,1051)
 1051 FORMAT(1H ,'INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL)'
     1         ,' : P11===>')
      WRITE(6,1050) (P11(I),I=1,I1)
 1050 FORMAT(1H ,6(2X,E10.3))
C
      WRITE(6,8000)
      WRITE(6,1055)
 1055 FORMAT(1H ,'COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) :'
     1          ,' QR1===>')
      WRITE(6,1050) (QR1(I),I=1,I1)
C
      WRITE(6,8000)
      WRITE(6,1061)
 1061 FORMAT(1H ,'COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>')
      WRITE(6,1060) (G11(I),I=1,I1)
 1060 FORMAT(1H ,6(2X,E10.3))
C
      WRITE(6,8000)
      WRITE(6,1070) (QR2(I),I=1,I2)
 1070 FORMAT(1H ,'COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL)'
     1          ,' : QR2===>'/,6(2X,E10.3))
C
      WRITE(6,8000)
C
 8000 FORMAT(1H ,' ')
      RETURN
      END
C
C     *******************   SUBROUTINE READD   *******************
C     *                                                          *
C     *   SUBROUTINE FOR READING OBSERVED INPUT EXCIATION  AND   *
C     *   RESPONSE OBSERVATION  DATA  FROM UNIT 8                *
C     *              CALLED BY THE MAIN PROGRAM                  *
C     ************************************************************
C     PURPOSE:
C       TO READ OBERVATION DATA FOR INPUT EXCITATION
C                         AND RESPONSE OBSERVATION FROM UNIT=8
C
C     USAGE:
C       READD(DY,Y,NN,I2,J2,J3,ICON,MC)
C
```

```
C     DESCRIPTION OF PARAMETERS
C        DY(J3): OBSERVED INPUT EXCITATION
C      Y(J2,J3): OBSERVATION DATA
C           I2 : NUMBER OF RESPONSE OBSERVATIONS
C        J2,J3 : DIMENSION OF [DY] OR [Y] IN CALLING PROGRAM
C         ICON : PARAMETER FOR STATE VECTOR EQUATION
C                AND OBSERVATION EQUATION
C          MC  : PARAMETERS FOR OBSERVATION DATA
C                IN (ICON.EQ.2)
C     REMARKS
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C      NONE
C ********************************************************************
C ********************************************************************
C                  < DESCRIPTION OF INPUT DATA IN UNIT 8 >
C ********************************************************************
C
C  ******   IF ICON = 1,2,4,5 AND 6   ******
C
C  1. HEADING CARD  (72A)
C
C  2. MASTER CONTROL DATA ;  NRSP  (I5)
C
C       NRSP : NUMBER OF RESPONSE COMPONENT RECORDS AT A CERTAIN NODE
C              TO BE SUPPLIED IN THIS DATA FILE (NRSP.LE.3)
C
C  3. GROUND ACCELERATION DATA
C
C    3-A.  TITLE CARD  (72A)
C
C    3-B.  GROUND ACCELERATION DATA  ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C  4. RESPONSE OBSERVATION DATA
C
C       NRSP COMPONENTS OF RESPONSE OBSERVATIONS MUST BE PROVIDED.
C          (FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
C           TO THE GROUND MOTION MUST BE USED.)
C
C       FOR EACH COMPONENT, FOLLOWING SET OF DATA MUST BE SUPPLIED.
C
C    4-A.  TITLE OF RESPONSE COMPONENT ( 72A )
C
C    4-B.  RESPONSE COMPONENT INDICATOR  ( I5 )
C                    = 1,  FOR DISPLACEMANT
C                      2,  FOR VELOCITY
C                      3,  FOR ACCELERATION
C
C    4-C.  OBSERVED RESPONSE DATA  ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C  ******   IF ICON = 3   ******
C
C  1. HEADING CARD ( 72A )
C
C  2. MASTER CONTROL CARD ;  NRSP ( I5 )
C       NRSP = 2 (REAL & IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION)
```

```
C
C  3. REAL PARTS OF FREQUENCY RESPONSE FUNCTION
C
C    3-A.  TITLE CARD   ( 72A )
C
C    3-B   RESPONSE COMPONENT INDICATOR   ( I5 )
C                 =  1   (REAL PARTS)
C
C    3-C.  REAL PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C  4. IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION
C
C    4-A.  TITLE CARD   ( 72A )
C
C    4-B   RESPONSE COMPONENT INDICATOR ( I5 )
C                 =  2   (IMAGINERY PARTS)
C
C    4-C.  IMAGINERY PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
C             NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
C             SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
C
C *********************************************************************
C
      SUBROUTINE READD(DY,Y,NN,I2,J2,J3,ICON,MC)
C      IMPLICIT REAL*8(A-H,O-Z)
      CHARACTER*72 DUMMY
      DIMENSION DY(J3),Y(J2,J3)
      DIMENSION MC(3),A(3,3000)
C
      READ (8,101) DUMMY
      READ (8,102) NRSP
  102 FORMAT(I5)
C
      DO 300 I=1,3
      DO 310 J=1,NN
      A(I,J)=0.0
      Y(I,J)=0.0
      DY(J)=0.0
  310 CONTINUE
  300 CONTINUE
C
      IF(ICON.EQ.3) GO TO 3000
C
      READ(8,101) DUMMY
      READ(8,5)  (DY(I),I=1,NN)
C
      DO 100 J=1,NRSP
      READ(8,101) DUMMY
      READ(8,102) JDX
      READ(8,5)  (A(JDX,I),I=1,NN)
  100 CONTINUE
    5 FORMAT(8(1PE10.3))
  101 FORMAT(72A)
C
      IF(ICON.EQ.2) GO TO 2000
C
      DO 210 J=1,I2
      DO 220 K=1,NN
```

```
      Y(J,K)=A(J,K)
  220 CONTINUE
  210 CONTINUE
C
      GO TO 1000
C
 2000 CONTINUE
      DO 510 I=1,3
      M=I
      IF(I.EQ.MC(1)) M=MC(2)
      IF(I.EQ.MC(2)) M=MC(1)
      DO 520 K=1,NN
      Y(M,K)=A(I,K)
  520 CONTINUE
  510 CONTINUE
C
      GO TO 1000
C
 3000 CONTINUE
      DO 600 I=1,2
      READ(8,101) DUMMY
      READ(8,102) JDX
      READ(8,5)  (Y(JDX,KK),KK=1,NN)
  600 CONTINUE
C
 1000 CONTINUE
C
      RETURN
      END
C
C     ****************   SUBROUTINE SETIK  ***************
C     *                                                   *
C     *   SUBROUTINE FOR SETTING UP INITIAL GUESS         *
C     *          CALLED BY THE MAIN PROGRAM               *
C     *****************************************************
C
C
      SUBROUTINE SETIK(ICON,IK,Y,NM1,J2,J3)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y(J2,J3)
C
      IK=2
      IF(ICON.EQ.3) GO TO 200
      IF(ICON.EQ.1) IK=2
      IF(ICON.EQ.2) IK=3
      IF(ICON.EQ.6) IK=4
C
      DO 100 I=1,IK
      Y(I,NM1)=0.0
  100 CONTINUE
  200 CONTINUE
C
C
      RETURN
      END
C
C     ***************   SUBROUTINE INIT ********************
C     *                                                     *
C     *   SUBROUTINE FOR SETTING UP INITIAL GUESS           *
C     *          CALLED BY THE MAIN PROGRAM                 *
```

```
C     ****************************************************
C
C     PURPOSE:
C       TO SET UP INITIAL GUESS FOR EK-WGI PROCEDURE
C
C     USAGE:
C       CALL INIT(Q,P2,G1,R,H1,QR1,QR2,P11,G11,I1,I2,J1,J2,F)
C
C     DESCRIPTION OF PARAMETERS
C       Q(J1,J1)  : SYSTEM NOISE COVARIANCE MATRIX
C      P2(J1,J1)  : ERROR COVARIANCE MATRIX OF THE FILTERED
C                   STATE
C      G1(J1,J1)  : SYSTEM NOISE COEFFICIENT MATRIX
C       R(J2,J2)  : OBSERVATION NOISE COVARIANCE MATRIX
C      H1(J2,J1)  : LINEARIZED MATRIX OF THE OBSERVATION EQ.
C                   REGARDING EACH PARAMETER
C         QR1(J1) : SYSTEM NOISE COVARIANCE MATRIX
C         QR2(J1) : OBSERVATION NOISE COVARIANCE MATRIX
C         P11(J1) : INITIAL GUESS FOR DIAGONAL ELEMENTS OF
C                   FILTERED ERROR COVARIANCE MATRIX
C         G11(J1) : INITIAL GUESS FOR DIAGONAL ELEMENTS OF
C                   SYSTEM NOISE COEFFICIENT MATRIX
C              I1 : DIMENSION OF EXTENDED STATE VECTOR
C                    (I1.LE.30)
C              I2 : NUMBER OF RESPONSE OBSERVATIONS
C                    (I2.LE.10)
C           J1,J2:   DIMENSION OF [Q],[P2],[G1],[R],[H1],[QR1],[QR2],
C                    [P11],[G11] OR [F]
C         F(J1,1) : PREDICTED STATE VECTOR
C
C      REMARK:
C          (1) PARAMETER I1 MUST BE LESS THAN 30
C          (2) PARAMETER I2 MUST BE LESS THAN 10
C
C      SUBROUTINES AND FUNCTION SUBROUTINES REQUIRED
C          NONE
C     ******************************************************************
C
C
      SUBROUTINE INIT(Q,P2,G1,R,H1,QR1,QR2,P11,G11,
     *                     I1,I2,J1,J2,F)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION P2(J1,J1),G1(J1,J1),R(J2,J2)
      DIMENSION P11(J1),G11(J1),H1(J2,J1)
      DIMENSION Q(J1,J1),F(J1,1),QR1(J1),QR2(J2)
C
      DO 10 I=1,I1
      DO 10 J=1,I1
      Q(I,J)=0.0
      P2(I,J)=0.0
      G1(I,J)=0.0
      F(I,1)=0.0
   10 CONTINUE
C
      DO 20 I=1,I2
      DO 20 J=1,I2
   20 R(I,J)=0.0
C
      DO 30 I=1,I1
      P2(I,I)=P11(I)
```

```
      G1(I,I)=G11(I)
      Q(I,I)=QR1(I)
   30 CONTINUE
C
      DO 40 I=1,I2
   40 R(I,I)=QR2(I)
C
      DO 50 I=1,I1
      DO 50 J=1,I2
   50 H1(J,I)=0.0
C
      RETURN
      END
C
C     **************      SUBROUTINE FF1     *******************
C     *                                                         *
C     *      SUBROUTINE FOR THE PREDICTED STATE VETCOR          *
C     *  OF LINEAR MULTI-DEGREE OF FREEDOM SYSTEM BY SOLVING    *
C     *  DIFFERENTIAL EQUATION USING RUNGE-KUTTA METHOD.        *
C     *                      ( ICON = 1 )                       *
C     *                 CALLED BY THE MAIN PROGRAM              *
C     ***********************************************************
C
C      PURPOSE:
C        TO COMPUTE THE PREDICTED STATE VECTOR OF LINEAR MULTI-
C        DEGREE OF FREEDOM SYSTEM (ICON.EQ.1).
C
C      USAGE:
C        CALL FF1(N,F,Y2,Y1,I1,DY,DT,J1,J3,KK)
C
C      DESCRIPTION OF PARAMETERS
C                   N : NUMBER OF DEGREE OF STRUCTURE
C F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
C           Y2(J1,1): FILTERED STATE VECTOR
C                 I1 : DIMENSION OF EXTENDED STATE VECTOR
C             DY(J3) : OBSERVED INPUT EXCIATION
C                 DT : TIME INCREMENT IN DATA IN SEC
C              J1,J3 : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
C                      PROGRAM
C                 KK : TIME IN DATA PROCESSING
C
C     REMARK:
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       RUNGE
C     *******************************************************************
C
      SUBROUTINE FF1(N,F,Y2,Y1,I1,DY,DT,J1,J3,KK)
C       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y2(J1,1),DY(J3),F(J1,1)
      DIMENSION QT(1,2),YY(1),Q(1,2)
      DIMENSION YT(1,2),ACK(1,2)
      DIMENSION Y(1,2),Y1(J1,1)
C
C
      DO 100 I=1,N
      II=5*(I-1)
C
      F(3+II,1)=Y2(3+II,1)
      F(4+II,1)=Y2(4+II,1)
```

```
      F(5+II,1)=Y2(5+II,1)
C
      ACK(1,1)=Y2(4+II,1)*Y2(4+II,1)
      ACK(1,2)=Y2(4+II,1)*Y2(3+II,1)*2.0
      ARPA=Y2(5+II,1)
C
C
      DO 200 J=1,2
      QT(1,J)=0.0
      YT(1,J)=Y2(J+II,1)
  200 CONTINUE
C
      DDYT=DY(KK)
      DDY=DY(KK+1)
      CALL RUNGE(1,ACK,DT,DDY,DDYT,Y,YY,YT,
     *           Q,QT,1,5,ARPA)
      F(1+II,1)=Y(1,1)
      F(2+II,1)=Y(1,2)
C
  100 CONTINUE
C
      DO 300 I=1,I1
      Y1(I,1)=F(I,1)
  300 CONTINUE
C
      RETURN
      END
C
C     **************      SUBROUTINE RUNGE  **********************
C     *                                                          *
C     *   SUBROUTINE FOR THE PREDICTED STATE VECTOR OF LINEAR   *
C     *   MDOF SYSTEM BY SOLVING DEFFERENTIAL EQUATION USING    *
C     *   RUNGE-KUTTA METHOD                                     *
C     *                    ( ICON = 1 )                          *
C     *                CALLED BY SUBROUTINE FF1                  *
C     ************************************************************
C
C
      SUBROUTINE RUNGE(N,ACK,DT,DDY,DDYT,
     * Y,YY,YT,Q,QT,M1,NK,ARPA)
C       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ACK(M1,2),Y(M1,2),YY(M1),YT(M1,2),Q(M1,2)
      DIMENSION QT(M1,2)
      DIMENSION P1(4),P2(4),P3(4),P4(4),P5(4)
      DIMENSION Z(10,2),T(10,2),R(10,2)
      DATA P1/0.5,1.0,1.0,0.5/
      DATA P2/1.0,0.2928932,1.7071068,0.333333/
      DATA P3/0.0,0.7071068,-0.7071068,0.0/
      DATA P4/1.0,0.5,0.5,0.0/
      DATA P5/0.0,0.5,0.5,1.0/
      DO 11 I=1,N
      DO 10 L=1,2
      Q(I,L)=QT(I,L)
      Y(I,L)=YT(I,L)
   10 CONTINUE
   11 CONTINUE
      DO 15 JJ=1,4
      DDYG=P4(JJ)*DDYT+P5(JJ)*DDY
      DO 12 I=1,N
      Z(I,1)=Y(I,2)*DT
```

```
      CALL MAT(ACK,Y,N,I,DDYG,Z12,M1,NK,ARPA)
      Z(I,2)=Z12*DT
   12 CONTINUE
      DO 14 I=1,N
      DO 13 L=1,2
      T(I,L)=P1(JJ)*Z(I,L)-Q(I,L)
      R(I,L)=P2(JJ)*T(I,L)
      Y(I,L)=Y(I,L)+R(I,L)
      Q(I,L)=3.0*R(I,L)-T(I,L)+P3(JJ)*Z(I,L)
   13 CONTINUE
   14 CONTINUE
   15 CONTINUE
      DO 17 I=1,N
      CALL MAT(ACK,Y,N,I,DDY,Z12,M1,NK,ARPA)
   17 YY(I)=Z12
      RETURN
      END
C
C     **************** SUBROUTINE MAT *********************
C     *                                                   *
C     *    SUBROUTINE FOR THE PREDICTED STATE VECTOR OF   *
C     *    LINEAR MDOF SYSTEM                             *
C     *                    ( ICON = 1 )                   *
C     *              CALLED BY SUBROUTINE RUNGE           *
C     *****************************************************
C
      SUBROUTINE MAT(ACK,Y,N,I,DDYG,Z12,M1,NK,ARPA)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION ACK(M1,2),Y(M1,2)
      IF(NK.EQ.5) GO TO 100
      Z12=-(ACK(I,1)*Y(I,1)+ACK(I,2)*Y(I,2))-DDYG
      Z12=Z12-ACK(I,1)*ARPA
      RETURN
  100 Z12=-(ACK(I,1)*Y(I,1)+ACK(I,2)*Y(I,2))-ARPA*DDYG
      RETURN
      END
C
C     ***************      SUBROUTINE FF2     *********************
C     *                                                           *
C     *      SUBROUTINE FOR THE PREDICTED STATE VETCOR            *
C     *  OF LINEAR MULTI-DEGREE OF FREEDOM SYSTEM BY SOLVING      *
C     *  DIFFERENTIAL EQUATION USING LINEAR ACCELERATION METHOD *
C     *                      ( ICON = 2 )                         *
C     *                 CALLED BY THE MAIN PROGRAM                *
C     *************************************************************
C
C      PURPOSE:
C        TO COMPUTE THE PREDICTED STATE VECTOR OF
C        LINEAR  MULTI-DEGREE OF FREEDOM SYSTEM (ICON.EQ.2).
C
C      USAGE:
C        CALL FF2(F,Y2,Y1,I1,DY,DT,J1,J3,KK,N,MC)
C
C      DESCRIPTION OF PARAMETERS
C  F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
C          Y2(J1,1): FILTERED STATE VECTOR
C               I1 : DIMENSION OF EXTENDED STATE VECTOR
C           DY(J3) : OBSERVED INPUT EXCIATION
C               DT : TIME INCREMENT IN DATA IN SEC
C            J1,J3 : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
```

```
C                        PROGRAM
C                    KK : TIME IN DATA PROCESSING
C                     N : NUMBER OF DEGREE OF FREEDOM STRUCTURE
C          MC(1),MC(2): PARAMETERS FOR OBSERVATION DATA
C                        IN (ICON.EQ.2)
C      REMARK:
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        MMUT
C      *****************************************************************
C
C
       SUBROUTINE FF2(F,Y2,Y1,I1,DY,DT,J1,J3,KK,N,MC)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION F(J1,1),Y2(J1,1),DY(J3),Y1(J1,1)
       DIMENSION A(3,3),B(3,1),A1(3,1)
       DIMENSION A2(3,3),B1(3,1),A3(3,1),MC(3)
C
C
       DO 1000 K=1,N
       K1=6*(K-1)
C
       DO 300 I=1,3
       B1(I,1)=0.0
       B(I,1)=0.0
   300 CONTINUE
C
C
       X4=Y2(4+K1,1)
       X5=Y2(5+K1,1)
       Z=-1.0/(1.0+DT*X4*X5+DT*DT*X5*X5/6.0)
       S=X5*X5*Z
       U=(DT*X4*X5+DT*DT*X5*X5/3.0)*Z
       T=(2.0*X4*X5+DT*X5*X5)*Z
C
       DO 100 I=1,3
       DO 100 J=1,3
   100 A(I,J)=0.0
C
       A(1,1)=1.0+S*DT*DT/6.0
       A(1,2)=DT*(1.0+DT/6.0*T)
       A(1,3)=DT*DT/6.0*(2.0+U)
       A(2,1)=DT/2.0*S
       A(2,2)=1.0+DT/2.0*T
       A(2,3)=DT/2.0*(1.0+U)
       A(3,1)=S
       A(3,2)=T
       A(3,3)=U
C
       DO 200 I=1,3
       DO 200 J=1,3
       I5=I
       J5=J
       IF(I.EQ.MC(1)) I5=MC(2)
       IF(I.EQ.MC(2)) I5=MC(1)
       IF(J.EQ.MC(1)) J5=MC(2)
       IF(J.EQ.MC(2)) J5=MC(1)
       A2(I5,J5)=A(I,J)
   200 CONTINUE
C
```

```
      B(1,1)=Z*DT*DT/6.0*DY(KK+1)
      B(2,1)=DT/2.0*Z*DY(KK+1)
      B(3,1)=Z*DY(KK+1)
C
      DO 400 M=1,3
      M1=M
      IF(M.EQ.MC(1)) M1=MC(2)
      IF(M.EQ.MC(2)) M1=MC(1)
      B1(M1,1)=B(M,1)
  400 CONTINUE
C
      B(1,1)=B1(1,1)*Y2(6+K1,1)
      B(2,1)=B1(2,1)*Y2(6+K1,1)
      B(3,1)=B1(3,1)*Y2(6+K1,1)
C
      DO 500 I=1,3
      A3(I,1)=Y2(I+K1,1)
  500 CONTINUE
C
      CALL MMUT(A2,A3,A1,3,3,1,3,3,3,1,3,1)
C
C
      F(1+K1,1)=A1(1,1)+B(1,1)
      F(2+K1,1)=A1(2,1)+B(2,1)
      F(3+K1,1)=A1(3,1)+B(3,1)
      F(4+K1,1)=Y2(4+K1,1)
      F(5+K1,1)=Y2(5+K1,1)
      F(6+K1,1)=Y2(6+K1,1)
C
 1000 CONTINUE
C
      DO 2000 I=1,I1
      Y1(I,1)=F(I,1)
 2000 CONTINUE
C
      RETURN
      END
C
C     ****************    SUBROUTINE MMUT    *****************
C     *                                                        *
C     *        SUBROUTINE FOR MATRIX MULTIPLICATION            *
C     *       CALLED BY PROGRAMS STEP2 , STEP5 AND STEP3       *
C     **********************************************************
C
C
      SUBROUTINE MMUT(A,B,C,I1,I2,I3,J1,J2,J3,J4,J5,J6)
C       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(J1,J2),B(J3,J4),C(J5,J6)
C
C        A(I1,I2)*B(I2,I3)=C(I1,I3)
C
      DO 100 II=1,I1
      DO 200 IJ=1,I3
      C(II,IJ)=0.0
  200 CONTINUE
  100 CONTINUE
C
      DO 300 II=1,I1
      DO 400 IJ=1,I3
      DO 500 IK=1,I2
```

```
         C(II,IJ)=C(II,IJ)+A(II,IK)*B(IK,IJ)
     500 CONTINUE
     400 CONTINUE
     300 CONTINUE
    1000 CONTINUE
         RETURN
         END
C
C        *****************    SUBROUTINE FF3   **********************
C        *                                                          *
C        *    SUBROUTINE FOR THE PREDICTED STATE VETCOR OF LINEAR   *
C        *    MULTI-DEGREE OF FREEDOM SYSTEM IN FREQUENCY DOMAIN    *
C        *                     ( ICON = 3 )                         *
C        *               CALLED BY THE MAIN PROGRAM                 *
C        ************************************************************
C
C         PURPOSE:
C           TO COMPUTE THE PREDICTED STATE VECTOR OF LINEAR MDOF
C           SYSTEM IN FREQUENCY DOMAIN  (ICON.EQ.3)
C           STATE VECTOR CONSISTS OF MODAL PARAMETERS IN FREQUENCY
C           RESPONSE FUCTION.
C
C         USAGE:
C           CALL FF3(F,Y2,Y1,J1,I1)
C
C         DESCRIPTION OF PARAMETERS
C  F(J1,1),Y1(J1,1) : PREDICTED STATE VECTOR
C          Y2(J1,1) : FILTERED STATE VECTOR
C                J1 : DIMENSION OF [F] OR [Y2]
C                I1 : DIMENSION OF EXTENDED STATE VECTOR
C
C        REMARK:
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C         NONE
C        ******************************************************************
C
C
C
         SUBROUTINE FF3(F,Y2,Y1,J1,I1)
C         IMPLICIT REAL*8(A-H,O-Z)
         DIMENSION F(J1,1),Y2(J1,1),Y1(J1,1)
C
         DO 100 I=1,I1
         F(I,1)=Y2(I,1)
     100 CONTINUE
C
         DO 200 I=1,I1
         Y1(I,1)=F(I,1)
     200 CONTINUE
C
C
         RETURN
         END
C
C        ***************       SUBROUTINE FF4      ********************
C        *                                                          *
C        *       SUBROUTINE FOR THE PREDICTED STATE VETCOR          *
C        *    OF NONLINEAR SINGLE DEGREE OF FREEDOM SYSTEM  WITH    *
C        *    NONPARAMETRIC RESTORING FORCE MODEL                   *
```

```
C     *                          ( ICON = 4 )                          *
C     *                  CALLED BY THE MAIN PROGRAM                    *
C     ****************************************************************
C
C      PURPOSE:
C        TO COMPUTE THE PREDICTED STATE VECTOR FOR SINGLE DEGREE OF
C        FREEDOM SYSTEM WITH NONPARAMETRIC RESTORING FORCE MODEL
C                      (ICON.EQ.4).
C
C      USAGE:
C        CALL FF4(F,Y2,Y1,DY,DT,J1,J3,KK,NM1)
C
C      DESCRIPTION OF PARAMETERS
C  F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
C           Y2(J1,1): FILTERED STATE VECTOR
C            DY(J3)  : OBSERVED INPUT EXCIATION
C                DT  : TIME INCREMENT IN DATA IN SEC
C             J1,J3  : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
C                      PROGRAM
C                KK  : TIME IN DATA PROCESSING
C                NM1: STARTING TIME IN DATA PROCESSING
C
C     REMARK:
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       RUNGEY
C     ******************************************************************
C
      SUBROUTINE FF4(F,Y2,Y1,DY,DT,J1,J3,KK,NM1)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y1(J1,1),Y2(J1,1),DY(J3),F(J1,1)
C
      DO 10 I=3,6
      F(I,1)=Y2(I,1)
   10 CONTINUE
C
      AM=1.0
      YYD=Y2(1,1)
      YYV=Y2(2,1)
      A3=Y2(3,1)
      A4=Y2(4,1)
      A5=Y2(5,1)
      A6=Y2(6,1)
C
      CALL RUNGEY(YYD,YYV,A3,A4,A5,A6,DY,DT,J1,J3,KK,AM,NM1)
C
      F(1,1)=YYD
      F(2,1)=YYV
C
      DO 100 I=1,6
      Y1(I,1)=F(I,1)
  100 CONTINUE
C
      RETURN
      END
C
C     ***************     SUBROUTINE RUNGEY    *********************
C     *                                                              *
C     *  SUBROUTINE FOR NONLINEAR SDOF SYSTEM WITH NONPARAMETRIC     *
C     *  RESTORING FORCE MODEL.  PREDICTED STATE IS COMPUTED BY      *
```

```
C      *  RUNGE-KUTTA METHOD.                                            *
C      *                         ( ICON = 4  )                           *
C      *                   CALLED BY PROGRAM FF4                         *
C      ******************************************************************
C
C
       SUBROUTINE RUNGEY(YY1,YY2,A3,A4,A5,A6,Z,DT,J1,J3,KK,AM,NM1)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Z(J3)
       DIMENSION X1(5),X2(5),BK1(5),BK2(5)
       DIMENSION R1(5),R2(5),Q1(5),Q2(5)
C
C      IF(KK.NE.1) GO TO 100
       Q1(1)=0.0
       Q2(1)=0.0
   100 CONTINUE
C
       ZZ=(Z(KK)+Z(KK+1))/2.0
C
C
       X1(1)=YY1
       X2(1)=YY2
C
       BK1(1)=DT*X2(1)
C
       IF(KK.EQ.NM1) THEN
       ZZ1=0.0
       ZZ2=0.0
       ELSE
       ZZ1=X1(1)*X1(1)*X1(1)
       ZZ2=X2(1)*X2(1)*X2(1)
       END IF
C
       BB1=-DT*(AM*Z(KK)+A3*X1(1)+A4*ZZ1+A5*X2(1)+A6*ZZ2)/AM
       BK2(1)=BB1
C
       R1(1)=BK1(1)/2.0-Q1(1)
       R2(1)=BK2(1)/2.0-Q2(1)
C
       X1(2)=X1(1)+R1(1)
       X2(2)=X2(1)+R2(1)
C
       Q1(2)=Q1(1)+3.0*R1(1)-BK1(1)/2.0
       Q2(2)=Q2(1)+3.0*R2(1)-BK2(1)/2.0
C
       BK1(2)=DT*X2(2)
C
       IF(KK.EQ.NM1) THEN
       ZZ1=0.0
       ZZ2=0.0
       ELSE
       ZZ1=X1(2)*X1(2)*X1(2)
       ZZ2=X2(2)*X2(2)*X2(2)
       END IF
C
       BB1=-DT*(AM*ZZ+A3*X1(2)+A4*ZZ1+A5*X2(2)+A6*ZZ2)/AM
       BK2(2)=BB1
C
C
       DA1=0.2928932
```

```
      R1(2)=DA1*(BK1(2)-Q1(2))
      R2(2)=DA1*(BK2(2)-Q2(2))
C
      X1(3)=X1(2)+R1(2)
      X2(3)=X2(2)+R2(2)
C
      Q1(3)=Q1(2)+3.0*R1(2)-DA1*BK1(2)
      Q2(3)=Q2(2)+3.0*R2(2)-DA1*BK2(2)
C
      BK1(3)=DT*X2(3)
C
      IF(KK.EQ.NM1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=X1(3)*X1(3)*X1(3)
      ZZ2=X2(3)*X2(3)*X2(3)
      END IF
C
      BB1=-DT*(AM*ZZ+A3*X1(3)+A4*ZZ1+A5*X2(3)+A6*ZZ2)/AM
      BK2(3)=BB1
C
C
      DA1=0.17071068E+01
      R1(3)=DA1*(BK1(3)-Q1(3))
      R2(3)=DA1*(BK2(3)-Q2(3))
C
      X1(4)=X1(3)+R1(3)
      X2(4)=X2(3)+R2(3)
C
      Q1(4)=Q1(3)+3.0*R1(3)-DA1*BK1(3)
      Q2(4)=Q2(3)+3.0*R2(3)-DA1*BK2(3)
C
      BK1(4)=DT*X2(4)
C
      IF(KK.EQ.NM1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=X1(4)*X1(4)*X1(4)
      ZZ2=X2(4)*X2(4)*X2(4)
      END IF
C
      BB1=-DT*(AM*Z(KK+1)+A3*X1(4)+A4*ZZ1+A5*X2(4)+A6*ZZ2)/AM
      BK2(4)=BB1
C
      R1(4)=(BK1(4)-2.0*Q1(4))/6.0
      R2(4)=(BK2(4)-2.0*Q2(4))/6.0
C
      X1(5)=X1(4)+R1(4)
      X2(5)=X2(4)+R2(4)
C
      Q1(5)=Q1(4)+3.0*R1(4)-BK1(4)/2.0
      Q2(5)=Q2(4)+3.0*R2(4)-BK2(4)/2.0
C
      YY1=X1(5)
      YY2=X2(5)
C
C
      Q1(1)=Q1(5)
```

```
      Q2(1)=Q2(5)
C
C
      RETURN
      END
C
C     *************** SUBROUTINE FF5 ************************
C     *                                                     *
C     *      SUBROUTINE FOR THE PREDICTED STATE VETCOR      *
C     *   OF SINGLE DEGREE OF FREEDOM SYSTEM WITH BILINEAR  *
C     *   HYSTERESIS                                        *
C     *                ( ICON = 5 )                         *
C     *           CALLED BY THE MAIN PROGRAM                *
C     *******************************************************
C
C      PURPOSE:
C        TO COMPUTE THE PREDICTED STATE VECTOR FOR SDOF SYSTEM
C        WITH BILINEAR HYSTERESIS (ICON.EQ.5).
C
C      USAGE:
C        CALL FF5(F,Y2,Y1,DY,DT,J1,J3,KK,NZ,XX,XXX,AK1)
C
C      DESCRIPTION OF PARAMETERS
C  F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
C           Y2(J1,1): FILTERED STATE VECTOR
C            DY(J3)  : OBSERVED INPUT EXCIATION
C                DT  : TIME INCREMENT IN DATA IN SEC
C             J1,J3  : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
C                      PROGRAM
C                KK  : TIME IN DATA PROCESSING
C      NZ,XX,XXX,AK1: PARAMETERS FOR BILINEAR HYSTERESIS
C
C     REMARK:
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       RUNGEN
C     *****************************************************************
C
      SUBROUTINE FF5(F,Y2,Y1,DY,DT,J1,J3,KK,NZ,XX,XXX,AK1)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION F(J1,1),Y2(J1,1),DY(J3)
      DIMENSION QT(30,2),YT(30,2),Y(30,2)
      DIMENSION Q(30,2),YY2(30),Y1(J1,1)
C
      DO 100 I=3,6
  100 F(I,1)=Y2(I,1)
      QT(1,1)=0.0
      QT(1,2)=0.0
      YT(1,1)=Y2(1,1)
      YT(1,2)=Y2(2,1)
      DDYT=DY(KK)
      DDY=DY(KK+1)
      CALL RUNGEN(1,DT,DDY,DDYT,Y,YY2,
     *     YT,Q,QT,J1,Y2,NZ,AR,XE,XX,XXX,AK1)
C
      F(1,1)=Y(1,1)
      F(2,1)=Y(1,2)
C
      DO 200 I=1,6
      Y1(I,1)=F(I,1)
```

```
  200 CONTINUE
C
      RETURN
      END
C
C     *************      SUBROUTINE RUNGEN    *****************
C     *                                                        *
C     * SUBROUTINE FOR SDOF SYSTEM WITH  BILINEAR HYSTERESIS *
C     * SOLVING D.E. BY RUNGE-KUTTA METHOD                     *
C     *                    ( ICON = 5 )                        *
C     *                CALLED BY SUBROUTINE FF5                *
C     **********************************************************
C
C
      SUBROUTINE RUNGEN(N,DT,DDY,DDYT,
     * Y,YY,YT,Q,QT,M1,Y2,NZ,AR,XE,XX,XXX,AK1)
C       IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y2(M1,1),Y(M1,2),YY(M1),YT(M1,2),Q(M1,2)
      DIMENSION QT(M1,2)
      DIMENSION P1(4),P2(4),P3(4),P4(4),P5(4)
      DIMENSION Z(10,2),T(10,2),R(10,2)
      DATA P1/0.5,1.0,1.0,0.5/
      DATA P2/1.0,0.2928932,1.7071068,0.333333/
      DATA P3/0.0,0.7071068,-0.7071068,0.0/
      DATA P4/1.0,0.5,0.5,0.0/
      DATA P5/0.0,0.5,0.5,1.0/
      DO 11 I=1,N
      DO 10 L=1,2
      Q(I,L)=QT(I,L)
      Y(I,L)=YT(I,L)
   10 CONTINUE
   11 CONTINUE
      DO 15 JJ=1,4
      DDYG=P4(JJ)*DDYT+P5(JJ)*DDY
      DO 12 I=1,N
      Z(I,1)=Y(I,2)*DT
      CALL MATN(Y2,Y,DDYG,Z12,M1,NZ,AR,XE,XX,XXX,AK1)
      Z(I,2)=Z12*DT
   12 CONTINUE
      DO 14 I=1,N
      DO 13 L=1,2
      T(I,L)=P1(JJ)*Z(I,L)-Q(I,L)
      R(I,L)=P2(JJ)*T(I,L)
      Y(I,L)=Y(I,L)+R(I,L)
      Q(I,L)=3.0*R(I,L)-T(I,L)+P3(JJ)*Z(I,L)
   13 CONTINUE
   14 CONTINUE
   15 CONTINUE
      DO 17 I=1,N
      CALL MATN(Y2,Y,DDY,Z12,M1,NZ,AR,XE,XX,XXX,AK1)
   17 YY(I)=Z12
      RETURN
      END
C
C     *****************   SUBROUTINE MATN     *****************
C     *                                                        *
C     *  SUBROUTINE FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS  *
C     *                    ( ICON = 5 )                        *
C     *               CALLED BY SUBROUTINE RUNGEN              *
C     **********************************************************
```

```
C
C
      SUBROUTINE MATN(Y2,Y,DDYG,Z12,J1,NZ,AR,XE,XX,XXX,AK1)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y2(J1,1),Y(J1,2)
C
      CALL GOSN(Y2,J1,NZ,XX,AK1,Y,XXX)
      Z12=-2.0*Y2(3,1)*Y2(4,1)*Y(1,2)
      Z12=Z12-Y2(4,1)*Y2(4,1)*AK1-DDYG
C
      RETURN
      END
C
C     ***************   SUBROUTINE GOSN    *******************
C     *                                                        *
C     * SUBROUTINE FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS    *
C     *                  ( ICON = 5 )                          *
C     *           CALLED BY SUBROUTINE MATN                    *
C     **********************************************************
C
C
      SUBROUTINE GOSN(Y2,J1,NZ,XX,AK1,Y,XXX)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Y2(J1,1),Y(J1,2)
C
      XE=Y2(5,1)
      AR=Y2(6,1)
C
      GO TO (100,200,300,400,500),NZ
C
C
  100 AK1=Y(1,1)
      GO TO 1000
C
C
  200 AK1=AR*Y(1,1)+(1.0-AR)*XE
      GO TO 1000
C
C
  300 AK1=Y(1,1)+(1.0-AR)*(XE-XX)
      GO TO 1000
C
C
  400 AK1=AR*Y(1,1)-(1.0-AR)*XE
      GO TO 1000
C
C
  500 AK1=Y(1,1)+(1.0-AR)*(-XX-XE)
C
C
 1000 CONTINUE
      RETURN
      END
C
C     ******************    SUBROUTINE FF6   **********************
C     *                                                              *
C     *          SUBROUTINE FOR THE PREDICTED STATE VETCOR           *
C     *   OF SINGLE DEGREE OF FREEDOM SYSTEM  WITH BOUC-WEN'S        *
C     *   HYSTERETIC MODEL                                           *
C     *                        ( ICON = 6 )                          *
```

```
C      *                    CALLED BY THE MAIN PROGRAM                    *
C      ****************************************************************
C
C       PURPOSE:
C         TO COMPUTE THE PREDICTED STATE VECTOR FOR SDOF SYSTEM WITH
C         BOUC-WEN'S HYSTERETIC MODEL (ICON.EQ.6)
C
C       USAGE:
C         CALL FF6(F,Y2,Y1,DY,DT,J1,J3,KK,AZ,NM1)
C
C       DESCRIPTION OF PARAMETERS
C  F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
C           Y2(J1,1): FILTERED STATE VECTOR
C            DY(J3) : INPUT EXCIATION
C                DT : TIME INCREMENT IN DATA IN SEC
C             J1,J3 : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
C                     PROGRAM
C                KK : TIME IN DATA PROCESSING
C                AZ : PARAMETER FOR BOUC AND WEN'S MODEL(AZ=1.0)
C               NM1 : START TIME IN DATA PROCESSING
C
C      REMARK:
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        RUNGXY
C      *******************************************************************
C
       SUBROUTINE FF6(F,Y2,Y1,Z,DT,J1,J3,KK,AZ,NM1)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Y1(J1,1),Y2(J1,1),Z(J3),F(J1,1)
C
C
       AM=1.0
       AC=2.0*Y2(5,1)*Y2(6,1)
       AK1=Y2(6,1)*Y2(6,1)
       BE=Y2(7,1)
       GA=Y2(8,1)
       AA=Y2(9,1)
       CA=Y2(10,1)
       CV=Y2(11,1)
       CN=Y2(12,1)
C
       DO 10 I=5,12
       F(I,1)=Y2(I,1)
    10 CONTINUE
C
       YYD=Y2(1,1)
       YYV=Y2(2,1)
       XXD=Y2(3,1)
       ZZE=Y2(4,1)
C
       CALL RUNGXY(YYD,YYV,YYA,Z,XXD,AM,AC,AK1,AA,BE,GA,AZ,J3,DT,KK,
      *            1.0,1.0,CA,CN,CV,ZZE,NM1)
C
       F(1,1)=YYD
       F(2,1)=YYV
       F(3,1)=XXD
       F(4,1)=ZZE
C
       DO 100 I=1,12
```

```
      Y1(I,1)=F(I,1)
  100 CONTINUE
C
      RETURN
      END
C
C     **************  SUBROUTINE RUNGXY  *********************
C     *                                                     *
C     *   SUBROUTINE FOR SDOF SYSTEM WITH BOUC-WEN'S MODEL  *
C     *   SOLVING D.E. BY RUNGE-KUTTA METHOD                *
C     *                 ( ICON = 1 )                        *
C     *               CALLED BY SUBROUTINE  FF6             *
C     *******************************************************
C
C
      SUBROUTINE RUNGXY(YYD,YYV,YYA,Z,XXD,AM,AC,AK1,AAA,BE,GA
     *                 ,AZ,N1,DT,KK,GNN,VVV,CA,CN,CV,ZZE,NM1)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION Z(N1)
      DIMENSION Y1(5),Y2(5),Y3(5),BK1(5),BK2(5),BK3(5)
      DIMENSION R1(5),R2(5),R3(5),Q1(5),Q2(5),Q3(5)
      DIMENSION Y4(5),BK4(5),R4(5),Q4(5)
C
      Y1(1)=YYD
      Y2(1)=YYV
      Y3(1)=XXD
      Y4(1)=ZZE
C
      IF(KK.NE.NM1) GO TO 100
      AA=AAA
      GN=GNN
      VV=VVV
      Q1(1)=0.0
      Q2(1)=0.0
      Q3(1)=0.0
      Q4(1)=0.0
  100 CONTINUE
C
      BK1(1)=DT*Y2(1)
      BK2(1)=-DT*(AM*Z(KK)+AC*Y2(1)+AK1*Y3(1))/AM
      YZ2=ABS(Y2(1))
      YZ3=ABS(Y3(1))
C
      IF(KK.EQ.NM1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(1)-VV*BE*YZ2*ZZ1*Y3(1))
      BK3(1)=(BB1-VV*DT*GA*Y2(1)*ZZ2)/GN
      BK4(1)=DT*AK1*Y3(1)*Y2(1)
C
      R1(1)=BK1(1)/2.0-Q1(1)
      R2(1)=BK2(1)/2.0-Q2(1)
      R3(1)=BK3(1)/2.0-Q3(1)
      R4(1)=BK4(1)/2.0-Q4(1)
C
```

```
      Y1(2)=Y1(1)+R1(1)
      Y2(2)=Y2(1)+R2(1)
      Y3(2)=Y3(1)+R3(1)
      Y4(2)=Y4(1)+R4(1)
C
      Q1(2)=Q1(1)+3.0*R1(1)-BK1(1)/2.0
      Q2(2)=Q2(1)+3.0*R2(1)-BK2(1)/2.0
      Q3(2)=Q3(1)+3.0*R3(1)-BK3(1)/2.0
      Q4(2)=Q4(1)+3.0*R4(1)-BK4(1)/2.0
C
C
      BK1(2)=DT*Y2(2)
      ZZ=(Z(KK)+Z(KK+1))/2.0
      BK2(2)=-DT*(AM*ZZ+AC*Y2(2)+AK1*Y3(2))/AM
      YZ2=ABS(Y2(2))
      YZ3=ABS(Y3(2))
C
      IF(KK.EQ.NM1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(2)-VV*BE*YZ2*ZZ1*Y3(2))
      BK3(2)=(BB1-VV*DT*GA*Y2(2)*ZZ2)/GN
      BK4(2)=DT*Y3(2)*Y2(2)*AK1
C
      DA1=0.2928932
      R1(2)=DA1*(BK1(2)-Q1(2))
      R2(2)=DA1*(BK2(2)-Q2(2))
      R3(2)=DA1*(BK3(2)-Q3(2))
      R4(2)=DA1*(BK4(2)-Q4(2))
C
      Y1(3)=Y1(2)+R1(2)
      Y2(3)=Y2(2)+R2(2)
      Y3(3)=Y3(2)+R3(2)
      Y4(3)=Y4(2)+R4(2)
C
      Q1(3)=Q1(2)+3.0*R1(2)-DA1*BK1(2)
      Q2(3)=Q2(2)+3.0*R2(2)-DA1*BK2(2)
      Q3(3)=Q3(2)+3.0*R3(2)-DA1*BK3(2)
      Q4(3)=Q4(2)+3.0*R4(2)-DA1*BK4(2)
C
C
      BK1(3)=DT*Y2(3)
      ZZ=(Z(KK)+Z(KK+1))/2.0
      BK2(3)=-DT*(AM*ZZ+AC*Y2(3)+AK1*Y3(3))/AM
      YZ2=ABS(Y2(3))
      YZ3=ABS(Y3(3))
      IF(KK.EQ.NM1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(3)-VV*BE*YZ2*ZZ1*Y3(3))
```

```
      BK3(3)=(BB1-VV*DT*GA*Y2(3)*ZZ2)/GN
      BK4(3)=DT*Y3(3)*Y2(3)*AK1
C
      DA1=0.17071068E+01
      R1(3)=DA1*(BK1(3)-Q1(3))
      R2(3)=DA1*(BK2(3)-Q2(3))
      R3(3)=DA1*(BK3(3)-Q3(3))
      R4(3)=DA1*(BK4(3)-Q4(3))
C
      Y1(4)=Y1(3)+R1(3)
      Y2(4)=Y2(3)+R2(3)
      Y3(4)=Y3(3)+R3(3)
      Y4(4)=Y4(3)+R4(3)
C
      Q1(4)=Q1(3)+3.0*R1(3)-DA1*BK1(3)
      Q2(4)=Q2(3)+3.0*R2(3)-DA1*BK2(3)
      Q3(4)=Q3(3)+3.0*R3(3)-DA1*BK3(3)
      Q4(4)=Q4(3)+3.0*R4(3)-DA1*BK4(3)
C
C
      BK1(4)=DT*Y2(4)
      BK2(4)=-DT*(AM*Z(KK+1)+AC*Y2(4)+AK1*Y3(4))/AM
      YZ2=ABS(Y2(4))
      YZ3=ABS(Y3(4))
C
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
C
      BB1=DT*(AA*Y2(4)-VV*BE*YZ2*(ZZ1)*Y3(4))
      BK3(4)=(BB1-VV*DT*GA*Y2(4)*(ZZ2))/GN
      BK4(4)=DT*Y3(4)*Y2(4)*AK1
C
      R1(4)=(BK1(4)-2.0*Q1(4))/6.0
      R2(4)=(BK2(4)-2.0*Q2(4))/6.0
      R3(4)=(BK3(4)-2.0*Q3(4))/6.0
      R4(4)=(BK4(4)-2.0*Q4(4))/6.0
C
       Y1(5)=Y1(4)+R1(4)
       Y2(5)=Y2(4)+R2(4)
       Y3(5)=Y3(4)+R3(4)
      Y4(5)=Y4(4)+R4(4)
C
       Q1(5)=Q1(4)+3.0*R1(4)-BK1(4)/2.0
       Q2(5)=Q2(4)+3.0*R2(4)-BK2(4)/2.0
       Q3(5)=Q3(4)+3.0*R3(4)-BK3(4)/2.0
      Q4(5)=Q4(4)+3.0*R4(4)-BK4(4)/2.0
C
       YY1=Y1(5)
       YY2=Y2(5)
       YY3=Y3(5)
      YY4=Y4(5)
C
       YYD=YY1
       YYV=YY2
       XXD=YY3
      ZZE=YY4
C
       Q1(1)=Q1(5)
       Q2(1)=Q2(5)
       Q3(1)=Q3(5)
```

```
      Q4(1)=Q4(5)
C
C
      AA=AAA-CA*ZZE
      GN=GNN+CN*ZZE
      VV=VVV+CV*ZZE
C
      YYA=-(AM*Z(KK+1)+AC*YYV+AK1*XXD)/AM
C
       RETURN
       END
C
C     **************      SUBROUTINE WW1       *****************
C     *                                                        *
C     *  SUBROUTINE FOR THE STATE TRANSITION MATRIX OF LINEAR  *
C     *  MDOF SYSTEM FORMULATED AS A CONTINUOUS STATE EQUATION *
C     *                     ( ICON = 1 )                       *
C     *               CALLED BY THE MAIN PROGRAM               *
C     **********************************************************
C
C     PURPOSE:
C       TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM.
C       STATE TRANSITION MATRIX IS CONSTRUCTED FROM CONTINUOUS
C       STATE EQUATION USING FIRST ORDER APPROXIMATION.(ICON=1)
C
C     USAGE:
C       CALL WW1(N,W1,Y2,I1,J1,J3,DT,DY,KK)
C
C     DESCRIPTION OF PARAMETERS
C                 N : NUMBER OF DEGREE OF FREEDOM STRUCTURE
C       W1(J1,J1) : STATE TRANSITION MATRIX OF THE BILINEAR
C                   HYSTERETIC SYSTEM
C        Y2(J1,1) : FILTERED STATE VECTOR
C              I1 : DIMENSION OF EXTENDED STATE VECTOR
C                   (I1.LE.30)
C           J1,J3 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
C              DT : TIME INCREMENT IN SEC
C          DY(J3) : OBSERVED INPUT EXCIATION
C              KK : TIME IN DATA PROCESSING
C
C     REMARK:
C     (1) PARAMETER I1 MUST BE LESS THAN 30
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        NONE
C     ***********************************************************************
C
C
      SUBROUTINE WW1(N,W1,Y2,I1,J1,J3,DT,DY,KK)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION W1(J1,J1),DY(J3),Y2(J1,1)
C
C
      DO 100 I=1,I1
      DO 100 J=1,I1
  100 W1(I,J)=0.0
C
C
      DO 200 I=1,N
      II=5*(I-1)
```

```
C
      W1(1+II,2+II)=DT
      W1(2+II,1+II)=-Y2(4+II,1)*Y2(4+II,1)*DT
      W1(2+II,2+II)=-2.0*Y2(3+II,1)*Y2(4+II,1)*DT
      W1(2+II,3+II)=-2.0*Y2(4+II,1)*Y2(2+II,1)*DT
      A1=Y2(3+II,1)*Y2(2+II,1)
      A2=Y2(4+II,1)*Y2(1+II,1)
      W1(2+II,4+II)=-2.0*(A1+A2)*DT
      W1(2+II,5+II)=-DY(KK)*DT
  200 CONTINUE
C
      DO 500 I=1,I1
  500 W1(I,I)=1.0+W1(I,I)
      RETURN
      END
C
C     *****************    SUBROUTINE WW2   ********************
C     *                                                         *
C     *  SUBROUTINE  FOR THE STATE TRANSTION MATRIX OF LINEAR   *
C     *  MDOF SYSTEM  FORMULATED AS A DISCRETE STATE EQUATION   *
C     *  BY LINAER ACCELERATION METHOD                          *
C     *                      ( ICON = 2 )                       *
C     *                 CALLED BY THE MAIN PROGRAM              *
C     ***********************************************************
C
C     PURPOSE:
C       TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM.
C       DISCRETE STATE EQUATION IS USED.  (ICON.EQ.2)
C
C     USAGE:
C       CALL WW2(W1,Y2,DY,I1,J1,DT,KK,J3,N,MC)
C
C     DESCRIPTION OF PARAMETERS
C       W1(J1,J1) : STATE TRANSITION MATRIX OF THE BILINEAR
C                   HYSTERETIC SYSTEM
C        Y2(J1,1) : FILTERED STATE VECTOR
C          DY(J3) : OBSERVED INPUT EXCIATION
C              I1 : DIMENSION OF EXTENDED STATE VECTOR
C                   (I1.LE.30)
C           J1,J3 : DIMENSION OF [W1],[Y2] OR [DY] IN CALLING
C                   PROGRAM
C              DT : TIME INCREMENT IN SEC
C              KK : TIME IN DATA PROCESSING
C               N : NUMBER OF DEGREE OF FREEDOM OF STRUCTURE
C     MC(1),MC(2) : PARAMETERS FOR OBSERVATION DATA
C                   IN (ICON.EQ.2)
C     REMARK:
C     (1) PARAMETER I1 MUST BE LESS THAN 30
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       NONE
C     ***********************************************************
C
      SUBROUTINE WW2(W1,Y2,DY,I1,J1,DT,KK,J3,N,MC)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION W1(J1,J1),Y2(J1,1),DY(J3),W(30,30)
      DIMENSION MC(3)
      DIMENSION C(30)
C
C
```

```
      DO 100 I=1,I1
      DO 100 J=1,I1
      W(I,J)=0.0
  100 W1(I,J)=0.0
C
C
      DO 1000 K=1,N
      K1=6*(K-1)
C
C
      DDT=DT*DT
      A4=Y2(4+K1,1)
      A5=Y2(5+K1,1)
      A6=Y2(6+K1,1)
C
      K11=1+K1
      K12=3+K1
      DO 600 I=K11,K12
  600 C(I)=0.0
C
      DO 700 I=K11,K12
      M1=MC(1)+K1
      M2=MC(2)+K1
      M=I
      IF(I.EQ.M1) M=M2
      IF(I.EQ.M2) M=M1
      C(M)=Y2(I,1)
  700 CONTINUE
C
      A1=C(1+K1)
      A2=C(2+K1)
      A3=C(3+K1)
C
      S=1.0+A4*A5*DT+A5*A5*DDT/6.0
      P1=A1*A5*A5+2.0*A2*A4*A5+DT*A2*A5*A5
      P2=DT*A3*A4*A5+A3*A5*A5*DDT/3.0+DY(KK+1)*A6
      PP=P1+P2
      SS=DDT/(6.0*S*S)
      W1(1+K1,1+K1)=1.0-(A5*A5*S)*SS
      W1(1+K1,2+K1)=DT-(2.0*A4*A5+DT*A5*A5)*S*SS
      W1(1+K1,3+K1)=DDT/3.0-(DT*A4*A5+A5*A5*DDT/3.0)*S*SS
      W1(1+K1,4+K1)=-((2.0*A2*A5+DT*A3*A5)*S-(DT*A5*PP))*SS
      WAA1=2.0*A1*A5+2.0*A2*A4+2.0*DT*A2*A5
      WAA2=DT*A3*A4+2.0*DDT*A3*A5/3.0
      W1(1+K1,5+K1)=-((WAA1+WAA2)*S-(DT*A4+DDT*A5/3.0)*PP)*SS
      W1(1+K1,6+K1)=-DY(KK+1)*S*SS
      W1(2+K1,1+K1)=-3.0/DT*(1.0-W1(1+K1,1+K1))
      W1(2+K1,2+K1)=1.0-3.0/DT*(DT-W1(1+K1,2+K1))
      W1(2+K1,3+K1)=DT/2.0-3.0/DT*(DDT/3.0-W1(1+K1,3+K1))
      W1(2+K1,4+K1)=3.0/DT*W1(1+K1,4+K1)
      W1(2+K1,5+K1)=3.0/DT*W1(1+K1,5+K1)
      W1(2+K1,6+K1)=3.0*W1(1+K1,6+K1)/DT
      W1(3+K1,1+K1)=-6.0/DDT*(1.0-W1(1+K1,1+K1))
      W1(3+K1,2+K1)=-6.0/DDT*(DT-W1(1+K1,2+K1))
      W1(3+K1,3+K1)=-6.0/DDT*(DDT/3.0-W1(1+K1,3+K1))
      W1(3+K1,4+K1)=6.0/DDT*W1(1+K1,4+K1)
      W1(3+K1,5+K1)=6.0/DDT*W1(1+K1,5+K1)
      W1(3+K1,6+K1)=6.0*W1(1+K1,6+K1)/DDT
      W1(4+K1,4+K1)=1.0
      W1(5+K1,5+K1)=1.0
```

```
      W1(6+K1,6+K1)=1.0
C
C
      K12=6+K1
      DO 200 M=K11,K12
      DO 200 L=K11,K12
  200 W(M,L)=0.0
C
      DO 400 I=K11,K12
      DO 400 J=K11,K12
      M=I
      L=J
      M1=MC(1)+K1
      M2=MC(2)+K1
      IF(I.EQ.M1) M=M2
      IF(I.EQ.M2) M=M1
      IF(J.EQ.M1) L=M2
      IF(J.EQ.M2) L=M1
      W(M,L)=W1(I,J)
  400 CONTINUE
C
      DO 500 I=K11,K12
      DO 500 J=K11,K12
      W1(I,J)=W(I,J)
  500 CONTINUE
C
C
 1000 CONTINUE
C
C
      RETURN
      END
C
C     ****************   SUBROUTINE WW3      ****************
C     *                                                       *
C     *         SUBROUTINE FOR THE STATE TRANSITION MATRIX    *
C     * FOR LINEAR MDOF SYSTEM  IN FREQUENCY DOMAIN           *
C     *                    ( ICON = 3 )                       *
C     *               CALLED BY THE MAIN PROGRAM              *
C     *********************************************************
C
C     PURPOSE:
C       TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM
C       IN FREQUENCY DOMAIN(ICON.EQ.3)
C
C     USAGE:
C       CALL WW3(W1,Y2,I1,J1)
C
C     DESCRIPTION OF PARAMETERS
C       W1(J1,J1) : STATE TRANSITION MATRIX OF THE FREQUENCY
C                   TRANSFER FUNCTION
C       Y2(J1,1)  : FILTERED STATE VECTOR
C              I1 : DIMENSION OF EXTENDED STATE VECTOR
C                   (I1.LE.30)
C              J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
C
C     REMARK:
C     (1) PARAMETER I1 MUST BE LESS THAN 30
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
```

```
C          NONE
C       ****************************************************
C
        SUBROUTINE WW3(W1,Y2,I1,J1)
C        IMPLICIT REAL*8(A-H,O-Z)
        DIMENSION W1(J1,J1),Y2(J1,1)
C
        DO 100 I=1,I1
        DO 100 J=1,I1
        W1(I,J)=0.0
    100 CONTINUE
C
C
        DO 200 I=1,I1
        W1(I,I)=1.0
    200 CONTINUE
C
        RETURN
        END
C
C       ****************     SUBROUTINE WW4    *******************
C       *                                                        *
C       *        SUBROUTINE FOR THE STATE TRANSTION MATRIX      *
C       * FOR SDOF SYSTEM WITH NONPARAMETRIC HYSTERETIC MODEL  *
C       *                     ( ICON = 4 )                       *
C       *               CALLED BY THE MAIN PROGRAM               *
C       **********************************************************
C
C       PURPOSE:
C         TO COMPUTE STATE TRANSITION MATRIX OF THE SDOF SYSTEM
C         WITH NONPARAMETRIC (POLYNOMINAL)  HYSTERETIC MODEL.
C         STATE TRANSITION MATRIX IS CONSTRUCTED FROM COTINUOUS
C         STATE EQUATION USING FIRST ORDER APPROXIMATION.
C
C       USAGE:
C         CALL WW4(W1,Y2,I1,J1,DT)
C
C       DESCRIPTION OF PARAMETERS
C         W1(J1,J1)  : STATE TRANSITION MATRIX OF THE NONPARAMETRIC
C                      MODEL
C         Y2(J1,1)   : FILTERED STATE VECTOR
C                I1  : DIMENSION OF EXTENDED STATE VECTOR
C                      (I1.LE.30)
C                J1  : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
C                DT  : TIME INCREMENT IN SEC
C
C       REMARK:
C       (1) PARAMETER I1 MUST BE LESS THAN 30
C
C       SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C          NONE
C       ****************************************************************
C
C
        SUBROUTINE WW4(W1,Y2,I1,J1,DT)
C        IMPLICIT REAL*8(A-H,O-Z)
        DIMENSION W1(J1,J1),Y2(J1,1)
C
        DO 100 I=1,I1
        DO 100 J=1,I1
```

```
  100 W1(I,J)=0.0
C
      A1=Y2(1,1)
      A2=Y2(2,1)
      A3=Y2(3,1)
      A4=Y2(4,1)
      A5=Y2(5,1)
      A6=Y2(6,1)
C
      W1(1,2)=DT
C
      W1(2,1)=-(3.0*A4*A1*A1+A3)*DT
      W1(2,2)=-(A5+3.0*A6*A2*A2)*DT
      W1(2,3)=-A1*DT
      W1(2,4)=-A1*A1*A1*DT
      W1(2,5)=-A2*DT
      W1(2,6)=-A2*A2*A2*DT
C
      DO 20 I=1,I1
   20 W1(I,I)=W1(I,I)+1.0
C
C
      RETURN
      END

C
C     ******************  SUBROUTINE  WW5  *******************
C     *                                                      *
C     *         SUBROUTINE FOR THE STATE TRANSTION MATRIX    *
C     *         FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS     *
C     *                     ( ICON = 5 )                     *
C     *               CALLED BY THE MAIN PROGRAM             *
C     ********************************************************
C
C     PURPOSE:
C       TO COMPUTE STATE TRANSITION MATRIX OF THE SDOF  SYSTEM
C       WITH BILINEAR HYSTERESIS.   STATE TRANSITION MATRIX IS
C       CONSTRUCTED FROM CONTINUOUS STATE EQUATION USING FIRST
C       ORDER APPROXIMATION.
C
C     USAGE:
C       CALL WW5(W1,Y2,DT,I1,J1,XX,NZ,XXX)
C
C     DESCRIPTION OF PARAMETERS
C       W1(J1,J1) : STATE TRANSITION MATRIX OF THE BILINEAR
C                   HYSTERETIC SYSTEM
C       Y2(J1,1)  : FILTERED STATE VECTOR
C              DT : TIME INCREMENT IN SEC
C              I1 : DIMENSION OF EXTENDED STATE VECTOR
C                   (I1.LE.30)
C              J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
C       XX,NZ,XXX : PARAMETERS FOR BILINEAR HYSTERESIS
C
C     REMARK:
C     (1) PARAMETER I1 MUST BE LESS THAN 30
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        NONE
C     *****************************************************************
C
```

```
      SUBROUTINE WW5(W1,Y2,DT,I1,J1,XX,NZ,XXX)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION W1(J1,J1),Y2(J1,1)
C
      DO 600 I=1,6
      DO 600 J=1,6
  600 W1(I,J)=0.0
C
      DO 700 I=1,6
  700 W1(I,I)=1.0
C
C
      W1(1,2)=DT
      W1(2,2)=1.0-2.0*Y2(3,1)*Y2(4,1)*DT
      W1(2,3)=-2.0*Y2(4,1)*DT*Y2(2,1)
C
C
      GO TO (100,200,300,400,500),NZ
C
  100 A1=1.0
      A4=Y2(1,1)
      A5=0.0
      A6=0.0
      GO TO 1000
C
  200 A1=Y2(6,1)
      A4=Y2(6,1)*Y2(1,1)+(1.0-Y2(6,1))*Y2(5,1)
      A5=1.0-Y2(6,1)
      A6=Y2(1,1)-Y2(5,1)
      GO TO 1000
C
  300 A1=1.0
      A4=(1.0-Y2(6,1))*(Y2(5,1)-XX)
      A4=A4+Y2(1,1)
      A5=1.0-Y2(6,1)
      A6=XX-Y2(5,1)
      GO TO 1000
C
  400 A1=Y2(6,1)
      A4=-(1.0-Y2(6,1))*Y2(5,1)
      A4=A4+Y2(6,1)*Y2(1,1)
      A5=-1.0+Y2(6,1)
      A6=Y2(1,1)+Y2(5,1)
      GO TO 1000
C
  500 A1=1.0
      A4=-(1.0-Y2(6,1))*(XX+Y2(5,1))
      A4=Y2(1,1)+A4
      A5=-1.0+Y2(6,1)
      A6=XX+Y2(5,1)
C
 1000 CONTINUE
      W1(2,1)=-Y2(4,1)*Y2(4,1)*DT*A1
      W1(2,4)=-2.0*Y2(3,1)*DT*Y2(2,1)
      W1(2,4)=W1(2,4)-2.0*Y2(4,1)*DT*A4
      W1(2,5)=-Y2(4,1)*Y2(4,1)*DT*A5
      W1(2,6)=-Y2(4,1)*Y2(4,1)*DT*A6
C
      RETURN
      END
```

```
C
C
C      *****************    SUBROUTINE WW6  *******************
C      *                                                      *
C      *        SUBROUTINE FOR THE STATE TRANSITION MATRIX    *
C      *   FOR SDOF SYSTEM WITH BOUC-WEN'S HYSTERESIS MODEL   *
C      *                    ( ICON = 6 )                      *
C      *           CALLED BY THE MAIN PROGRAM                 *
C      ********************************************************
C
C      PURPOSE:
C        TO COMPUTE STATE TRANSITION MATRIX OF SDOF SYSTEM WITH
C        BOUC-WEN'S HYSTERESIS MODEL.  STATE TRANSITION MATRIX
C        IS CONSTRUCTED  FROM  CONTINUOUS STATE EQUATION  USING
C        FIRST ORDER APPROXIMATION.
C
C      USAGE:
C        CALL WW6(W1,Y2,I1,J1,DT,KK,AAZ,NM1)
C
C      DESCRIPTION OF PARAMETERS
C        W1(J1,J1) : STATE TRANSITION MATRIX OF BOUC AND WEN'S
C                    MODEL
C        Y2(J1,1)  : FILTERED STATE VECTOR
C               DT : TIME INCREMENT IN SEC
C               I1 : DIMENSION OF EXTENDED STATE VECTOR
C                    (I1.LE.30)
C               J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
C               DT : TIME INCREMENT IN SEC
C               KK : TIME IN DATA PROCESSING
C              AAZ : PARAMETER FOR BOUC AND WEN'S MODEL
C              NM1 : STARTING TIME IN DATA PROCESSING
C
C      REMARK:
C      (1) PARAMETER I1 MUST BE LESS THAN 30
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C         NONE
C      *****************************************************************
C
C
C
       SUBROUTINE WW6(W1,Y2,I1,J1,DT,KK,AAZ,NM1)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION W1(J1,J1),Y2(J1,1)
C
C
       DO 100 I=1,I1
       DO 100 J=1,I1
   100 W1(I,J)=0.0
C
C
       A1=Y2(1,1)
       A2=Y2(2,1)
       A3=Y2(3,1)
       A4=Y2(4,1)
       A5=Y2(5,1)
       A6=Y2(6,1)
       A7=Y2(7,1)
       A8=Y2(8,1)
       A9=Y2(9,1)
```

```
      A10=Y2(10,1)
      A11=Y2(11,1)
      A12=Y2(12,1)
C
C
      W1(1,2)=DT
      W1(2,1)=0.0
      W1(2,2)=-2.0*A5*A6*DT
      W1(2,3)=-A6*A6*DT
      W1(2,4)=0.0
      W1(2,5)=-2.0*A6*A2*DT
      W1(2,6)=-2.0*(A5*A2+A3*A6)*DT
C
      W1(3,1)=0.0
C
      C4=(1.0+A12*A4)
C
      IF(KK.NE.NM1) GO TO 3000
      W1(3,2)=0.0
      W1(3,3)=0.0
      GO TO 4000
C
 3000 CONTINUE
C
      C2=ABS(A2)
      C3=ABS(A3)
      B1=C3**(AAZ-1.0)
      B2=C3**AAZ
      B3=C3**(AAZ-2.0)
C
C
      D1=A9-A10*A4
      D2=1.0+A11*A4
      D3=A7*C2*B1*A3/A2+A8*B2
      W1(3,2)=DT*(D1-D2*D3)/C4
C
      D1=(1.0+A11*A4)
      D2=(AAZ-1.0)*A7*C2*B3*A3/A3
      D3=A7*C2*B1+AAZ*A8*A2*B1/A3
      W1(3,3)=(-D1*(D2+D3))*DT/C4
C
 4000 CONTINUE
C
C
      W1(3,1)=0.0
C
      D1=-A10*A2
      D2=-A11*(A7*C2*B1*A3+A8*A2*B2)
      D3=(A9-A10*A4)*A2
      D4=1.0+A11*A4
      D5=A7*C2*B1*A3+A8*A2*B2
      D6=((D1+D2)*C4-A12*(D3-D4*D5))/(C4*C4)
      W1(3,4)=D6*DT
C
      W1(3,5)=0.0
      W1(3,6)=0.0
C
      D1=-(1.0+A11*A4)*(C2*B1*A3)
      W1(3,7)=D1*DT/C4
C
```

```
      D1=-(1.0+A11*A4)*(A2*B2)
      W1(3,8)=D1*DT/C4
C
      W1(3,9)=A2*DT/C4
C
      W1(3,10)=-A2*A4*DT/C4
C
      D1=A7*C2*B1*A3+A8*A2*B2
      W1(3,11)=-A4*D1*DT/C4
C
      D1=(A9-A10*A4)*A2
      D2=(1.0+A11*A4)*(A7*C2*B1*A3+A8*A2*B2)
      W1(3,12)=(-A4*(D1-D2))*DT/(C4*C4)
C
      W1(4,2)=A3*A6*DT*A6
      W1(4,3)=A2*DT*A6*A6
      W1(4,6)=2.0*A2*DT*A3*A6
C
C
      DO 10 I=1,I1
   10 W1(I,I)=1.0+W1(I,I)
C
      RETURN
      END
C
C     ******************    SUBROUTINE STEP5     ****************
C     *                                                         *
C     *      SUBROUTINE FOR ERROR COVARIANCE MATRIX  OF         *
C     *      THE PREDICTED STATE                                *
C     *            CALLED BY THE MAIN PROGRAM                   *
C     ***********************************************************
C
C     PURPOSE:
C        TO COMPUTE ERROR COVARIANCE MATRIX OF THE PREDICTED
C        STATE
C
C     USAGE:
C        CALL STEP5(P1,W1,P2,W2,G1,Q,G2,I1,J1)
C
C     DESCRIPTION OF PARAMETERS
C     P1(J1,J1): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
C     W1(J1,J1): STATE TRANSITION MATRIX OF THE SYSTEM
C     P2(J1,J1): ERROR COVARIANCE MATRIX OF THE FILTERED STATE
C     W2(J1,J1): TRANSPOSED MATRIX OF [W1]
C     G1(J1,J1): SYSTEM NOISE COEFFICIENT MATRIX
C      Q(J1,J1): SYSTEM NOISE COVARIANCE MATRIX
C     G2(J1,J1): TRANSPOSED MATRIX OF [G1]
C            I1: DIMENSION OF EXTENDED STATE VECTOR
C                (I1.LE.30)
C            J2: DIMENSION OF [P1],[W1],[P2],[W2],[G1],[Q]
C                OR [G2] IN CALLING PROGRAM
C
C     REMARKS
C        (1) PARAMETER I1 MUST BE LESS THAN 30
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C         TEN  MMUT
C     *****************************************************************
C
      SUBROUTINE STEP5(P1,W1,P2,W2,G1,Q,G2,I1,J1)
```

```
C        IMPLICIT REAL*8(A-H,O-Z)
         DIMENSION P1(J1,J1),W1(J1,J1),P2(J1,J1)
         DIMENSION W2(J1,J1),G1(J1,J1),Q(J1,J1),G2(J1,J1)
         DIMENSION C7(30,30),C8(30,30)
         DIMENSION C9(30,30),C10(30,30)
         DATA K1/30/
C
C        ------- [W2] <== [W1] ------------------------------
         CALL TEN(W1,W2,I1,I1,J1,J1,J1,J1)
C        ------- [C7] <== [W1]*[P2] -------------------------
         CALL MMUT(W1,P2,C7,I1,I1,I1,J1,J1,J1,J1,K1,K1)
C        ------- [C9] <== [C7]*[W2] -------------------------
         CALL MMUT(C7,W2,C9,I1,I1,I1,K1,K1,J1,J1,K1,K1)
C        ------- [G2] <== [G1] TRANSPOSE --------------------
         CALL TEN(G1,G2,I1,I1,J1,J1,J1,J1)
C        ------- [C8] <== [G1]*[Q] --------------------------
         CALL MMUT(G1,Q,C8,I1,I1,I1,J1,J1,J1,J1,K1,K1)
C        ------- [C10] <== [C8]*[G2] ------------------------
         CALL MMUT(C8,G2,C10,I1,I1,I1,K1,K1,J1,J1,K1,K1)
C
C
C        ------- [P1]<== [C9]+[C10] -------------------------
         DO 100 I=1,I1
         DO 200 J=1,I1
         P1(I,J)=C9(I,J)+C10(I,J)
     200 CONTINUE
     100 CONTINUE
C        ---------------------------------------------------
C
         RETURN
         END
C
C        ***************   SUBROUTINE TEN      *******************
C        *                                                        *
C        *          SUBROUTINE FOR MATRIX TRANSPOSITION           *
C        *     CALLED BY SUBROUTINES STEP2, STEP3 AND STEP5       *
C        **********************************************************
C
C        PURPOSE:
C          TO COMPUTE TRANSPOSED MATRIX
C
C        USAGE:
C          CALL TEN(A1,A2,I1,I2,J1,J2,J3,J4)
C
C        DESCRIPTION OF PARAMETERS
C                A1(J1,J2): MATRIX IN CALLING PROGRAM
C                A2(J3,J4): TRANSPOSED MATRIX OF [A1]
C      I1,I2,J1,J2,J3,J4 : DIMENSION OF [A1] AND [A2] IN CALLING
C                          PROGRAM
C
C        SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C            NONE
C        ******************************************************************
C
         SUBROUTINE TEN(A1,A2,I1,I2,J1,J2,J3,J4)
C          IMPLICIT REAL*8(A-H,O-Z)
         DIMENSION A1(J1,J2),A2(J3,J4)
C
C             A2(I1,I2) <==  A1(I2,I1)
C
```

```
      DO 100 II=1,I1
      DO 200 IJ=1,I2
      A2(IJ,II)=0.0
  200 CONTINUE
  100 CONTINUE
C
C
      DO 300 II=1,I1
      DO 400 IJ=1,I2
      A2(IJ,II)=A1(II,IJ)
  400 CONTINUE
  300 CONTINUE
      RETURN
      END
C
C     *****************  SUBROUTINE HH1    ****************
C     *                                                    *
C     *   SUBROUTINE FOR LINEARIZED OBSERVATION VECTOR     *
C     *   EQ. REGARDING AS EACH PARAMETER                  *
C     *          CALLED BY THE MAIN PROGRAM                *
C     ******************************************************
C
C      PURPOSE:
C        TO COMPUTE LINEARIZED OBSERVATION VECTOR BY USING
C        PREDICTED STATE VECTOR
C
C      USAGE:
C        CALL HH1(H1,I2,DT,J1,J2,KK,ICON,Y1,N)
C
C      DESCRIPTION OF PARAMETERS
C      H1(J2,J1): LINEARIZED OBSERVATION VECTOR EQ.
C                N: NUMBER OF DEGREE OF FREEDOM STRUCTURE
C               KK: TIME IN DATA PROCESSING
C               DT: TIME INCREMENT IN SEC
C               I2: NUMBER OF RESPONSE OBSERVATIONS
C            J1,J2: DIMENSION OF [AHH] OR [Y1] IN CALLING
C                   PROGRAM
C             ICON: PARAMETER FOR STATE VECTOR EQUATION
C                   AND OBSERVATION VECTOR EQUATION
C
C      REMARKS
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        NONE
C      ******************************************************
C
       SUBROUTINE HH1(H1,I2,DT,J1,J2,KK,ICON,Y1,N)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION H1(J2,J1),Y1(J1,1)
C
C
       IQ=1
       DO 100 I=1,N
       IF(ICON.NE.3) THEN
       IF(ICON.EQ.1) IQ=5
       IF(ICON.EQ.2) IQ=6
       II=IQ*(I-1)
C
       DO 200 IIJ=1,I2
       H1(IIJ,IIJ+II)=1.0
```

```
  200 CONTINUE
C
      ELSE
C
      II=3*(I-1)
      A1=Y1(II+1,1)
      A2=Y1(II+2,1)
      A3=Y1(II+3,1)
      OME=FLOAT(KK-1)*DT
C
      B1=A2*A2-OME*OME
      B2=-A3*B1
      B3=2.0*A1*A2*OME
      B4=B3*B3
      B5=B1*B1+B4
      B6=2.0*A3*A1*A2*OME
C
      C1=-B2*2.0*B3*2.0*A2*OME/(B5*B5)
      H1(1,II+1)=C1
C
      C1=-2.0*A3*A2*B5
      C2=2.0*B1*2.0*A2
      C3=2.0*B3*2.0*A1*OME
      C4=-B2*(C2+C3)
      C5=(C1+C4)/(B5*B5)
      H1(1,II+2)=C5
C
      C1=-B1/B5
      H1(1,II+3)=C1
C
C
C
      C1=2.0*A3*A2*OME*B5
      C2=2.0*2.0*A1*A2*OME
      C3=C2*2.0*A2*OME
      C4=B6*C3
      H1(2,II+1)=(C1-C4)/(B5*B5)
C
      C1=2.0*A3*A1*OME*B5
      C2=2.0*B1*2.0*A2
      C3=2.0*2.0*A1*A2*OME
      C4=C3*2.0*A1*OME
      C5=(C1-B6*(C2+C4))/(B5*B5)
      H1(2,II+2)=C5
C
      C1=2.0*A1*A2*OME
      C2=C1/B5
      H1(2,II+3)=C2
C
      END IF
  100 CONTINUE
C
      RETURN
      END
C
C     ***************          SUBROUTINE STEP1        *****************
C     *                                                                 *
C     *              SUBROUTINE FOR KALMAN GAIN MATRIX                  *
C     *                  CALLED BY THE MAIN PROGRAM                     *
C     *******************************************************************
```

```
C     PURPOSE:
C       TO COMPUTE THE KALMAN GAIN MATRIX
C
C     USAGE:
C       CALL STEP1(AK,P1,H1,H2,R,I1,I2,J1,J2)
C
C     DESCRIPTION OF PARAMETERS
C        AK(J1,J2): KALMAN GAIN MATRIX
C        P1(J1,J2): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
C        H1(J2,J1): LINEARIZED MATRIX OF THE OBSERVATION EQUATION
C                   REGARDING EACH PARAMETER
C        H2(J1,J2): TRANSPOSED MATRIX OF [H1]
C         R(J2,J2): OBSERVATION NOISE COVARIANCE MATRIX
C               I1: DIMENSION OF EXTENDED STATE VECTOR
C                   (I1.LE.30)
C               I2: NUMBER OF RESPONSE OBSERVATIONS
C                   (I2.LE.10)
C            J1,J2: DIMENSION OF [AK],[P1],[H1],[H2] OR [R]
C                   IN CALLING PROGRAM
C
C     REMARKS:
C       (1) PARAMETER I1 MUST BE LESS THAN 30
C       (2) PARAMETER I2 MUST BE LESS THAN 10
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C          TEN MMUT
C     ****************************************************************
C
      SUBROUTINE STEP1(AK,P1,H1,H2,R,I1,I2,J1,J2)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION AK(J1,J2),P1(J1,J1),H1(J2,J1)
      DIMENSION H2(J1,J2),R(J2,J2)
      DIMENSION C1(30,30),C2(10,10)
      DIMENSION C4(2,2)
      DATA K1/30/
C
C
C     ---------  [H2]<== [H1]  TRANSPOSE ----------------
      CALL TEN(H1,H2,I2,I1,J2,J1,J1,J2)
C     ---------  [C1]<== [H1]*[P1] ----------------------
      CALL MMUT(H1,P1,C1,I2,I1,I1,J2,J1,J1,J1,K1,K1)
C     ---------  [C2]<== [C1]*[H2] ----------------------
      CALL MMUT(C1,H2,C2,I2,I1,I2,K1,K1,J1,J2,J2,J2)
C
C     ---------  [C2]<== [C2]+[R]  ----------------------
      DO 200 I=1,I2
      DO 200 J=1,I2
      C2(I,J)=C2(I,J)+R(I,J)
  200 CONTINUE
C
      IF(I2.EQ.2) GO TO 400
      IF(I2.EQ.1) GO TO 600
C
C     --------  INVERSE MATRIX [C2]<==[C2]---------------
  400 CONTINUE
      A=C2(1,1)*C2(2,2)-C2(2,1)*C2(1,2)
      A=1.0/A
      C4(1,1)=C2(1,1)
      C4(1,2)=C2(1,2)
      C4(2,1)=C2(2,1)
```

```
      C4(2,2)=C2(2,2)
      C2(1,1)=A*C4(2,2)
      C2(1,2)=-A*C4(2,1)
      C2(2,1)=-A*C4(1,2)
      C2(2,2)=A*C4(1,1)
      GO TO 500
  600 CONTINUE
      C2(1,1)=1.0/C2(1,1)
  500 CONTINUE
C
C     -------- [C1]<== [P1]*[H2] ------------------------
      CALL MMUT(P1,H2,C1,I1,I1,I2,J1,J1,J1,J2,K1,K1)
C     -------- [AK]<== [C1]*[C2] -----------------------
      CALL MMUT(C1,C2,AK,I1,I2,I2,K1,K1,J2,J2,J1,J2)
C
C
      RETURN
      END
C
C    *****************  SUBROUTINE HH2    ****************
C    *                                                   *
C    *        SUBROUTINE FOR OBSREVATION VECTOR EQ.      *
C    *              CALLED BY THE MAIN PROGRAM           *
C    *****************************************************
C
C     PURPOSE:
C       TO COMPUT ESTIMATED OBSERVATIONS BY USING PREDICTED
C       STATE VECTOR
C
C     USAGE:
C       CALL HH2(N,AHH,Y1,KK,DT,I2,J1,J2,ICON)
C
C     DESCRIPTION OF PARAMETERS
C             N: NUMBER OF DEGREE OF FREEDOM OF STRUCTURE
C     AHH(J2,1): ESTIMATED OBSERVATION VECTOR
C      Y1(J1,1): PREDICTED STATE VECTOR
C            KK: TIME IN DATA PROCESSING
C            DT: TIME INCREMENT IN SEC
C            I2: NUMBER OF RESPONSE OBSERVATIONS
C         J1,J2: DIMENSION OF [AHH] OR [Y1] IN CALLING
C                PROGRAM
C          ICON: PARAMETER FOR STATE VECTOR EQUATION
C                AND OBSERVATION VECTOR EQUATION
C
C     REMARKS
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       NONE
C     ******************************************************
C
      SUBROUTINE HH2(N,AHH,Y1,KK,DT,I2,J1,J2,ICON)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION AHH(J2,1),Y1(J1,1)
C
      IQ=1
      DO 100 I=1,I2
      AHH(I,1)=0.0
  100 CONTINUE
C
      IF(ICON.EQ.3) GO TO 10
```

```
      IF(ICON.EQ.1) IQ=5
      IF(ICON.EQ.2) IQ=6
C
      DO 200 I=1,N
      II=IQ*(I-1)
      DO 300 J=1,I2
      AHH(J,1)=AHH(J,1)+Y1(J+II,1)
  300 CONTINUE
  200 CONTINUE
      GO TO 20
C
   10 CONTINUE
      DO 400 I=1,N
      II=3*(I-1)
      OME=FLOAT(KK-1)*DT
C
      A1=Y1(II+2,1)*Y1(II+2,1)-OME*OME
      AA1=A1*A1
      A1=2.0*Y1(II+1,1)*Y1(II+2,1)*OME
      AA2=A1*A1
      AA=AA1+AA2
      AA1=-Y1(II+3,1)*(Y1(II+2,1)*Y1(II+2,1)-OME*OME)
      AA2=2.0*Y1(II+3,1)*Y1(II+1,1)*Y1(II+2,1)*OME
C
      AHH(1,1)=AHH(1,1)+AA1/AA
      AHH(2,1)=AHH(2,1)+AA2/AA
  400 CONTINUE
C
   20 CONTINUE
C
      RETURN
      END
C
C     ***************    SUBROUTINE STEP2   *****************
C     *                                                      *
C     *       SUBROUTINE FOR THE FILTERED STATE VECTOR       *
C     *                CALLED BY THE MAIN PROGRAM            *
C     ********************************************************
C
C     PURPOSE:
C       TO COMPUTE THE FILTERED STATE VECTOR
C
C     USAGE:
C       CALL STEP2(Y2,Y1,AK,Z,AHH,I1,I2,J1,J2)
C
C     DESCRIPTION OF PARAMETERS
C        Y2(J1,1): FILTERED STATE VECTOR
C        Y1(J1,1): PREDICTED STATE VECTOR
C        AK(J1,1): KALMAN GAIN MATRIX
C         Z(J2,1): OBSERVATION VECTOR
C       AHH(J2,1): EVALUATED OBSERVATION VECTOR BY USING
C                  STATE VECTOR
C              I1: DIMENSION OF EXTENDED STATE VECTOR
C                  (I1.LE.30)
C              I2: NUMBER OF RESPONSE OBSERVATIONS
C                  (I2.LE.10)
C           J1,J2: DIMENSION OF [AK],[P1],[H1],[H2] OR [R]
C                  IN CALLING PROGRAM
C
C     REMARKS
```

```
C      (1) PARAMETER I1 MUST BE LESS THAN 30
C      (2) PARAMETER I2 MUST BE LESS THAN 10
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C            MMUT
C      ******************************************************************
C
       SUBROUTINE STEP2(Y2,Y1,AK,Z,AHH,I1,I2,J1,J2)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Y2(J1,1),Y1(J1,1),AK(J1,J2)
       DIMENSION Z(J2,1),AHH(J2,1)
       DIMENSION C3(10,1),C4(30,1),Y6(30,1)
       DATA K1/30/
C
C      ------ [C3]<== [Z]-[AHH]---------------------------
       DO 100 I=1,I2
       C3(I,1)=Z(I,1)-AHH(I,1)
   100 CONTINUE
C
C      ------ [C4]<== [AK]*[C3] --------------------------
       CALL MMUT(AK,C3,C4,I1,I2,1,J1,J2,J2,1,K1,1)
C
C      ------ [Y6]<== [Y1]+[C4] --------------------------
       DO 200 I=1,I1
       Y6(I,1)=Y1(I,1)+C4(I,1)
   200 CONTINUE
  1000 CONTINUE
C
C
C      -----  [Y2]<== [Y6] ------------------------------
       DO 3000 I=1,I1
  3000 Y2(I,1)=Y6(I,1)
C
       RETURN
       END
C
C      ***************    SUBROUTINE STEP3    ****************
C      *                                                     *
C      *    SUBROUTINE FOR ERROR COVARIANCE MATRIX OF         *
C      *    THE FILTERED STATE                               *
C      *              CALLED BY THE MAIN PROGRAM             *
C      *******************************************************
C
C      PURPOSE:
C        TO COMPUTE ERROR COVARIANCE MATRIX OF THE FILTERED STATE
C
C      USAGE:
C        CALL STEP3(P2,AK,H1,P1,R,I1,I2,J1,J2)
C
C      DESCRIPTION OF PARAMETERS
C      P2(J1,J1): ERROR COVARIANCE MATRIX OF THE FILTERED STATE
C      AK(J1,J2): KALMAN GAIN MATRIX
C      H1(J2,J1): LINEARIZED MATRIX OF THE OBSERVATION EQUATION
C                 REGARDING EACH PARAMETER
C      P1(J1,J2): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
C       R(J2,J2): OBSERVATION NOISE COVARIANCE MATRIX
C            I1 : DIMENSION OF EXTENDED STATE VECTOR
C                 (I1.LE.30)
C            I2 : NUMBER OF RESPONSE OBSERVATIONS
C                 (I2.LE.10)
```

```
C          J1,J2: DIMENSION OF [P2],[AK],[H1],[P1] AND [R]
C
C     REMARKS:
C      (1) PARAMETER I1 MUST BE LESS THAN 30
C      (2) PARAMETER I2 MUST BE LESS THAN 10
C
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C        TEN, MMUT
C     ****************************************************************
C
      SUBROUTINE STEP3(P2,AK,H1,P1,R,I1,I2,J1,J2)
C      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION P2(J1,J1),AK(J1,J2),H1(J2,J1),P1(J1,J1)
      DIMENSION C5(30,30)
      DIMENSION C55(30,30),CP(30,30),AK11(30,30)
      DIMENSION R(J2,J2)
      DATA K1/30/
C
C
C     ------- [C5]<== [AK]*[H1]-------------------------
      CALL MMUT(AK,H1,C5,I1,I2,I1,J1,J2,J2,J1,K1,K1)
C
C     ------- [C5]<== -[C5]  ----------------------------
      DO 100 I=1,I1
      DO 100 J=1,I1
      C5(I,J)=-C5(I,J)
  100 CONTINUE
C
C     -------  [C5]<== [II]+[C5]   ([II];UNIT MATRIX) ----
      DO 200 I=1,I1
      C5(I,I)=1.0+C5(I,I)
  200 CONTINUE
C
C     ------- [C55]<== [C5]  TRANSPOSE -----------------
      CALL TEN(C5,C55,I1,I1,K1,K1,K1,K1)
C
C     ------ [CP]<== [C5]*[P1] -------------------------
      CALL MMUT(C5,P1,CP,I1,I1,I1,K1,K1,J1,J1,K1,K1)
C     ------ [C5]<== [CP]*[C55] ------------------------
      CALL MMUT(CP,C55,C5,I1,I1,I1,K1,K1,K1,K1,K1,K1)
C     ---- [AK11]<== [AK]  TRANSPOSE --------------------
      CALL TEN(AK,AK11,I1,I2,J1,J2,K1,K1)
C     ----- [C55]<== [AK]*[R] --------------------------
      CALL MMUT(AK,R,C55,I1,I2,I2,J1,J2,J2,J2,K1,K1)
C     ------ [CP]<== [C55]*[AK11]  ---------------------
      CALL MMUT(C55,AK11,CP,I1,I2,I1,K1,K1,K1,K1,K1,K1)
C
C     ------ [P2]<== [C5]+[CP]  ------------------------
      DO 500 I=1,I1
      DO 600 J=1,I1
      P2(I,J)=C5(I,J)+CP(I,J)
  600 CONTINUE
  500 CONTINUE
C
C
      RETURN
      END
C
C     ******************  SUBROUTINE SETN   ******************
C     *                                                       *
```

```
C      * SUBROUTINE FOR IDENTIFICATION OF BILINEAR HYSTERESIS *
C      *                CALLED BY THE MAIN PROGRAM             *
C      ********************************************************
C
C
       SUBROUTINE SETN(Y3,J1,J3,KK,NZ,XX,XXX)
C       IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Y3(J1,J3)
C
       P1=Y3(1,KK)
       P2=Y3(2,KK-1)*Y3(2,KK)
C
C
       XE=Y3(5,KK)
       GO TO (100,200,300,400,500),NZ
C
C
   100 IF(P1.GE.XE) GO TO 200
       IF(P1.LE.-XE) GO TO 400
       NZ=1
       GO TO 1000
C
C
   200 IF(NZ.EQ.3) GO TO 220
       IF(NZ.EQ.1) GO TO 220
       IF(NZ.EQ.5) GO TO 220
       IF(P2.LE.0.0) GO TO 300
   220 NZ=2
       GO TO 1000
C
C
   300 IF(NZ.EQ.3) GO TO 310
       XX=P1
   310 IF(P1.GE.XX.AND.NZ.EQ.3) GO TO 200
       XXX=XX-2.0*XE
       IF(P1.LE.XXX.AND.NZ.EQ.3) GO TO 400
       NZ=3
       GO TO 1000
C
C
   400 IF(NZ.EQ.3) GO TO 420
       IF(NZ.EQ.1) GO TO 420
       IF(NZ.EQ.5) GO TO 420
       IF(P2.LE.0.0) GO TO 500
   420 NZ=4
       GO TO 1000
C
C
   500 IF(NZ.EQ.5) GO TO 510
       XX=P1
   510 IF(P1.LE.XX.AND.NZ.EQ.5) GO TO 400
       XXX=XX+2.0*XE
       IF(P1.GE.XXX.AND.NZ.EQ.5) GO TO 200
       NZ=5
  1000 CONTINUE
       RETURN
       END
C
C      **************   SUBROUTINE WRITEB    ******************
C      *                                                       *
```

```
C      *    SUBROUTINE FOR PRINT OUT THE RESULT  ON UNIT 6      *
C      *                CALLED BY THE MAIN PROGRAM                *
C      ************************************************************
C
C      PURPOSE:
C        TO PRINT OUT THE RESULT UNIT=6
C
C      USAGE:
C        CALL WRITEB(Y,DY,Y3,K2,I1,J1,J2,J3,NN,Y4)
C
C      DESCRIPTION OF PARAMETERS
C          Y(J2,J3) : OBSERVATION DATA
C            DY(J3) : INPUT EXCITATION
C         Y3(J1,J3) : ESTIMATED STATE VECTOR AT EACH STEP
C                     FROM NM1 TO NM2
C                K2 : NUMBER OF RESPONSE OBSERVATIONS
C                I1 : DIMENSION OF EXTENDED STATE VECTOR
C                     (I1.LE.30)
C             J2,J3 : DIMENSION OF [Y],[DY],AND [Y3]
C                     IN CALLING PROGRAM
C                NN : TOTAL NUMBER OF DATA POINT
C         Y4(J1,J3) : ERROR COVARIANCE MATRIX OF THE FILTERED
C                     STATE AT EACH STEP
C      REMARKS
C       (1) PARAMETER I1 MUST BE LESS THAN 30
C
C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C       NONE
C      ***************************************************************
C
       SUBROUTINE WRITEB(Y,DY,Y3,K2,I1,J1,J2,J3,NN,Y4)
C        IMPLICIT REAL*8(A-H,O-Z)
       DIMENSION Y(J2,J3),DY(J3),Y3(J1,J3)
       DIMENSION Y4(J1,J3)
       DIMENSION Y8(30)
       DATA K90/30/
C
       WRITE(6,8000)
       WRITE(6,710)
   710 FORMAT(1H ,
      1   '***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***')
       WRITE(6,8000)
C
       NOT=5
       NNN=NN-10
       L1=K2/6
       IF(L1.EQ.0) GO TO 100
       DO 20 L2=1,L1
       DO 10 L5=NNN,NN,NOT
       L4=6*(L2-1)+1
       L10=6*L2
       WRITE(6,503) L5
   503 FORMAT(1H ,'OBSERVED AT=',I5)
       WRITE(6,500)  (Y(L3,L5),L3=L4,L10)
    10 CONTINUE
    20 CONTINUE
C
       K3=K2
       L3=L1*6+1
       GO TO 200
```

```
  100 K3=K2
      L3=1
  200 CONTINUE
      DO 30 L1=NNN,NN,NOT
      WRITE(6,503) L1
      WRITE(6,500)  (Y(L2,L1),L2=L3,K3)
   30 CONTINUE
C
C
      NNN=NN-10
C
      WRITE(6,8000)
      WRITE(6,740)
  740 FORMAT(1H ,
     1 '***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***')
      WRITE(6,8000)
      L1=I1/6
      IF(L1.EQ.0) GO TO 400
      DO 410 L2=1,L1
      DO 420 L5=NNN,NN,NOT
      L4=6*(L2-1)+1
      L10=6*L2
      WRITE(6,504) L5
  504 FORMAT(1H ,'ESTIMATED AT=',I5)
      WRITE(6,500)(Y3(L3,L5),L3=L4,L10)
  420 CONTINUE
      WRITE(6,501)
  410 CONTINUE
C       DO 810 L2=1,L1
C       DO 820 L5=NNN,NN,NOT
C       L4=6*(L2-1)+1
C       L10=6*L2
C       WRITE(6,500)(Y4(L3,L5),L3=L4,L10)
C  820 CONTINUE
C       WRITE(6,501)
C  810 CONTINUE
      IL=I1-L1*6
      IF(IL.LE.0 ) GO TO 3000
      K3=I1
      L3=L1*6+1
      GO TO 430
  400 K3=I1
      L3=1
  430 DO 440 L1=NNN,NN,NOT
      WRITE(6,504) L1
  440 WRITE(6,500)  (Y3(L2,L1),L2=L3,K3)
      WRITE(6,501)
C       C11=0.0
C       DO 840 L1=NNN,NN,NOT
C       DO 4001 J=1,I1
C 4001 C11=Y4(J,L1)**2+C11
C       C11=SQRT(C11)
C       WRITE(6,500)  ((Y4(L2,L1),L2=L3,K3),C11)
C       C11=0.0
C  840 CONTINUE
 3000 CONTINUE
C
      AN=NN
      A2=K2
      K9=2*K2
```

```
      K10=3*K2+1
      DO 5000 I=1,I1
 5000 Y8(I)=0.0
      DO 5010 I=1,K2
      II=I+K2
      DO 5020 J=1,NN
      AA=Y(I,J)-Y3(I,J)
      AB=AA*AA
      AC=Y(I,J)*Y(I,J)
      Y8(I)=Y8(I)+AB
      Y8(II)=Y8(II)+AC
 5020 CONTINUE
      Y8(I)=Y8(I)/AN
      Y8(II)=Y8(II)/AN
 5010 CONTINUE
      DO 5030 I=1,K2
      II=I+K2
 5030 Y8(K9+I)=Y8(I)/Y8(II)*100.0
      DO 5040 I=1,K2
 5040 Y8(K10)=Y8(K10)+Y8(K9+I)
      Y8(K10)=Y8(K10)/A2
      AA=0.0
      DO 5050 I=1,K2
      II=I+K9
      A1=Y8(II)-Y8(K10)
      A2=A1*A1
      AA=AA+A2
 5050 CONTINUE
      Y8(K10)=SQRT(AA)
      WRITE(6,6000)  Y8(K10)
 6000 FORMAT(1H ,'THETA=',E15.8)
C
      WRITE(6,8000)
  500 FORMAT(1H ,6(1X,E11.4))
  501 FORMAT(1H ,72('-'))
 8000 FORMAT(1H ,' ')
      RETURN
      END
C
C     *************      SUBROUTINE WRITEC     *****************
C     *                                                         *
C     *  SUBROUTINE FOR GENERATING OUTPUT FILES FOR PLOTTING *
C     *                     UNIT 22 - 30                        *
C     *               CALLED BY THE MAIN PROGRAM                *
C     *********************************************************
C
C     IF (ICON.LE.3)  NO OUTPUT FILES FOR PLOTTING
C
C     IF (ICON.GE.4 AND NCON.EQ.1), UNIT 22-30 WILL BE GENERATED.
C         UNIT 22    : ESTIMATED HYSTERESIS DATA
C         UNIT 23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
C                      AS FILTERED STATE VECTOR
C
C     ****************************************************************
C
C
      SUBROUTINE WRITEC(ICON,NCON,DT,N,ND,Y3,GG1,J1,J3)
      DIMENSION Y3(J1,J3),GG1(J3),TIME(3000)
C
      II4=6
```

```
      II5=5
      II6=ND
      IF (ICON.GE.4.AND.NCON.EQ.1) THEN
      WRITE(22,1600) II5,II5,II6
      WRITE(22,1700) (Y3(1,KK),KK=1,ND)
      WRITE(22,1600) II5,II4,II6
      WRITE(22,1700) (GG1(KK),KK=1,ND)
C
      DO 100 I=1,ND
      TIME(I)=FLOAT(I-1)*DT
  100 CONTINUE
C
      IF(ICON.EQ.4.OR.ICON.EQ.5) THEN
      IA=22
      DO 20 I=3,6
      IA=IA+1
      WRITE(IA,1600) II5,II5,II6
      WRITE(IA,1700) (TIME(KK),KK=1,ND)
      WRITE(IA,1600) II5,II4,II6
      WRITE(IA,1700) (Y3(I,KK),KK=1,ND)
      REWIND IA
   20 CONTINUE
C
      ELSE
C
      IA=22
      DO 25 I=5,12
      IA=IA+1
      WRITE(IA,1600) II5,II5,II6
      WRITE(IA,1700) (TIME(KK),KK=1,ND)
      WRITE(IA,1600) II5,II4,II6
      WRITE(IA,1700) (Y3(I,KK),KK=1,ND)
      REWIND IA
   25 CONTINUE
C
      END IF
      END IF
 1600 FORMAT(3I5)
 1700 FORMAT(8(1PE10.3))
C
  300 CONTINUE
      RETURN
      END
```

APPENDIX I-2

DESCRIPTION OF INPUT DATA IN UNIT 3

(free format)

1. HEADING CARD

2. MASTER CONTROL CARD; ICON,NCON,ITE,PITE

```
ICON:  ANALYSIS CASE
   ICON=1 : LINEAR (MDOF) RUNGE-KUTTA METHOD
   ICON=2 : LINEAR (MDOF) LINEAR ACCLERATION METHOD
   ICON=3 : LINEAR (MDOF) FREQUENCY DOMAIN
   ICON=4 : NONLINEAR (SDOF) NONPARAMETRIC MODEL
   ICON=5 : NONLINEAR (SDOF) BILINEAR HYSTRESIS
   ICON=6 : NONLINEAR (SDOF) BOUC-WEN'S MODEL

NCON : OUTPUT COTROL

   IF(ICON.LE.3), NO OUTPUT DATA FILES EXCEPT UNIT 6 ARE GENERATED AND
                  ANY POSITIVE INTEGER VALUE MAY BE INPUT FOR NCON.

   IF(ICON.GE.4 AND NCON=1), UNIT 22-30 ARE GENERATED FOR PLOTTING.
        UNIT=22 : ESTIMATED HYSTERESIS
        UNIT=23-30 : CONVERGENCY PROCESS OF EACH PARAMETER

ITE : TOTAL NUMBER OF GLOBAL ITERATIONS (ITE.GE.1)

PITE : WEIGHT FOR EK-WGI PROCEDURE  (PITE.GT.1.0)
```

3. CONTROL CARD; N,I1,I2,MC2

```
N   : NUMBER OF DEGREES OF FREEDOM(OR MODES) TO BE IDENTIFIED

I1 : DIMENSION OF EXTENDED STATE VECTOR (I1.LE.30)
```

TABLE 5-I COMPONENTS OF STATE VECTOR

ICON	I1	COMPONENTS OF STATE VECTOR
1	5*N	Uij, dUij/dt, hj, wj, Pij for each mode j=1,..,N
2	6*N	Uij, dUij/dt, ddUij/dtdt, hj, wi, Pij for each mode j=1,...,N
3	3*N	hj, wj, Pij for each mode j=1,...,N
4	6	Z, dZ/dt, a1, a2, a3, a4
5	6	Z, dZ/dt, h, w, Ze, alfa
6	12	Z, dZ/dt, phi, e, h, w, be, ga, A0, ca, cv, cn

```
NOTE :
   FOR ICON=6, (SEE SECTION 3.4)
     phi = hysteretic function,
     e   = dissipated hysteretic energy,
     h   = damping ratio,  w = natural frequency,
     be  = beta,  ga = gamma,
     A0  = A0, ca = delta A, cv = delta nu, cn = delta eta
```

I2 : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING
IF ICON IS 1,4,5 OR 6, I2 IS RECOMMENED AS 2.
IF ICON IS 3, I2 MUST BE 2.

MC2 : CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED
(REQUIRED ONLY FOR ICON=2)

TABLE 5-II RESPONSE OBSERVATIONS* USED

ICON	I2	MC2	RESPONSE COMPONENTS USED
1	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
2	1	1	DISPLACEMENT RESPONSE
		2	VELOCITY RESPONSE
		3	ACCELERATION RESPONSE
	2	1	DISPLACEMENT AND VELOCITY RESPONSE
		2	ACCELERATION AND VELOCITY RESPONSE
3	2		REAL AND IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION WILL BE USED.
4	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
5	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY
6	1		DISPLACEMENT ONLY
	2		DISPLACEMENT AND VELOCITY

NOTE : FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE TO THE GROUND MUST BE USED.

4. OBSERVATION DATA CARD; NN,DT,NM1,NM2

NN : TOTAL NUMBER OF OBSERVATION DATA POINTS OF EACH RECORD
DT : TIME INCREMENT(SEC) OR FREQUENCY INCREMENT(RAD/SEC) IN DATA
NM1 : STRATING DATA POINT USED FOR FILTERING
NM2 : ENDING DATA POINT USED FOR FILTERING

5. INITIAL GUESS FOR FILTERED STATE VECTOR; Y2(I,1), I=1,I1

DATA MUST BE SUPPLIED FOR Y2(I,1), I=1,I1.
FOR DEFINITION OF STATE VECTOR Y2(I), SEE TABLE 5-I.

6. INITIAL GUESS FOR ERROR COVARIANCE MATRIX OF THE FILTERED STATE; P11(I), I=1,I1

INITIAL VALUES FOR THE ERROR COVARIANCE MATRIX OF THE FILTERED STATE VECTOR IS ASSUMED AS DIAGONAL. INITIAL VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPIED; P11(I), I=1,I1.

7. SYSTEM NOISE COVARIANCE MATRIX; QR1(I), I=1,I1

COVARIANCE MATRIX OF SYSTEM NOISE IS ASSUMED TO BE DIAGONAL. VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPLIED; QR1(I), I=1,I1

8. SYSTEM NOISE COEFFICIENT MATRIX; G11(I), I=1,I1

COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
MUST BE PROVIDED; G11(I), I=1,I1

9. OBSERVATION NOISE COVARIANCE MATRIX; QR2(I),I=1,I2

COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
DIAGONAL. DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
QR2(I), I=1,I2.

APPENDIX I-3

DESCRIPTION OF INPUT DATA IN UNIT 8

```
******    IF ICON = 1,2,4,5 AND 6    ******

1. HEADING CARD   (72A)

2. MASTER CONTROL DATA ;  NRSP   (I5)

     NRSP : NUMBER OF RESPONSE COMPONENT RECORDS AT A CERTAIN NODE
            TO BE SUPPLIED IN THIS DATA FILE (NRSP.LE.3)

3. GROUND ACCELERATION DATA

  3-A.   TITLE CARD   (72A)

  3-B.   GROUND ACCELERATION DATA   ( 8(1PE10.3) )
            NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
            SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.

4. RESPONSE OBSERVATION DATA

     NRSP COMPONENTS OF RESPONSE OBSERVATIONS MUST BE PROVIDED.
        (FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
         TO THE GROUND MOTION MUST BE USED.)

     FOR EACH COMPONENT, FOLLOWING SET OF DATA MUST BE SUPPLIED.

  4-A.   TITLE OF RESPONSE COMPONENT ( 72A )

  4-B.   RESPONSE COMPONENT INDICATOR   ( I5 )
                  = 1,   FOR DISPLACEMANT
                    2,   FOR VELOCITY
                    3,   FOR ACCELERATION

  4-C.   OBSERVED RESPONSE DATA   ( 8(1PE10.3) )
            NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
            SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
```

****** IF ICON = 3 ******

1. HEADING CARD (72A)

2. MASTER CONTROL CARD ; NRSP (I5)
   NRSP = 2 (REAL & IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION)

3. REAL PARTS OF FREQUENCY RESPONSE FUNCTION

   3-A. TITLE CARD (72A)

   3-B RESPONSE COMPONENT INDICATOR (I5)
   = 1 (REAL PARTS)

   3-C. REAL PARTS OF FREQUENCY RESPONSE DATA (8(1PE10.3))
   NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.

4. IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION

   4-A. TITLE CARD (72A)

   4-B RESPONSE COMPONENT INDICATOR (I5)
   = 2 (IMAGINERY PARTS)

   4-C. IMAGINERY PARTS OF FREQUENCY RESPONSE DATA (8(1PE10.3))
   NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.

APPENDIX II

INPUT/OUTPUT DATA FILES FOR PROGRAM EXKAL2

II − 1 General Control Input Data File (Unit = 3)

II-1-1 Linear MDOF Structure : ICON=1

(a) Step I : For First Mode Only

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 1ST MODE, ICON=1; W/ 1% NOISE IN VARIANCE
2     1    1   5   2.0
3     1    5   2    1
4     1000  0.015  1  1000
5    0.0   0.0   0.5  5.0  0.5
6    1.0   1.0   1.0  1.0  1.0
7    0.0   0.0   0.0  0.0  0.0
8    1.0   1.0   1.0  1.0  1.0
9    1.0   5.0
```

(b) Step II : For Second Mode Only

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 2ND MODE, ICON=1; W/ 1% NOISE IN VARIANCE
2     1    1   5  2.0
3     2   10   2    1
4     1000  0.015  1  1000
5    0.0  0.0  0.0745    6.302  0.959
6    0.0  0.0  0.5       15.0   0.5
7    1.0   1.0   0.0  0.0  0.0
8    1.0   1.0   1.0  1.0  1.0
9    0.0   0.0   0.0  0.0  0.0
10   0.0   0.0   0.0  0.0  0.0
11   1.0   1.0   1.0  1.0  1.0
12   1.0   1.0   1.0  1.0  1.0
13   1.0   5.0
```

(c) Step III : For First and Second Modes

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 2 MODES, ICON=1; W/ 1% NOISE IN VARIANCE
2     1    1   5  2.0
3     2   10   2    1
4     1000  0.015  1  1000
5    0.0  0.0  0.0745    6.302  0.959
6    0.0  0.0  0.071     9.517  0.326
7    1.0   1.0   0.1  1.0  0.1
8    1.0   1.0   0.1  1.0  0.1
9    0.0   0.0   0.0  0.0  0.0
10   0.0   0.0   0.0  0.0  0.0
11   1.0   1.0   1.0  1.0  1.0
12   1.0   1.0   1.0  1.0  1.0
13   1.0   5.0
```

II-1-2 Linear MDOF Structure : ICON=2

(a) Step I : For First Mode Only

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 1ST MODES , ICON=2;  W/ 1 % NOISE IN VARIANCE
2     2    1    5  100.0
3     1    6    1    3
4     1000   0.015   1  1000
5    0.0  0.0  0.0  0.5  5.0   0.5
6    1.0  1.0  5.0  1.0  4.0   1.0
7    0.0  0.0  0.0  0.0  0.0   0.0
8    1.0  1.0  1.0  1.0  1.0   1.0
9    50.0
```

(b) Step II : For Second Mode Only

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 2ND MODE , ICON=2;  W/ 1 % NOISE IN VARIANCE
2     2    1    5  100.0
3     2   12    1    3
4     1000   0.015   1  1000
5    0.0  0.0  0.0  0.175  6.615   1.121
6    0.0  0.0  0.0  0.5     15.0   0.5
7    1.0  1.0  5.0  0.0  0.0   0.0
8    1.0  1.0  5.0  1.0  4.0   1.0
9    0.0  0.0  0.0  0.0  0.0   0.0
10   0.0  0.0  0.0  0.0  0.0   0.0
11   1.0  1.0  1.0  1.0  1.0   1.0
12   1.0  1.0  1.0  1.0  1.0   1.0
13   50.0
```

(c) Step III : For First and Second Modes

(line no.)

```
1    SYS-ID FOR 2-DOF, FOR 2 MODES , ICON=2;  W/ 1 % NOISE IN VARIANCE
2     2    1   10  100.0
3     2   12    1    3
4     1000   0.015   1  1000
5    0.0  0.0  0.0  0.175  6.615   1.121
6    0.0  0.0  0.0  0.021  9.562   0.078
7    1.0  1.0  5.0  0.1  1.0   0.2
8    1.0  1.0  5.0  0.1  1.0   0.2
9    0.0  0.0  0.0  0.0  0.0   0.0
10   0.0  0.0  0.0  0.0  0.0   0.0
11   1.0  1.0  1.0  1.0  1.0   1.0
12   1.0  1.0  1.0  1.0  1.0   1.0
13   50.0
```

II-1-3 Linear MDOF Structure : ICON=3

(a) Step I : For First Mode Only

(line no.)

```
ID FOR 2-D,ICON=3;for 1st mode only,H(w) from Displ,W/ 1% NOISE IN VARIANCE
 3    1   10  10.0
 1    3    2    1
 350    0.1023  11    70
0.5    10.0  0.5
0.1    4.0   1.0
0.0    0.0   0.0
1.0    1.0   1.0
0.1    0.1
```

(b) Step II : For Second Mode Only

(line no.)

```
ID FOR 2-D,ICON=3;for 2nd mode only,H(w) from Displ,W/ 1% NOISE IN VARIANCE
 3    1   10  10.0
 2    6    2    1
 350    0.1023  11    170
0.0557  6.186  0.766
0.5      15.0   0.5
0.0    0.0    0.0
0.1    4.0    1.0
0.0    0.0    0.0
0.0    0.0    0.0
1.0    1.0    1.0
1.0    1.0    1.0
0.1    0.1
```

(c) Step III : For First and Second Modes

(line no.)

```
ID FOR 2-D,ICON=3;for 1st & 2nd modes,H(w) from Displ,W/ 1% NOISE IN VARIANCE
 3    1   10  10.0
 2    6    2    1
 350    0.1023  11    170
0.0557  6.186  0.766
0.051    9.313  0.2675
0.1    1.0    1.0
0.1    1.0    1.0
0.0    0.0    0.0
0.0    0.0    0.0
1.0    1.0    1.0
1.0    1.0    1.0
0.1    0.1
```

II-1-4 Nonlinear SDOF Structure with Bilinear Hysteresis : ICON=5

(a) Step I : For Linear Parameters Only

(line no.)

```
SYS-ID FOR 1-D BILIN. ICON=5, FOR LIN PARA. ONLY; W/ NO NOISE
 5     1     5  2.0
 1     6     2     1
 1000    0.015    1   150
0.0  0.0   0.5    5.0  100.0   1.0
1.0  1.0   1.0    1.0   1.0   1.0
0.0  0.0   0.0    0.0   0.0   0.0
1.0  1.0   1.0    1.0   1.0   1.0
1.0  1.0
```

(b) Step II : For Nonlinear Parameters Only

(line no.)

```
SYS-ID FOR 1-D BILIN. ICON=5, FOR NONLIN PARA.; W/ NO NOISE
 5     1     5  2.0
 1     6     2     1
 1000    0.015    1   1000
0.0  0.0   0.098  3.16  1.0   0.5
1.0  1.0   0.0    0.0   1.0   1.0
0.0  0.0   0.0    0.0   0.0   0.0
1.0  1.0   1.0    1.0   1.0   1.0
1.0  1.0
```

(c) Step III : For Linear and Nonlinear Parameters

(line no.)

```
SYS-ID FOR 1-D BILIN. ICON=5, FOR LIN & NONLIN PARA.; W/O NOISE
 5     1     5   10.0
 1     6     2     1
 1000    0.015    1   1000
0.0  0.0  0.098  3.16  3.04 0.10
1.0  1.0  0.1    1.0   1.0  0.1
0.0  0.0  0.0    0.0   0.0  0.0
1.0  1.0  1.0    1.0   1.0  1.0
1.0  1.0
```

II-1-5 Nonlinear SDOF Structure with Bouc-Wen's Hysteresis : ICON=6

(a) Step I : For Linear Parameters Only

(line no.)

```
1    SYS-ID FOR 1-D BOUC-WEN HYSTERE. ICON=6, FOR LIN PARA. ONLY; W/O NOISE
2     6    1    5   2.0
3     1   12    2    1
4     1000   0.015   1   150
5    0.0  0.0  0.0  0.0   0.5  5.0   0.0  0.0   1.0  0.0  0.0  0.0
6    1.0  1.0  1.0  1.0   1.0  1.0   0.0  0.0   0.0  0.0  0.0  0.0
7    0.0  0.0  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0  0.0  0.0
8    1.0  1.0  1.0  1.0   1.0  1.0   1.0  1.0   1.0  1.0  1.0  1.0
9    1.0  1.0
```

(b) Step II : For Nonlinear Parameters Only

(line no.)

```
1    SYS-ID FOR 1-D BOUC-WEN HYSTERE. ICON=6, FOR NONLIN PARA. ONLY; W/O NOISE
2     6    1    5   2.0
3     1   12    2    1
4     1000   0.015   1   1000
5    0.0  0.0  0.0  0.0 0.105  3.177 0.0  0.0   1.0  0.0  0.0  0.0
6    1.0  1.0  1.0  1.0   0.0  0.0   1.0  1.0   0.0  0.0  0.0  0.0
7    0.0  0.0  0.0  0.0   0.0  0.0   0.0  0.0   0.0  0.0  0.0  0.0
8    1.0  1.0  1.0  1.0   1.0  1.0   1.0  1.0   1.0  1.0  1.0  1.0
9    1.0  1.0
```

(c) Step III : For Linear and Nonlinear Parameters

(line no.)

```
1    SYS-ID FOR 1-D BOUC-WEN HYSTERE. ICON=6, FOR LIN & NONLIN PARA.; W/O NOISE
2     6    1    5   2.0
3     1   12    2    1
4     1000   0.015   1   1000
5    0.0  0.0  0.0  0.0 0.105 3.177 0.072 0.259  1.0  0.0  0.0  0.0
6    1.0  1.0  1.0  1.0   0.1  1.0   0.1  0.1    0.0  0.0  0.0  0.0
7    0.0  0.0  0.0  0.0   0.0  0.0   0.0  0.0    0.0  0.0  0.0  0.0
8    1.0  1.0  1.0  1.0   1.0  1.0   1.0  1.0    1.0  1.0  1.0  1.0
9    1.0  1.0
```

II − 2 Excitation and Response Observation Data Files (Unit = 8)

II-2-1 Linear MDOF Structure : ICON=1 and 2

(line no.)

```
 OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
   3
 OBSERVED INPUT EXCIATION
 9.800e-01-1.470e+00 1.470e+00 6.762e+00 1.431e+01 4.920e+01 5.527e+01-2.215e+01
-5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
-9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
-2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
 7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
 1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
-1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
-2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
-3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
 2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01
```

Intermidiate data have been omitted.

```
 DISPLACEMENT RESPONSE
   1
 0.000e+00-1.628e-01 9.042e-02-2.115e-01-2.270e-01 1.830e-01-1.646e-01-2.909e-01
 1.493e-01-2.780e-01 3.624e-03-3.870e-01-9.767e-02-3.467e-01-1.837e-01-1.675e-01
 6.333e-01-1.684e-01 2.845e-01 8.646e-03 2.842e-01-2.156e-01 1.197e-01-4.587e-01
-5.936e-02-8.803e-02 3.155e-01 6.353e-02 1.115e-01-1.062e-01-2.329e-01-9.030e-02
-1.479e-01-2.788e-02 3.014e-01-1.008e-01 1.459e-01 4.499e-03-2.060e-01 2.577e-01
 3.319e-02 3.219e-01 1.889e-01 1.605e-01 6.311e-02 1.909e-01 2.167e-01 2.080e-01
-2.593e-01-2.696e-01 1.959e-01-1.569e-02-5.816e-01-1.193e-01-6.908e-02-5.862e-02
-4.900e-01 3.406e-02-5.230e-01 8.835e-02-6.540e-01-2.507e-01-5.413e-01-1.912e-02
-1.769e-01-3.734e-01-4.724e-01-2.523e-01-4.921e-01-5.525e-01-6.128e-02-3.096e-01
 3.049e-01 8.405e-02-2.604e-02 2.497e-01 4.962e-01 4.402e-01 3.244e-01 6.219e-01
```

Intermidiate data have been omitted.

```
 VELOCITY RESPONSE
   2
 0.000e+00-1.219e+00 6.917e-01-1.649e+00-1.909e+00 7.656e-01-2.501e+00-3.473e+00
 6.512e-01-1.914e+00 4.808e-01-2.425e+00-5.886e-01-2.691e+00-9.737e-01-4.618e-02
 6.372e+00 1.620e-01 3.440e+00 1.304e+00 3.145e+00-1.186e+00 7.581e-01-3.798e+00
-5.272e-01-4.466e-01 2.826e+00 1.371e+00 2.158e+00 6.825e-01-3.457e-01 3.984e-01
-3.376e-01 5.881e-01 3.351e+00 5.927e-01 2.548e+00 1.234e+00-8.417e-01 2.223e+00
 1.505e-01 1.994e+00 8.035e-01 4.033e-01-7.477e-01-4.775e-01-7.677e-01-4.782e-01
-3.394e+00-3.192e+00 5.937e-01-1.127e+00-6.155e+00-3.484e+00-3.676e+00-3.419e+00
-5.777e+00-9.150e-01-4.021e+00 1.829e+00-3.262e+00-1.182e-01-1.942e+00 2.430e+00
 1.543e+00 5.989e-01 5.669e-01 2.778e+00 1.493e+00 1.285e+00 5.117e+00 3.647e+00
 8.087e+00 5.670e+00 3.661e+00 3.975e+00 5.129e+00 4.790e+00 3.969e+00 5.746e+00
```

Intermidiate data have been omitted.

```
 ACCELERATION RESPONSE
   3
 0.000e+00-1.231e+01 6.130e+00-2.461e+01-3.311e+01-3.219e+01-6.494e+01 5.314e+00
 7.857e+01 1.586e+00 2.018e+01-3.449e+01-4.273e+01-1.940e+01 4.669e+01 4.931e+01
 6.721e+01-2.024e+01 3.574e+01 5.213e+00 8.122e+00-6.220e+01-1.960e+01-3.501e+01
 2.536e+01 7.522e+00 5.117e+01 5.508e+01 3.808e+01 1.030e+01-2.273e+01-2.736e+01
-1.721e+01 1.774e+01 5.685e+01 1.598e+01 2.035e+01-2.232e+01-4.872e+01-2.826e+00
-2.710e+01 1.723e+00 1.636e+00-1.435e+01-4.421e+01-5.711e+01-1.261e+01 5.619e+01
-7.946e+00-2.153e+01 3.351e+01-4.901e+01-1.229e+02-7.782e+01-5.487e+01 2.628e+01
 1.820e+01 5.186e+01 5.833e+01 9.446e+01-3.300e+01 1.394e+01 1.689e+01 4.816e+01
 3.677e+01 5.525e+01 4.463e+01 5.151e+01 4.579e+01-6.756e+00 6.355e+01 5.222e+01
 1.259e+01-1.286e+00-9.011e+01-9.377e+01 7.020e+01 2.351e+01 4.775e+01-3.538e+01
```

The rest of the data has been omitted.

II-2-2 Linear MDOF Structure : ICON=3

(line no.)

```
2D LIN. H(w); COMPUTED FROM STR. DISPL.,NPT=350,DW=0.1023,W/ 1% NOISE IN VAR.
  2
 REAL PART OH H(w)
  1
 0.000e+00-3.263e-02-2.490e-02-1.823e-02-5.324e-02-2.462e-02-9.281e-03 3.424e-03
 8.354e-03-9.255e-03-2.441e-02-2.734e-02-2.570e-02-2.218e-02-1.484e-02-5.533e-02
-2.793e-02-2.373e-02-2.791e-02-3.619e-02-2.719e-02-2.509e-02-2.499e-02-2.585e-02
-2.682e-02-2.551e-02-1.930e-02-2.012e-02-2.576e-02-2.948e-02-3.091e-02-2.998e-02
-2.006e-02-3.662e-02-3.337e-02-3.175e-02-3.090e-02-3.074e-02-3.154e-02-3.505e-02
-1.810e-02-3.056e-02-3.527e-02-4.042e-02-4.492e-02-4.427e-02-4.227e-02-4.446e-02
-4.922e-02-5.449e-02-5.880e-02-6.137e-02-6.286e-02-6.558e-02-7.240e-02-8.489e-02
-1.006e-01-1.100e-01-1.023e-01-8.142e-02-5.883e-02-3.701e-02-3.746e-04 7.618e-02
 1.015e-01 7.960e-02 6.381e-02 5.617e-02 5.575e-02 7.567e-02 3.253e-02 3.243e-02
 3.308e-02 3.352e-02 3.395e-02 3.456e-02 3.466e-02 2.955e-02 2.302e-02 1.685e-02
 1.167e-02 8.474e-03 7.323e-03 7.879e-03 1.085e-02 5.445e-03 4.659e-03 4.966e-03
 3.559e-03 4.567e-04 1.482e-03 8.255e-03 1.505e-02 2.043e-02 2.421e-02 2.628e-02
 2.693e-02 2.671e-02 2.618e-02 2.585e-02 2.342e-02 2.166e-02 2.106e-02 2.049e-02
 1.996e-02 1.936e-02 1.729e-02 1.530e-02 1.550e-02 1.544e-02 1.547e-02 1.595e-02
 1.661e-02 1.639e-02 1.548e-02 1.466e-02 1.466e-02 1.239e-02 1.211e-02 1.159e-02
 1.093e-02 1.004e-02 9.612e-03 1.026e-02 1.006e-02 9.531e-03 8.955e-03 8.484e-03
 8.270e-03 8.306e-03 8.335e-03 8.086e-03 8.596e-03 8.364e-03 7.887e-03 7.376e-03
 6.866e-03 6.482e-03 6.781e-03 7.397e-03 6.554e-03 5.835e-03 5.556e-03 6.092e-03
 7.783e-03 6.129e-03 4.784e-03 4.542e-03 4.716e-03 5.041e-03 5.390e-03 5.759e-03
 6.320e-03 6.256e-03 5.313e-03 4.863e-03 4.731e-03 5.025e-03 6.520e-03 7.073e-03
 1.419e-03 1.752e-03 2.376e-03 3.091e-03 3.881e-03 4.669e-03 5.288e-03 5.420e-03
 4.595e-03 3.422e-03 3.179e-03 3.485e-03 3.875e-03 4.199e-03 4.406e-03 4.465e-03
 4.349e-03 4.140e-03 4.103e-03 3.880e-03 3.471e-03 3.064e-03 2.977e-03 3.293e-03
 3.520e-03 3.480e-03 3.293e-03 3.077e-03 3.049e-03 3.821e-03 4.798e-03 4.542e-03
 3.979e-03 3.482e-03 3.082e-03 2.793e-03 2.659e-03 2.738e-03 3.039e-03 3.384e-03
```

Intermidiate data have been omitted.

```
 IMAGINERY PART OF H(W)
  2
 0.000e+00 4.940e-03 1.489e-02 9.646e-02-2.441e-02-8.539e-03-8.861e-05 9.159e-04
-1.181e-02-2.223e-02-1.234e-02-1.302e-03 6.037e-03 1.150e-02 2.023e-02 4.257e-03
 8.895e-03 1.300e-02 2.058e-02 2.749e-03 5.892e-04 9.095e-04 1.104e-03 1.748e-03
 3.644e-03 7.152e-03 6.412e-03-8.652e-04-2.240e-03 3.383e-05 3.395e-03 7.242e-03
 1.347e-02-2.797e-03 4.025e-03 5.053e-03 4.676e-03 3.423e-03 1.179e-03-4.034e-03
 3.116e-02 4.823e-03 1.719e-03 1.557e-03 5.168e-03 9.962e-03 9.345e-03 7.122e-03
 6.903e-03 9.190e-03 1.342e-02 1.817e-02 2.159e-02 2.284e-02 2.335e-02 2.732e-02
 4.127e-02 6.906e-02 1.023e-01 1.272e-01 1.429e-01 1.587e-01 1.819e-01 1.718e-01
 9.780e-02 6.139e-02 4.981e-02 4.526e-02 4.314e-02 2.677e-02 1.278e-02 2.069e-02
 2.044e-02 1.826e-02 1.514e-02 1.166e-02 9.747e-03 8.381e-03 4.828e-03 3.348e-03
 4.660e-03 7.619e-03 1.080e-02 1.347e-02 1.654e-02 2.416e-02 1.993e-02 1.899e-02
 1.887e-02 2.185e-02 2.931e-02 3.352e-02 3.329e-02 3.077e-02 2.696e-02 2.268e-02
 1.868e-02 1.535e-02 1.270e-02 1.017e-02 6.924e-03 7.198e-03 6.754e-03 6.120e-03
 5.373e-03 4.247e-03 2.525e-03 4.097e-03 4.223e-03 3.581e-03 2.744e-03 2.066e-03
 2.250e-03 3.040e-03 3.338e-03 3.176e-03 3.517e-03 2.049e-03 1.623e-03 1.206e-03
 8.538e-04 8.003e-04 1.638e-03 1.533e-03 9.341e-04 6.543e-04 6.613e-04 9.190e-04
 1.298e-03 1.536e-03 1.465e-03 9.492e-04 2.778e-04 4.382e-04 3.796e-04 3.526e-04
 4.547e-04 8.036e-04 1.319e-03 4.503e-04-2.351e-04-6.033e-05 4.821e-04 1.182e-03
 2.045e-04-1.716e-03-9.400e-04-9.826e-05 4.324e-04 6.400e-04 5.593e-04 2.788e-04
 1.380e-04 8.599e-04 7.250e-04 2.507e-04-1.423e-04-4.542e-04-3.116e-04 5.897e-03
 3.425e-03 1.704e-03 1.106e-03 8.422e-04 7.278e-04 6.644e-04 4.960e-04 1.359e-05
-5.412e-04-1.981e-04 4.639e-04 6.848e-04 6.004e-04 4.034e-04 1.861e-04-1.385e-05
-1.521e-04-9.963e-05-7.682e-05-2.281e-04-2.598e-04-4.933e-05 3.513e-04 4.805e-04
 2.052e-04-1.118e-04-2.596e-04-1.374e-04 3.713e-04 9.785e-04 3.231e-04-4.783e-04
```

The rest of the data has been omitted.

II-2-3 Nonlinear SDOF Structure with Bilinear Hysteresis : ICON=5

(line no.)

```
   OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
     3
   OBSERVED INPUT EXCIATION
 9.800e-01-1.470e+00 1.470e+00 6.762e+00 1.431e+01 4.920e+01 5.527e+01-2.215e+01
-5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
-9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
-2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
 7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
 1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
-1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
-2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
-3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
 2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01
```

Intermidiate data have been omitted.

```
   DISPLACEMENT RESPONSE
     1
 0.000e+00 5.485e-05 2.736e-04 7.286e-05-1.724e-03-7.723e-03-2.359e-02-4.851e-02
-6.976e-02-8.097e-02-8.739e-02-9.226e-02-1.003e-01-1.157e-01-1.313e-01-1.377e-01
-1.347e-01-1.300e-01-1.275e-01-1.252e-01-1.239e-01-1.276e-01-1.407e-01-1.609e-01
-1.818e-01-1.991e-01-2.140e-01-2.247e-01-2.278e-01-2.257e-01-2.211e-01-2.178e-01
-2.181e-01-2.193e-01-2.164e-01-2.066e-01-1.906e-01-1.716e-01-1.546e-01-1.411e-01
-1.302e-01-1.219e-01-1.151e-01-1.083e-01-1.041e-01-1.071e-01-1.204e-01-1.367e-01
-1.456e-01-1.491e-01-1.501e-01-1.495e-01-1.577e-01-1.815e-01-2.212e-01-2.723e-01
-3.227e-01-3.670e-01-4.052e-01-4.313e-01-4.487e-01-4.675e-01-4.875e-01-5.046e-01
-5.197e-01-5.315e-01-5.342e-01-5.268e-01-5.094e-01-4.807e-01-4.445e-01-3.958e-01
-3.334e-01-2.679e-01-2.025e-01-1.474e-01-1.025e-01-4.709e-02 2.075e-02 1.023e-01
```

Intermidiate data have been omitted.

```
   VELOCITY RESPONSE
     2
 0.000e+00 1.097e-02 1.084e-02-5.074e-02-2.074e-01-6.788e-01-1.450e+00-1.678e+00
-1.072e+00-5.281e-01-3.418e-01-3.612e-01-7.928e-01-1.150e+00-7.998e-01-5.486e-02
 3.388e-01 2.359e-01 1.429e-01 1.521e-01-2.268e-02-5.438e-01-1.166e+00-1.442e+00
-1.287e+00-1.064e+00-8.948e-01-4.679e-01-7.743e-04 2.594e-01 3.103e-01 9.758e-02
-1.046e-01 9.762e-03 4.148e-01 8.825e-01 1.215e+00 1.240e+00 1.014e+00 8.087e-01
 6.404e-01 4.832e-01 4.530e-01 4.096e-01 1.010e-01-5.619e-01-1.119e+00-8.865e-01
-3.621e-01-1.519e-01 5.294e-02-1.333e-01-1.031e+00-2.134e+00-3.135e+00-3.500e+00
-3.162e+00-2.792e+00-2.181e+00-1.343e+00-1.139e+00-1.341e+00-1.254e+00-1.061e+00
-9.444e-01-5.319e-01 1.624e-01 8.103e-01 1.561e+00 2.168e+00 2.758e+00 3.777e+00
 4.343e+00 4.431e+00 4.125e+00 3.169e+00 3.200e+00 4.098e+00 5.053e+00 5.578e+00
```

Intermidiate data have been omitted.

```
   ACCELERATION RESPONSE
     3
 0.000e+00 1.463e+00-1.480e+00-6.731e+00-1.416e+01-4.869e+01-5.413e+01 2.368e+01
 5.722e+01 1.524e+01 9.602e+00-1.219e+01-4.536e+01-2.253e+00 4.893e+01 5.039e+01
 2.095e+00-1.582e+01 3.422e+00-2.193e+00-2.111e+01-4.838e+01-3.453e+01-2.310e+00
 2.298e+01 6.748e+00 1.580e+01 4.112e+01 2.116e+01 1.353e+01-6.737e+00-2.163e+01
-5.330e+00 2.058e+01 3.343e+01 2.892e+01 1.542e+01-1.212e+01-1.803e+01-9.308e+00
-1.313e+01-7.824e+00 3.790e+00-9.577e+00-3.157e+01-5.680e+01-1.751e+01 4.855e+01
 2.136e+01 6.662e+00 2.066e+01-4.548e+01-7.424e+01-7.282e+01-6.063e+01 1.194e+01
 3.310e+01 1.635e+01 6.505e+01 4.665e+01-1.936e+01-7.582e+00 1.922e+01 6.426e+00
 9.147e+00 4.585e+01 4.672e+01 3.967e+01 6.039e+01 2.063e+01 5.802e+01 7.777e+01
-2.282e+00 1.397e+01-5.469e+01-7.286e+01 7.711e+01 4.258e+01 8.472e+01-1.470e+01
```

The rest of the data has been omitted.

II-2-4 Nonlinear SDOF Structure with Bouc-Wen's Hysteresis : ICON=6

(line no.)

```
 OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
   3
 OBSERVED INPUT EXCIATION
 9.800e-01-1.470e+00 1.470e+00 6.762e+00 1.431e+01 4.920e+01 5.527e+01-2.215e+01
-5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
-9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
-2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
 7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
 1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
-1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
-2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
-3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
 2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01
```

Intermidiate data have been omitted.

```
 DISPLACEMENT RESPONSE
   1
 0.000e+00-1.823e-05 9.168e-05-2.173e-04-2.122e-03-8.232e-03-2.421e-02-4.924e-02
-7.059e-02-8.189e-02-8.840e-02-9.336e-02-1.015e-01-1.170e-01-1.327e-01-1.392e-01
-1.362e-01-1.317e-01-1.293e-01-1.271e-01-1.259e-01-1.297e-01-1.429e-01-1.632e-01
-1.843e-01-2.017e-01-2.167e-01-2.275e-01-2.308e-01-2.289e-01-2.244e-01-2.212e-01
-2.217e-01-2.231e-01-2.204e-01-2.107e-01-1.950e-01-1.762e-01-1.594e-01-1.462e-01
-1.354e-01-1.273e-01-1.208e-01-1.143e-01-1.102e-01-1.134e-01-1.270e-01-1.435e-01
-1.526e-01-1.564e-01-1.576e-01-1.572e-01-1.656e-01-1.896e-01-2.296e-01-2.809e-01
-3.315e-01-3.761e-01-4.146e-01-4.410e-01-4.588e-01-4.780e-01-4.985e-01-5.161e-01
-5.318e-01-5.442e-01-5.477e-01-5.411e-01-5.245e-01-4.967e-01-4.615e-01-4.138e-01
-3.525e-01-2.880e-01-2.237e-01-1.698e-01-1.260e-01-7.175e-02-5.070e-03 7.536e-02
```

Intermidiate data have been omitted.

```
 VELOCITY RESPONSE
   2
 0.000e+00 3.688e-03 3.614e-03-5.793e-02-2.146e-01-6.864e-01-1.458e+00-1.685e+00
-1.078e+00-5.345e-01-3.481e-01-3.678e-01-7.998e-01-1.156e+00-8.058e-01-6.083e-02
 3.322e-01 2.289e-01 1.361e-01 1.451e-01-2.992e-02-5.515e-01-1.173e+00-1.450e+00
-1.294e+00-1.072e+00-9.033e-01-4.766e-01-1.032e-02 2.492e-01 2.992e-01 8.570e-02
-1.169e-01-2.704e-03 4.021e-01 8.693e-01 1.201e+00 1.226e+00 9.992e-01 7.941e-01
 6.256e-01 4.685e-01 4.384e-01 3.949e-01 8.601e-02-5.771e-01-1.134e+00-9.003e-01
-3.762e-01-1.661e-01 3.898e-02-1.480e-01-1.046e+00-2.149e+00-3.151e+00-3.516e+00
-3.179e+00-2.810e+00-2.201e+00-1.366e+00-1.166e+00-1.371e+00-1.287e+00-1.099e+00
-9.865e-01-5.779e-01 1.120e-01 7.556e-01 1.502e+00 2.106e+00 2.693e+00 3.709e+00
 4.272e+00 4.358e+00 4.050e+00 3.092e+00 3.124e+00 4.021e+00 4.976e+00 5.500e+00
```

Intermidiate data have been omitted.

```
 ACCELERATION RESPONSE
   3
 0.000e+00 1.468e+00-1.473e+00-6.723e+00-1.415e+01-4.868e+01-5.412e+01 2.369e+01
 5.723e+01 1.525e+01 9.605e+00-1.219e+01-4.536e+01-2.256e+00 4.893e+01 5.038e+01
 2.087e+00-1.583e+01 3.417e+00-2.197e+00-2.111e+01-4.838e+01-3.454e+01-2.325e+00
 2.296e+01 6.716e+00 1.576e+01 4.108e+01 2.112e+01 1.349e+01-6.777e+00-2.167e+01
-5.365e+00 2.055e+01 3.340e+01 2.889e+01 1.540e+01-1.214e+01-1.804e+01-9.316e+00
-1.314e+01-7.824e+00 3.792e+00-9.572e+00-3.156e+01-5.679e+01-1.751e+01 4.855e+01
 2.136e+01 6.663e+00 2.066e+01-4.548e+01-7.423e+01-7.283e+01-6.066e+01 1.188e+01
 3.300e+01 1.621e+01 6.487e+01 4.644e+01-1.958e+01-7.822e+00 1.896e+01 6.149e+00
 8.857e+00 4.555e+01 4.642e+01 3.939e+01 6.013e+01 2.039e+01 5.781e+01 7.759e+01
-2.431e+00 1.385e+01-5.478e+01-7.293e+01 7.705e+01 4.254e+01 8.470e+01-1.470e+01
```

The rest of the data has been omitted.

II – 3 Output Files for Estimated Parameters (Unit = 6)

II-3-1 Linear MDOF Structure : ICON=1 (Step II in Table 4-I)

(line no.)

```
 SYS-ID FOR 2-DOF, FOR 2ND MODE, ICON=1; W/ 1% NOISE IN VARIANCE

ANALYSIS CASE : ICON====>    1

OUTPUT CONTROL : NCON====>    1

NO. OF GLOBAL ITERATIONS : ITE ====>    5

WEIGHT FOR GLOBAL ITERATION : PITE===>       0.2000e+01

NO. OF DOF OF SYSTEM : N===>    2

DIMENSION OF STATE VECTOR : I1===>   10

NO. OF RESPONSE OBSERVATIONS USED : I2===>    2

DATA OF OBSERVED RECORDS TO BE USED :
  NN= 1000      DT=     0.0150    NM1=     1   NM2= 1000

INITIAL GUESS OF STATE VECTOR : Y2===>
    0.000e+00   0.000e+00   0.745e-01   0.630e+01   0.959e+00   0.000e+00
  0.000e+00   0.500e+00   0.150e+02   0.500e+00

INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11===>
    0.100e+01   0.100e+01   0.000e+00   0.000e+00   0.000e+00   0.100e+01
  0.100e+01   0.100e+01   0.100e+01   0.100e+01

COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1===>
    0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00
  0.000e+00   0.000e+00   0.000e+00   0.000e+00

COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>
    0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01
  0.100e+01   0.100e+01   0.100e+01   0.100e+01

COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2===>
  0.100e+01   0.500e+01

 0.00000e+00 0.00000e+00 0.74500e-01 0.63020e+01 0.95900e+00 0.00000e+00
0.00000e+00 0.50000e+00 0.15000e+02 0.50000e+00
 0.10000e+01 0.10000e+01 0.00000e+00 0.00000e+00 0.00000e+00 0.10000e+01
0.10000e+01 0.10000e+01 0.10000e+01 0.10000e+01

    ***** NUMBER OF ITERATIONS=    1************

INITIAL GUESS OF THE STATE VECTOR =
     0.00000     0.00000     0.07450     6.30200     0.95900     0.00000
   0.00000     0.50000    15.00000     0.50000

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
 -0.7348e+00 -0.4453e+01
OBSERVED AT=  995
 -0.8556e+00 -0.1075e+00
OBSERVED AT= 1000
 -0.8594e+00  0.2417e+01
```

(Appendix II-3-1 Continued)

```
***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
 -0.9843e+00 -0.5515e+01  0.7450e-01  0.6302e+01  0.9590e+00 -0.9621e-01
ESTIMATED AT=  995
 -0.1146e+01 -0.1017e+00  0.7450e-01  0.6302e+01  0.9590e+00 -0.2912e-01
ESTIMATED AT= 1000
 -0.1031e+01  0.3518e+01  0.7450e-01  0.6302e+01  0.9590e+00  0.4832e-01
-----------------------------------------------------------------------------
ESTIMATED AT=  990
  0.2814e+00  0.6699e-01  0.9545e+01  0.3109e+00
ESTIMATED AT=  995
  0.1090e+01  0.6699e-01  0.9545e+01  0.3109e+00
ESTIMATED AT= 1000
  0.1004e+01  0.6692e-01  0.9546e+01  0.3106e+00
-----------------------------------------------------------------------------
THETA= 0.38190711e+00


    ***** NUMBER OF ITERATIONS=     2************


INITIAL GUESS OF THE STATE VECTOR =
     0.00000      0.00000      0.07450      6.30200      0.95900      0.00000
    0.00000      0.06692      9.54597      0.31061

ND3=     1      ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
 -0.7348e+00 -0.4453e+01
OBSERVED AT=  995
 -0.8556e+00 -0.1075e+00
OBSERVED AT= 1000
 -0.8594e+00  0.2417e+01

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
 -0.9930e+00 -0.5665e+01  0.7450e-01  0.6302e+01  0.9590e+00 -0.1090e+00
ESTIMATED AT=  995
 -0.1162e+01 -0.1351e+00  0.7450e-01  0.6302e+01  0.9590e+00 -0.4787e-01
ESTIMATED AT= 1000
 -0.1045e+01  0.3611e+01  0.7450e-01  0.6302e+01  0.9590e+00  0.3360e-01
-----------------------------------------------------------------------------
ESTIMATED AT=  990
  0.1412e+00  0.6877e-01  0.9530e+01  0.3186e+00
ESTIMATED AT=  995
  0.1076e+01  0.6877e-01  0.9530e+01  0.3186e+00
ESTIMATED AT= 1000
  0.1120e+01  0.6873e-01  0.9530e+01  0.3185e+00
-----------------------------------------------------------------------------
THETA= 0.24070369e+00
```

The rest of the data has been omitted.

II-3-2 Linear MDOF Structure : ICON=2 (Step II in Table 4-II)

(line no.)

```
 SYS-ID FOR 2-DOF, FOR 2ND MODE , ICON=2;  W/ 1 % NOISE IN VARIANCE

ANALYSIS CASE : ICON====>    2

OUTPUT CONTROL : NCON====>    1

NO. OF GLOBAL ITERATIONS : ITE ====>    5

WEIGHT FOR GLOBAL ITERATION : PITE===>       0.1000e+03

NO. OF DOF OF SYSTEM : N===>    2

DIMENSION OF STATE VECTOR : I1===>   12

NO. OF RESPONSE OBSERVATIONS USED : I2===>    1

CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED : MC2 ====>      3

DATA OF OBSERVED RECORDS TO BE USED :
  NN= 1000     DT=    0.0150    NM1=    1   NM2= 1000

INITIAL GUESS OF STATE VECTOR : Y2===>
    0.000e+00   0.000e+00   0.000e+00   0.175e+00   0.661e+01   0.112e+01
  0.000e+00   0.000e+00   0.000e+00   0.500e+00   0.150e+02   0.500e+00

INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11===>
    0.100e+01   0.100e+01   0.500e+01   0.000e+00   0.000e+00   0.000e+00
  0.100e+01   0.100e+01   0.500e+01   0.100e+01   0.400e+01   0.100e+01

COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1===>
    0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00
  0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00

COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>
    0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01
  0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01

COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2===>
  0.500e+02

 0.00000e+00 0.00000e+00 0.00000e+00 0.17500e+00 0.66150e+01 0.11210e+01
0.00000e+00 0.00000e+00 0.00000e+00 0.50000e+00 0.15000e+02 0.50000e+00
 0.10000e+01 0.10000e+01 0.50000e+01 0.00000e+00 0.00000e+00 0.00000e+00
0.10000e+01 0.10000e+01 0.50000e+01 0.10000e+01 0.40000e+01 0.10000e+01

   ***** NUMBER OF ITERATIONS=     1************

INITIAL GUESS OF THE STATE VECTOR =
      0.00000      0.00000      0.00000      0.17500      6.61500      1.12100
    0.00000      0.00000      0.00000      0.50000     15.00000      0.50000

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
  0.1267e+03
OBSERVED AT=  995
  0.3679e+02
OBSERVED AT= 1000
  0.6559e+02
```

(Appendix II-3-2 Continued)

```
***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
  0.1238e+03 -0.5463e+00 -0.1108e+01  0.1750e+00  0.6615e+01  0.1121e+01
ESTIMATED AT=  995
 -0.6181e+01  0.4013e+01 -0.9283e+00  0.1750e+00  0.6615e+01  0.1121e+01
ESTIMATED AT= 1000
  0.2790e+02  0.6098e+01 -0.5565e+00  0.1750e+00  0.6615e+01  0.1121e+01
-----------------------------------------------------------------------
ESTIMATED AT=  990
 -0.2606e+02  0.1899e+01  0.3014e+00  0.1288e-01  0.9617e+01  0.2557e-01
ESTIMATED AT=  995
 -0.3213e+02 -0.4439e+00  0.3473e+00  0.1323e-01  0.9615e+01  0.2635e-01
ESTIMATED AT= 1000
 -0.1881e+02 -0.2463e+01  0.2200e+00  0.1360e-01  0.9615e+01  0.2716e-01
-----------------------------------------------------------------------
THETA= 0.00000000e+00


   ***** NUMBER OF ITERATIONS=    2************

INITIAL GUESS OF THE STATE VECTOR =
     0.00000      0.00000      0.00000      0.17500      6.61500      1.12100
    0.00000      0.00000      0.00000      0.01360      9.61546      0.02716

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
  0.1267e+03
OBSERVED AT=  995
  0.3679e+02
OBSERVED AT= 1000
  0.6559e+02

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
  0.1338e+03 -0.5463e+00 -0.1108e+01  0.1750e+00  0.6615e+01  0.1121e+01
ESTIMATED AT=  995
 -0.3464e+01  0.4013e+01 -0.9283e+00  0.1750e+00  0.6615e+01  0.1121e+01
ESTIMATED AT= 1000
  0.2840e+02  0.6098e+01 -0.5565e+00  0.1750e+00  0.6615e+01  0.1121e+01
-----------------------------------------------------------------------
ESTIMATED AT=  990
 -0.1608e+02  0.1982e+01  0.2435e+00  0.1759e-01  0.9556e+01  0.7631e-01
ESTIMATED AT=  995
 -0.2941e+02  0.4023e-01  0.3179e+00  0.1783e-01  0.9555e+01  0.7685e-01
ESTIMATED AT= 1000
 -0.1831e+02 -0.1876e+01  0.2353e+00  0.1813e-01  0.9554e+01  0.7751e-01
-----------------------------------------------------------------------
THETA= 0.00000000e+00
```

The rest of the data has been omitted.

II-3-3 Linear MDOF Structure : ICON=3 (Step II in Table 4-III)

(line no.)

```
ID FOR 2-D,ICON=3;for NONLIN. para. only,H(w) from Displ,W/ 1% NOISE IN
ANALYSIS CASE : ICON====>    3
OUTPUT CONTROL : NCON====>    1
NO. OF GLOBAL ITERATIONS : ITE ====>    5
WEIGHT FOR GLOBAL ITERATION : PITE===>       0.1000e+02
NO. OF DOF OF SYSTEM : N===>    2
DIMENSION OF STATE VECTOR : I1===>    6
NO. OF RESPONSE OBSERVATIONS USED : I2===>    2
DATA OF OBSERVED RECORDS TO BE USED :
  NN=  350      DT=    0.1023    NM1=    11   NM2=  170
INITIAL GUESS OF STATE VECTOR : Y2===>
   0.557e-01   0.619e+01   0.766e+00   0.500e+00   0.150e+02   0.500e+00
INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11===>
   0.000e+00   0.000e+00   0.000e+00   0.100e+00   0.400e+01   0.100e+01
COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1===>
   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00
COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>
   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01
COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2===>
  0.100e+00   0.100e+00
 0.55700e-01 0.61860e+01 0.76600e+00 0.50000e+00 0.15000e+02 0.50000e+00
 0.00000e+00 0.00000e+00 0.00000e+00 0.10000e+00 0.40000e+01 0.10000e+01
   ***** NUMBER OF ITERATIONS=     1************
INITIAL GUESS OF THE STATE VECTOR =
     0.05570     6.18600     0.76600     0.50000     15.00000     0.50000
ND3=   11      ND5=  170
***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
OBSERVED AT=  150
  0.7073e-02  0.5897e-02
OBSERVED AT=  155
  0.3881e-02  0.7278e-03
OBSERVED AT=  160
  0.3422e-02 -0.1981e-03
***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
ESTIMATED AT=  150
  0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5083e+00
ESTIMATED AT=  155
  0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5081e+00
ESTIMATED AT=  160
  0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5078e+00
-----------------------------------------------------------------------
THETA= 0.24053818e+07
```

```
    ***** NUMBER OF ITERATIONS=    2************

INITIAL GUESS OF THE STATE VECTOR =
     0.05570     6.18600     0.76600     0.50083    14.99316     0.50783

ND3=   11     ND5=  170

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  150
  0.7073e-02  0.5897e-02
OBSERVED AT=  155
  0.3881e-02  0.7278e-03
OBSERVED AT=  160
  0.3422e-02 -0.1981e-03

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  150
  0.5570e-01  0.6186e+01  0.7660e+00  0.5122e+00  0.1492e+02  0.5701e+00
ESTIMATED AT=  155
  0.5570e-01  0.6186e+01  0.7660e+00  0.5124e+00  0.1492e+02  0.5688e+00
ESTIMATED AT=  160
  0.5570e-01  0.6186e+01  0.7660e+00  0.5126e+00  0.1492e+02  0.5664e+00
-----------------------------------------------------------------------
THETA= 0.29459793e+07


    ***** NUMBER OF ITERATIONS=    3************

INITIAL GUESS OF THE STATE VECTOR =
     0.05570     6.18600     0.76600     0.51257    14.91778     0.56638

ND3=   11     ND5=  170

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  150
  0.7073e-02  0.5897e-02
OBSERVED AT=  155
  0.3881e-02  0.7278e-03
OBSERVED AT=  160
  0.3422e-02 -0.1981e-03

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  150
  0.5570e-01  0.6186e+01  0.7660e+00  0.6525e+00  0.1392e+02  0.7811e+00
ESTIMATED AT=  155
  0.5570e-01  0.6186e+01  0.7660e+00  0.6539e+00  0.1392e+02  0.7774e+00
ESTIMATED AT=  160
  0.5570e-01  0.6186e+01  0.7660e+00  0.6545e+00  0.1391e+02  0.7705e+00
-----------------------------------------------------------------------
THETA= 0.31820210e+07
```

The rest of the data has been omitted.

II-3-4 Nonlinear SDOF Structure with Bilinear Hysteresis : ICON=5 (Step II in Table 4-IV)

(line no.)

```
 SYS-ID FOR 1-D BILIN. ICON=5, FOR NONLIN PARA.; W/ NO NOISE

ANALYSIS CASE : ICON====>    5

OUTPUT CONTROL : NCON====>    1

NO. OF GLOBAL ITERATIONS : ITE ====>    5

WEIGHT FOR GLOBAL ITERATION : PITE===>       0.2000e+01

NO. OF DOF OF SYSTEM : N===>    1

DIMENSION OF STATE VECTOR : I1===>    6

NO. OF RESPONSE OBSERVATIONS USED : I2===>    2

DATA OF OBSERVED RECORDS TO BE USED :
  NN= 1000      DT=    0.0150     NM1=     1   NM2= 1000

INITIAL GUESS OF STATE VECTOR : Y2===>
   0.000e+00   0.000e+00   0.980e-01   0.316e+01   0.100e+01   0.500e+00

INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11===>
   0.100e+01   0.100e+01   0.000e+00   0.000e+00   0.100e+01   0.100e+01

COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1===>
   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00

COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>
   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01

COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2===>
  0.100e+01   0.100e+01

 0.00000e+00 0.00000e+00 0.98000e-01 0.31600e+01 0.10000e+01 0.50000e+00
 0.10000e+01 0.10000e+01 0.00000e+00 0.00000e+00 0.10000e+01 0.10000e+01

   ***** NUMBER OF ITERATIONS=     1************

INITIAL GUESS OF THE STATE VECTOR =
     0.00000     0.00000     0.09800     3.16000     1.00000     0.50000

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
  0.8194e+00 -0.4046e+01
OBSERVED AT=  995
  0.5885e+00 -0.3076e+01
OBSERVED AT= 1000
  0.3485e+00 -0.2889e+01

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
  0.1336e+01 -0.4257e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1417e+00
ESTIMATED AT=  995
  0.1087e+01 -0.3343e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1416e+00
ESTIMATED AT= 1000
  0.8251e+00 -0.3192e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1415e+00
----------------------------------------------------------------------
THETA= 0.13464621e+01
```

```
  ***** NUMBER OF ITERATIONS=    2************

INITIAL GUESS OF THE STATE VECTOR =
    0.00000     0.00000     0.09800     3.16000     3.11378     0.14153

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
  0.8194e+00 -0.4046e+01
OBSERVED AT=  995
  0.5885e+00 -0.3076e+01
OBSERVED AT= 1000
  0.3485e+00 -0.2889e+01

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
  0.1010e+01 -0.4192e+01  0.9800e-01  0.3160e+01  0.3088e+01  0.1179e+00
ESTIMATED AT=  995
  0.7666e+00 -0.3256e+01  0.9800e-01  0.3160e+01  0.3088e+01  0.1179e+00
ESTIMATED AT= 1000
  0.5122e+00 -0.3089e+01  0.9800e-01  0.3160e+01  0.3088e+01  0.1179e+00
-----------------------------------------------------------------------
THETA= 0.23372850e+01


  ***** NUMBER OF ITERATIONS=    3************

INITIAL GUESS OF THE STATE VECTOR =
    0.00000     0.00000     0.09800     3.16000     3.08817     0.11787

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
  0.8194e+00 -0.4046e+01
OBSERVED AT=  995
  0.5885e+00 -0.3076e+01
OBSERVED AT= 1000
  0.3485e+00 -0.2889e+01

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
  0.9381e+00 -0.4197e+01  0.9800e-01  0.3160e+01  0.3070e+01  0.1087e+00
ESTIMATED AT=  995
  0.6948e+00 -0.3253e+01  0.9800e-01  0.3160e+01  0.3070e+01  0.1087e+00
ESTIMATED AT= 1000
  0.4410e+00 -0.3077e+01  0.9800e-01  0.3160e+01  0.3070e+01  0.1087e+00
-----------------------------------------------------------------------
THETA= 0.24773815e+01
```

The rest of the data has been omitted.

II-3-5 Nonlinear SDOF Structure with Bouc-Wen's Hysteresis : ICON=6 (Step II in Table 4-V)

(line no.)

```
 SYS-ID FOR 1-D BOUC-WEN HYSTERE. ICON=6, FOR NONLIN PARA. ONLY; W/O NOIS

ANALYSIS CASE : ICON====>    6

OUTPUT CONTROL : NCON====>    1

NO. OF GLOBAL ITERATIONS : ITE ====>    5

WEIGHT FOR GLOBAL ITERATION : PITE===>       0.2000e+01

NO. OF DOF OF SYSTEM : N===>    1

DIMENSION OF STATE VECTOR : I1===>   12

NO. OF RESPONSE OBSERVATIONS USED : I2===>    2

DATA OF OBSERVED RECORDS TO BE USED :
  NN= 1000     DT=    0.0150    NM1=    1   NM2= 1000

INITIAL GUESS OF STATE VECTOR : Y2===>
   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.105e+00   0.318e+01
  0.000e+00   0.000e+00   0.100e+01   0.000e+00   0.000e+00   0.000e+00

INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11===>
   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.000e+00   0.000e+00
  0.100e+01   0.100e+01   0.000e+00   0.000e+00   0.000e+00   0.000e+00

COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1===>
   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00
  0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00   0.000e+00

COEFFICIENT MATRIX OF SYSTEM NOISE : G11===>
   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01
  0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01   0.100e+01

COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2===>
  0.100e+01   0.100e+01

 0.00000e+00 0.00000e+00 0.00000e+00 0.00000e+00 0.10500e+00 0.31770e+01
0.00000e+00 0.00000e+00 0.10000e+01 0.00000e+00 0.00000e+00 0.00000e+00
 0.10000e+01 0.10000e+01 0.10000e+01 0.10000e+01 0.00000e+00 0.00000e+00
0.10000e+01 0.10000e+01 0.00000e+00 0.00000e+00 0.00000e+00 0.00000e+00

   ***** NUMBER OF ITERATIONS=    1************

INITIAL GUESS OF THE STATE VECTOR =
     0.00000     0.00000     0.00000     0.00000     0.10500     3.17700
    0.00000     0.00000     1.00000     0.00000     0.00000     0.00000

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
 -0.1717e+00 -0.2122e+01
OBSERVED AT=  995
 -0.2463e+00 -0.8555e+00
OBSERVED AT= 1000
 -0.3128e+00 -0.5041e+00
```

```
***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
 -0.2640e+00 -0.2102e+01  0.3399e+00  0.2969e+03  0.1050e+00  0.3177e+01
ESTIMATED AT=  995
 -0.3364e+00 -0.8896e+00  0.2681e+00  0.2966e+03  0.1050e+00  0.3177e+01
ESTIMATED AT= 1000
 -0.4009e+00 -0.5800e+00  0.2001e+00  0.2964e+03  0.1050e+00  0.3177e+01
------------------------------------------------------------------------
ESTIMATED AT=  990
  0.7190e-01  0.2561e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
ESTIMATED AT=  995
  0.7189e-01  0.2561e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
ESTIMATED AT= 1000
  0.7187e-01  0.2563e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
------------------------------------------------------------------------
THETA= 0.22151820e+00


   ***** NUMBER OF ITERATIONS=    2************

INITIAL GUESS OF THE STATE VECTOR =
     0.00000     0.00000     0.00000     0.00000     0.10500     3.17700
    0.07187     0.25627     1.00000     0.00000     0.00000     0.00000

ND3=    1     ND5= 1000

***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***

OBSERVED AT=  990
 -0.1717e+00 -0.2122e+01
OBSERVED AT=  995
 -0.2463e+00 -0.8555e+00
OBSERVED AT= 1000
 -0.3128e+00 -0.5041e+00

***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***

ESTIMATED AT=  990
 -0.2278e+00 -0.1673e+01  0.2918e+00  0.3041e+03  0.1050e+00  0.3177e+01
ESTIMATED AT=  995
 -0.2748e+00 -0.4721e+00  0.2512e+00  0.3041e+03  0.1050e+00  0.3177e+01
ESTIMATED AT= 1000
 -0.3190e+00 -0.2029e+00  0.2124e+00  0.3040e+03  0.1050e+00  0.3177e+01
------------------------------------------------------------------------
ESTIMATED AT=  990
  0.7211e-01  0.2573e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
ESTIMATED AT=  995
  0.7212e-01  0.2573e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
ESTIMATED AT= 1000
  0.7214e-01  0.2573e+00  0.1000e+01  0.0000e+00  0.0000e+00  0.0000e+00
------------------------------------------------------------------------
THETA= 0.18674874e+00
```

The rest of the data has been omitted.

APPENDIX III-1

FORTRAN LISTING OF PROGRAM SRESP

```
      PROGRAM SRESP
C
C*****************************************************************
C                           PROGRAM SRESP
C*****************************************************************
C       A COMPUTER PROGRAM FOR SIMULATING RESPONSE OBSERVATION
C        RECORDS WHICH WILL BE USED FOR SYSTEM IDENTIFICATION.
C*****************************************************************
C          THIS PROGRAM IS  ORIGINALLY CODED BY DR.O.MARUYAMA
C              UNDER THE GUIDANCE OF PROF. M. HOSHIYA
C              DEPARTMENT OF CIVIL ENGINEERING
C              MUSASHI INSTITUTE OF TECHNOLOGY
C              1-28-1, TAMAZUTSUMI SETAGAYA-KU,
C                     TOKYO 158,JAPAN
C ----------------------------------------------------------------
C                   LATER REVISED BY DR.O.MARUYAMA
C             UNDER THE SUPERVISION OF PROF. M.SHINOZUKA
C      DEPARTMENT OF CIVIL ENGINEERING AND OPERATIONS RESEARCH
C               SCHOOL OF ENGINEERING/APPLIED SCIENCE
C       PRINCETON UNIVERSITY PRINCETON, N.J. 08544, U.S.A.
C
C             THIS IS VERSION **** SRESP *************
C                      (04, JANUARY 1989)
C******************************************************************
C
C  *  PURPOSE:
C  *        TO  GENERATE  SIMULATED RESPONSE OBSERVATION RECORDS
C  *  FOR A LINEAR MULTI-DEGREE OF FREEDOM SYSTEM OR  A NONLINEAR
C  *  SINGLE DEGREE OF FREEDOM SYSTEM UNDER EARTHQUAKE EXCITATION.
C  *  INPUT GROUND ACCELERATION RECORD  AND  SIMULATED  RESPONSE
C  *  OBSERVATION RECORDS OF RELATIVE DISPLACEMENT, VELOCITY AND
C  *  ACCELERATION   WILL BE STORED  IN DATA FILE (UNIT=7)   FOR
C  *  PARAMETER IDENTIFICATION BY USING PROGRAM EXKAL2.
C
C******************************************************************
C
C   INPUT DATA FILES
C
C      GENERAL INPUT DATA :  UNIT=2
C
C      INPUT GROUND ACCELERATION :  UNIT=7
C        INPUT DATA MUST FURNISHED AS
C          1. TITLE CARD OF INPUT EXCITATION
C          2. GROUND ACCELERATION DATA CARDS WITH A FORMAT OF 8(1PE10.3)
C
C   OUTPUT DATA FILES
C
C      GENERAL OUTPUT :  UNIT=6
C
C      FOR SYSTEM IDENTIFICATION : UNIT=8
C
C      FOR PLOTTING EXCITATION/RESPONSE RECORDS : UNIT=31-35
C
C   SYSTEM SUBROUTINES REQUIRIED
C
C      GGUBS AND GGNML FROM IMLS : FOR RANDOM NUMBER GENERATION
C
C*********************************************************************
C                 DISCRIPTION OF INPUT DATA IN UNIT 2
C                       ***  FREE  FORMAT  ***
```

```
C*********************************************************************
C
C   1. HEADING CARD
C
C   2. MASTER CONTROL CARD ; ICOM, NCOM, KCOM
C
C      ICOM: ANALYSIS CASE
C        ICOM=1 : LINEAR MULTI-DEGREE OF FREEDOM SYSTEM
C        ICOM=2 : SINGLE-DEGREE OF FREEDOM SYSTEM WITH BILINEAR SPRING
C                                                     (NON-HYSTERETIC)
C        ICOM=3 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BILINEAR HYSTERESIS
C        ICOM=4 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BOUC AND WEN'S
C                 HYSTERETIC MODEL
C
C      NCOM: OUTPUT CONTROL
C        NCOM=1 : GENERATING  OUTPUT  DATA  FILE  (UNIT=8)   FOR SYSTEM
C                 IDENTIFICATION  BY USING PROGRAM EXKAL2.
C                 UNIT 8 INCLUDES INPUT EXCITATION AND RELATIVE DISPLACEMENT,
C                 VELOCITY AND ACCELERATION OF STRUCTURE TO GROUND MOTION.
C
C        NCOM=2 : GENERATING OUTPUT DATA FILES (UNIT= 31-34)  FOR PLOTTING
C                 EXCITATION/RESPONSE OBSERVATIONS.
C                 UNIT=31   : INPUT EXCIATION
C                 UNIT=32   : RELATIVE DISPLACEMENT OF STRUCTURE
C                 UNIT=33   : RELATIVE VELOCITY OF STRUCTURE
C                 UNIT=34   : RELATIVE ACCELERATION OF STRUCTURE
C
C        NCOM=3 : GENERATING OUTPUT DATA FILE (UNIT= 35)  FOR PLOTTING
C                 HYSTERETIC BEHAVOIR
C
C     KCOM: NOISE CONTROL
C        KCOM=1 : NOISE IMPOSED RESPONSE OBSERVATIONS
C        OTHERWISE : NOISE  FREE
C
C   ----------------------------------------------------------------
C
C   3. CONTROL CARD :  N,NN,DT,XN
C
C        N  : NUMBER OF MODES USED FOR IDENTIFICATION OF LINEAR MDOF SYSTEM
C             OR  NUMBER OF MOF (=1)  FOR NONLINEAR SMDOF SYSTEM
C        NN : TOTAL NUMBER OF DATA POINTS IN INPUT EXCITATION RECORD
C             AS WELL AS OUTPUT RESPONSE RECORDS TO BE GENERATED
C        DT : TIME INCREMENT IN DATA (SEC)
C        XN : SCALE FACTOR FOR INPUT EXCIATION IN UNIT=7
C
C   ----------------------------------------------------------------
C
C   4. LINEAR PARAMETER CARDS : BETA1(I),OME(I),PA1(I), I=1,N
C       ( N-CARDS MUST BE SUPPLIED FOR MDOF SYSTEM ANALYZED USING N-MODES.)
C        BETA1(I): MODAL DAMPING RATIO FOR I-TH MODE
C        OME1(I) : NATURAL CIRCULAR FREQUENCY FOR I-TH MODE (RAD/SEC)
C        PA1(I)  :
C            IF ICOM=1, PATICIPATION FACTOR FOR I-TH MODE AT THE NODE
C                       WHERE RESPONSE OBSERVATION IS MADE,
C            OTHERWISE, MAY BE OMITTED.
C
C   ----------------------------------------------------------------
C
C   5. NONLINEAR PARAMETER CARD : REQUIRED ONLY FOR ICOM= 2, 3 OR 4
C
```

```
C        IF ICOM =2 OR 3 (BILINEAR SPRING,NON-HYSTERETIC OR HYSTERESIS);
C             U1  : YIELDING DISPLACEMENT
C            AA2  : RATIO OF POST-YIELDING STIFFNESS TO
C                   PRE-YIELDING STIFFNESS
C
C        IF ICOM =4 (BOUC-WEN'S HYSTERESIS,SECTION 3-4);
C            BE,GA,CA,CV,CN: PARAMETERS FOR BOUC-WEN'S MODEL
C
C           NOTE :
C               BE=BETA; GA=GAMMA; CA=DELTA A; CV= DELTA NU; CN=DELTA ETA.
C               PARAMETER A0 AND N HAVE BEEN FIXED AS A0=1.0 AND N=1.
C
C   -----------------------------------------------------------------
C
C   6. OBSERVATION NOISE DATA CARD : REQUIRED ONLY FOR KCOM =1
C
C              Y1 : LOWER RANGE OF GAUSSIAN WHITE NOISE IN HZ
C              Y2 : UPPER RANGE OF GAUSSIAN WHITE NOISE IN HZ
C              PA : NOISE RATIO TO STRUCTURAL RESPONSE IN VARIANCE
C
C*********************************************************************
C
C
      DIMENSION YA(3000),YV(3000),YD(3000),F(3000),Z(3000)
      DIMENSION XD(3000),FF(3000),YA1(3000),YV1(3000)
      DIMENSION YD1(3000),BETA1(20),OME1(20),PA1(20)
      DATA N1/3000/
C
C     ---   NUMERICAL VALUE OF THE PARAMETERS OF THE MODEL ------
C                         FROM UNIT=2
      CALL READA(AM,AC,AK1,AK2,U1,DT,N,NN,ICOM,AA,BE,GA,AZ,XN,NCOM
     *          ,GN,VV,CA,CN,CV,OME,Y1,Y2,PA,BETA1,OME1,PA1,KCOM)
C
      DO 500 I=1,N1
      YA(I)=0.0
      YV(I)=0.0
      YD(I)=0.0
      YA1(I)=0.0
      YV1(I)=0.0
      YD1(I)=0.0
      F(I) =0.0
      FF(I)=0.0
      XD(I)=0.0
      Z(I) =0.0
  500 CONTINUE
C
C     ----  READ INPUT EXCITATION -----
C             FROM UNIT=7
      CALL READB(Z,NN,N1,XN)
C     --------------------------------
      IF(ICOM.EQ.1) GO TO 10
      IF(ICOM.EQ.2) GO TO 20
      IF(ICOM.EQ.3) GO TO 30
      IF(ICOM.EQ.4) GO TO 40
C
   10 CONTINUE
C     --- RESTORING FORCE CHARACTERISTIC ===> LINEAR --
C
      DO 200 I=1,N
      AC=2.0*BETA1(I)*OME1(I)
```

```
      AK1=OME1(I)*OME1(I)
      PPA=PA1(I)
      CALL LINE(AM,AC,AK1,PPA,YA1,YV1,YD1,Z,NN,DT,N1,F)
C
      DO 300 II=1,NN
      YA(II)=YA(II)+YA1(II)
      YV(II)=YV(II)+YV1(II)
      YD(II)=YD(II)+YD1(II)
  300 CONTINUE
  200 CONTINUE
      GO TO 50
C
   20 CONTINUE
C     --- RESTORING FORCE CHARACTERISTIC ===> NONLINEAR SPRING --
C                                              (NO HYSTERESIS)
      CALL NOSP(AM,AC,AK1,AK2,U1,YA,YV,YD,Z,NN,DT,N1,F)
      GO TO 50
C
   30 CONTINUE
C     --- RESTORING FORCE CHARACTERISTIC ===> BILINEAR HYSTERESIS  --
C
      CALL BILI(AM,AC,AK1,AK2,U1,DT,YA,YV,YD,Z,NN,N1,F)
      GO TO 50
C
   40 CONTINUE
C     --- RESTORING FORCE CHARACTERISTIC ===> BOUC-WEN'S HYSTERESIS --
C
      CALL VERS(YD,YV,YA,Z,XD,AM,AC,AK1,AA,BE,GA,AZ,N1,DT,KK,NN,F
     *          ,GN,VV,CA,CN,CV)
C
   50 CONTINUE
C
      DO 51 I=1,NN
      FF(I)=F(I)/(OME*OME)
   51 CONTINUE
C
      IF(KCOM.EQ.1) THEN
      CALL NOISE1(Y1,Y2,PA,YD,YV,YA,N1,NN,DT,KCOM)
C
      DD1=OME*OME
      DO 11 I=1,NN
      FF(I)=-(AM*Z(I)+AM*YA(I)+AC*YV(I))/DD1
   11 CONTINUE
      END IF
C
      CALL WRITEB(Z,YD,YV,YA,FF,N1,NN,DT,NCOM)
C
      STOP
      END
C
C     ******************** SUBROUTINE READA ***********************
C     *                                                           *
C     *   SUBROUTINE FOR READING GENERAL INPUT DATA  FROM UNIT 2  *
C     *             CALLED BY THE MAIN PROGRAM                    *
C     *************************************************************
C
      SUBROUTINE READA(AM,AC,AK1,AK2,U1,DT,N,NN,ICOM,AA,BE,GA,AZ,XN,NCOM
     *      ,GN,VV,CA,CN,CV,OME,Y1,Y2,PA,BETA1,OME1,PA1,KCOM)
C
      CHARACTER*72 TEXT
```

```
      DIMENSION BETA1(20),OME1(20),PA1(20)
C
      READ(2,1200) TEXT
      WRITE(6,1201) TEXT
 1200 FORMAT(72A)
 1201 FORMAT(2X,72A)
C
      READ(2,*) ICOM,NCOM,KCOM
      WRITE(6,1202) ICOM,NCOM,KCOM
 1202 FORMAT(/2X,'ICOM,NCOM,KCOM = ',5X,3I5/)
C
      READ(2,*) N,NN,DT,XN
      WRITE(6,1203) N,NN,DT,XN
 1203 FORMAT(/2X,'N,NN,DT,XN =',5X,2I5,2E11.3/)
C
      DO 100 I=1,N
      IF (ICOM.EQ.1) READ(2,*) BETA1(I),OME1(I) ,PA1(I)
      IF (ICOM.NE.1) READ(2,*) BETA1(I),OME1(I)
      WRITE(6,1204) BETA1(I),OME1(I) ,PA1(I)
 1204 FORMAT(/2X,'LINEAR PARAMETERS; BETA(I),OME1(I),PA1(I)=',
     1         1X,3E11.3/)
  100 CONTINUE
C
      IF (ICOM.EQ.2.OR.ICOM.EQ.3) THEN
      READ(2,*) U1, AA2
      WRITE(6,1205) U1, AA2
 1205 FORMAT(/2X,'NONLINEAR PARAMETERS; U1,AA2 =',1X,2E11.3/)
      END IF
      IF(ICOM.EQ.4) THEN
      READ(2,*) BE,GA,CA,CV,CN
      WRITE(6,1206) BE,GA,CA,CV,CN
 1206 FORMAT(/2X,'BOUC-WEN MODEL; BE,GA,CA,CV,CN ='/5X,5E11.3/)
      END IF
C
      IF(KCOM.EQ.1) THEN
      READ(2,*) Y1 ,Y2 ,PA
      WRITE(6,1207) Y1 ,Y2 ,PA
 1207 FORMAT(/2X,'OBSERVATION NOISE DATA; Y1,Y2,PA=',1X,3E11.3)
      END IF
C
      AM=1.0
      AA=1.0
      GN=1.0
      VV=1.0
      AZ=1.0
C
      IF(N.EQ.1) THEN
      BETA=BETA1(1)
      OME=OME1(1)

      AC=2.0*BETA*OME
C
      AK1=OME*OME
      AK2=AA2*OME*OME
      END IF
C
      RETURN
      END
C
C     **************** SUBROUTINE READB **********************
```

```
C     *                                                         *
C     * SUBROUTINE FOR READING INPUT EXCIATION FROM UNIT 7     *
C     *              CALLED BY THE MAIN PROGRAM                 *
C     ***********************************************************
C
      SUBROUTINE READB(Z,NN,N1,XN)
      CHARACTER*72 TEXT
      DIMENSION Z(N1),Z1(3000)
C
C
      READ (7,101) TEXT
      WRITE(6,102) TEXT
  101 FORMAT(72A)
  102 FORMAT(2X,72A//)
C
      READ(7,100)  (Z(KK),KK=1,NN)
  100 FORMAT(8(1PE10.3))
C
      DO 10 KK=1,NN
      Z1(KK)=XN*Z(KK)
   10 CONTINUE
C
      DO 20 KK=1,NN
      Z(KK)=Z1(KK)
   20 CONTINUE
C
      RETURN
      END
C
C     ********************* SUBROUTINE LINE *********************
C     *                                                          *
C     * SUBROUTINE FOR A LINEAR MULTI-DEGREE OF FREEDOM SYSTEM   *
C     *              CALLED BY  THE MAIN PROGRAM                 *
C     ************************************************************
C
      SUBROUTINE LINE(AM,AC,AK,PA,YA,YV,YD,Z,NN,DT,N1,F)
      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1),F(N1)
C
      DO 5 I=1,NN
      YA(I)=0.0
      YV(I)=0.0
      YD(I)=0.0
    5 CONTINUE
C
C
      DO 10 KK=1,NN
C
      A1=-AM*PA*Z(KK+1)-AK*YD(KK)
      A2=-YV(KK)*(AC+DT*AK)
      A3=-YA(KK)*(DT*AC/2.0+(DT*DT)*AK/3.0)
      A4=AM+DT*AC/2.0+(DT*DT)*AK/6.0
C
      AA1=(A1+A2+A3)/A4
      YA(KK+1)=AA1
C
      A5=DT/2.0
      A6=(DT*DT)/3.0
      A7=(DT*DT)/6.0
C
      YV(KK+1)=YV(KK)+A5*YA(KK)+A5*AA1
```

```
      YD(KK+1)=YD(KK)+DT*YV(KK)+A6*YA(KK)+A7*AA1
      F(KK)=AK*YD(KK)
C
   10 CONTINUE
C
      RETURN
      END
C
C     ******************** SUBROUTINE NOSP ***********************
C     *                                                          *
C     *   SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH  *
C     *   A NONLINEAR SPRING (NON-HYSTERETIC)                    *
C     *               CALLED BY THE MAIN PROGRAM                 *
C     ************************************************************
      SUBROUTINE NOSP(AM,AC,AK1,AK2,U1,YA,YV,YD,Z,NN,DT,N1,F)
      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
      DIMENSION F(N1)
C
      A1=DT/2.0
      A2=(DT*DT)/3.0
      AK3=(AK1-AK2)*U1
C
      DO 10 KK=1,NN
C
      UK=ABS(YD(KK))
      IF(UK.LE.U1) GO TO 20
      IF(YD(KK).LT.-U1) GO TO 30
      IF(YD(KK).GT.U1) GO TO 40
C
   20 CONTINUE
      A3=AM*Z(KK+1)+AK1*YD(KK)
      A4=YV(KK)*(AC+DT*AK1)
      A5=YA(KK)*(A1*AC+A2*AK1)
      A6=AM+A1*AC+(DT*DT)*AK1/6.0
      AA1=-(A3+A4+A5)/A6
      YA(KK+1)=AA1
C
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE(YA,YV,YD,Z,DT,N1,KK,U1,1,AM,AC,AK1,AK2)
      GO TO 50
C
   30 CONTINUE
      A3=AM*Z(KK+1)+AK2*YD(KK)
      A4=YV(KK)*(AC+DT*AK2)
      A5=YA(KK)*(A1*AC+A2*AK2)
      A6=AM+A1*AC+(DT*DT*AK2)/6.0
      AA1=-(A3+A4+A5-AK3)/A6
      YA(KK+1)=AA1
C
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE(YA,YV,YD,Z,DT,N1,KK,U1,2,AM,AC,AK1,AK2)
      GO TO 50
C
   40 CONTINUE
      A3=AM*Z(KK+1)+AK2*YD(KK)
      A4=YV(KK)*(AC+DT*AK2)
      A5=YA(KK)*(A1*AC+A2*AK2)
      A6=AM+A1*AC+(DT*DT)*AK2/6.0
      AA1=-(A3+A4+A5+AK3)/A6
      YA(KK+1)=AA1
```

```
C
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE(YA,YV,YD,Z,DT,N1,KK,U1,2,AM,AC,AK1,AK2)
   50 CONTINUE
C
      CC1=YD(KK+1)
      CALL RES1(CC1,U1,AK1,AK2,F,KK,N1)
C
   10 CONTINUE
      RETURN
      END
C
C     ********************* SUBROUTINE REVD ***********************
C     *                                                           *
C     *   SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM  WITH  *
C     *   A BILINEAR SPRING(NON-HYSTERETIC)                       *
C     *                  CALLED BY SUBROUTINE NOSP                *
C     *************************************************************
      SUBROUTINE REVD(AA1,YA,YV,YD,DT,N1,KK)
      DIMENSION YA(N1),YV(N1),YD(N1)
C
      A1=DT/2.0
      A2=(DT*DT)/3.0
      A3=(DT*DT)/6.0
C
      YV(KK+1)=YV(KK)+A1*YA(KK)+A1*AA1
      YD(KK+1)=YD(KK)+DT*YV(KK)+A2*YA(KK)+A3*AA1
C
      RETURN
      END
C
C     ********************* SUBROUTINE TUNE ***********************
C     *                                                           *
C     *   SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH   *
C     *   A BILINEAR SPRING(NON-HYSTERETIC)                       *
C     *               CALLED BY SUBROUTINE NOSP                   *
C     *************************************************************
      SUBROUTINE TUNE(YA,YV,YD,Z,DT,N1,KK,U1,ICOM,AM,AC,AK1,AK2)
      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
C
C
      IF(ICOM.EQ.1) GO TO 10
      IF(ICOM.EQ.2) GO TO 20
C
   10 CONTINUE
      X=ABS(YD(KK+1))
      X1=YD(KK+1)
C
      IF(X.LE.U1) THEN
      GO TO 100
      ELSE
C
      IF(X1.GT.0.0) THEN
      YYD=U1
      DTT=(YYD-YD(KK))/YV(KK)
      YYV=YV(KK)+DTT*YA(KK)
      YYA=-(AC*YYV+AK1*U1+AM*Z(KK))/AM
C
      DTA=DT-DTT
      B1=DTA/2.0
```

```
      B2=DTA*DTA/3.0
      B3=DTA*DTA/6.0
C
      A1=AM*Z(KK+1)+AK2*YYD
      A2=YYV*(AC+DTA*AK2)
      A3=YYA*(B1*AC+B2*AK2)
      A4=(AK1-AK2)*U1
      A5=AM+B1*AC+B3*AK2
      YY1=-(A1+A2+A3+A4)/A5
      YY2=YYV+B1*YYA+B1*YY1
      YY3=YYD+DTA*YYV+B2*YYA+B3*YY1
      YA(KK+1)=YY1
      YV(KK+1)=YY2
      YD(KK+1)=YY3
C
      ELSE
      YYD=-U1
      DTT=(YYD-YD(KK))/YV(KK)
      YYV=YV(KK)+DTT*YA(KK)
      YYA=-(AC*YYV-AK1*U1+AM*Z(KK))/AM
C
      DTA=DT-DTT
      B1=DTA/2.0
      B2=DTA*DTA/3.0
      B3=DTA*DTA/6.0
C
      A1=AM*Z(KK+1)+AK2*YYD
      A2=YYV*(AC+DTA*AK2)
      A3=YYA*(B1*AC+B2*AK2)
      A4=-(AK1-AK2)*U1
      A5=AM+B1*AC+B3*AK2
      YY1=-(A1+A2+A3+A4)/A5
      YY2=YYV+B1*YYA+B1*YY1
      YY3=YYD+DTA*YYV+B2*YYA+B3*YY1
      YA(KK+1)=YY1
      YV(KK+1)=YY2
      YD(KK+1)=YY3
      END IF
      END IF
      GO TO 100
C
   20 CONTINUE
      X=ABS(YD(KK+1))
      X1=YD(KK+1)
C
      IF(X.GE.U1) THEN
      GO TO 100
      ELSE
C
      IF(X1.GT.0.0) THEN
      YYD=U1
      ELSE
      YYD=-U1
      END IF
C
      DTT=(YYD-YD(KK))/YV(KK)
      YYV=YV(KK)+DTT*YA(KK)
      YYA=-(AC*YYV+AK2*YYD+(AK1-AK2)*YYD+AM*Z(KK))/AM
C
      DTA=DT-DTT
```

```
      B1=DTA/2.0
      B2=(DTA*DTA)/3.0
      B3=(DTA*DTA)/6.0
C
      A1=AM*Z(KK+1)+AK1*YYD
      A2=YYV*(AC+DTA*AK1)
      A3=YYA*(B1*AC+B2*AK1)
      A4=AM+B1*AC+B3*AK1
      YY1=-(A1+A2+A3)/A4
      YY2=YYV+B1*YYA+B1*YY1
      YY3=YYD+DTA*YYV+B2*YYA+B3*YY1
      YA(KK+1)=YY1
      YV(KK+1)=YY2
      YD(KK+1)=YY3
      END IF
  100 CONTINUE
      RETURN
      END
C
C     ****************** SUBROUTINE BILI ***********************
C     *                                                          *
C     *  SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM  WITH  *
C     *  A BILINEAR HYSTERETIC BEHAVOIR                          *
C     *                CALLED BY THE MAIN PROGRAM                *
C     ************************************************************
      SUBROUTINE BILI(AM,AC,AK1,AK2,U1,DT,YA,YV,YD,Z,NN,N1,F)
      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
      DIMENSION F(N1)
C
C
C
      UA0=U1
      UB0=-U1
      BB=0.0
C
      DO 10 KK=1,NN
C
C
C
C     XD=ABS(YD(KK))
      XD1=YD(KK)
      XV1=YV(KK)
      A1=AM*Z(KK+1)
      A2=AC*(YV(KK)+DT*YA(KK)/2.0)
      A3=YD(KK)+DT*YV(KK)
      A4=A3+DT*DT*YA(KK)/3.0
      A5=DT/2.0
      A6=(DT*DT)/6.0
C
      IF(XD1.GE.UB0.AND.XD1.LE.UA0) GO TO 20
      IF(XD1.GE.UA0.AND.XV1.GE.0.0) GO TO 30
      IF(XD1.LE.UB0.AND.XV1.LE.0.0) GO TO 50
C
   20 CONTINUE
      AA1=(-(A1+A2+AK1*A4)-BB)/(AM+A5*AC+A6*AK1)
      YA(KK+1)=AA1
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE2(YA,YV,YD,DT,N1,KK,AM,AC,AK1,AK2,
     *           Z,U1,BB,UA0,UB0,1)
      GO TO 70
```

```
C
   30 CONTINUE
      CC=(AK1-AK2)*U1
      AA1=(-(A1+A2+AK2*A4)-CC)/(AM+A5*AC+A6*AK2)
      YA(KK+1)=AA1
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE2(YA,YV,YD,DT,N1,KK,AM,AC,AK1,AK2,
     *          Z,U1,BB,UA0,UB0,2)
      GO TO 70
C
   50 CONTINUE
      CC=(AK1-AK2)*U1
      AA1=(-(A1+A2+AK2*A4)+CC)/(AM+A5*AC+A6*AK2)
      YA(KK+1)=AA1
      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
      CALL TUNE2(YA,YV,YD,DT,N1,KK,AM,AC,AK1,AK2,
     *          Z,U1,BB,UA0,UB0,3)
      GO TO 70
C
   70 CONTINUE
C
      DD1=YD(KK+1)
      VV1=YV(KK+1)
C
      CALL RES2(DD1,VV1,BB,U1,UA0,UB0,AK1,AK2,F,KK,N1)
C
   10 CONTINUE
      RETURN
      END
C
C     ****************** SUBROUTINE TUNE2 *********************
C     *                                                          *
C     *  SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM  WITH  *
C     *  A BILINEAR HYSTERETIC BEHAVOIR                          *
C     *                 CALLED BY SUBROUTINE BILI                *
C     ************************************************************
      SUBROUTINE TUNE2(YA,YV,YD,DT,N1,KK,AM,AC,AK1,AK2,
     *     Z,U1,BB,UA0,UB0,ICOM)
      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
C
      A1=YD(KK+1)
      A2=YV(KK+1)
C
      IF(ICOM.EQ.1) GO TO 10
      IF(ICOM.EQ.2) GO TO 20
      IF(ICOM.EQ.3) GO TO 30
C
   10 CONTINUE
C
      IF(A1.GE.UB0.AND.A1.LE.UA0) GO TO 100
      IF(A1.GE.UA0.AND.A2.GE.0.0) GO TO 50
      IF(A1.LE.UB0.AND.A2.LE.0.0) GO TO 60
C
   50 CONTINUE
C
      DTT=(UA0-YD(KK))/YV(KK)
      YYD=UA0
      YYV=YV(KK)+DTT*YA(KK)
      YYA=-(AC*YYV+AK1*YYD+BB+AM*Z(KK))/AM
C
```

```
      DTA=DT-DTT
      B1=DTA/2.0
      B2=(DTA*DTA)/3.0
      B3=DTA*DTA/6.0
      B4=AM*Z(KK+1)
      B5=AC*(YYV+B1*YYA)
      B6=AK2*(YYD+DTA*YYV+B2*YYA)
      B7=AM+B1*AC+B3*AK2
      B8=-(AK1-AK2)*U1
C
      AA1=-(B4+B5+B6-B8)/B7
      AA2=YYV+B1*YYA+B1*AA1
      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
      YA(KK+1)=AA1
      YV(KK+1)=AA2
      YD(KK+1)=AA3
C
      GO TO 100
C
   60 CONTINUE
      DTT=(UB0-YD(KK))/YV(KK)
      YYD=UB0
      YYV=YV(KK)+DTT*YA(KK)
      YYA=-(AC*YYV+AK1*YYD+BB+AM*Z(KK))/AM
C
      DTA=DT-DTT
      B1=DTA/2.0
      B2=DTA*DTA/3.0
      B3=DTA*DTA/6.0
      B4=AM*Z(KK+1)
      B5=AC*(YYV+B1*YYA)
      B6=AK2*(YYD+DTA*YYV+B2*YYA)
      B7=AM+B1*AC+B3*AK2
      B8=(AK1-AK2)*U1
C
      AA1=-(B4+B5+B6-B8)/B7
      AA2=YYV+B1*YYA+B1*AA1
      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
      YA(KK+1)=AA1
      YV(KK+1)=AA2
      YD(KK+1)=AA3
      GO TO 100
C
   20 CONTINUE
      IF(A1.GE.UA0.AND.A2.GE.0.0) GO TO 100
      IF(A1.GE.UA0.AND.A2.LE.0.0) GO TO 70
C
   70 CONTINUE
      DTT=-YV(KK)/YA(KK)
      YYD=YD(KK)+DTT*YV(KK)+(DTT*DTT*YA(KK))/2.0
      YYV=0.0
      YYA=-(AC*YYV+AK2*YYD+(AK1-AK2)*U1+AM*Z(KK))/AM
C
      UA0=YYD
      UB0=YYD-2.0*U1
      BB=-(AK1-AK2)*(UA0-U1)
C
      DTA=DT-DTT
      B1=DTA/2.0
      B2=(DTA*DTA)/3.0
```

```
      B3=(DTA*DTA)/6.0
      B4=AM*Z(KK+1)
      B5=AC*(YYV+B1*YYA)
      B6=AK1*(YYD+DTA*YYV+B2*YYA)
      B7=AM+B1*AC+B3*AK1
C
      AA1=-(B4+B5+B6+BB)/B7
      AA2=YYV+B1*YYA+B1*AA1
      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
      YA(KK+1)=AA1
      YV(KK+1)=AA2
      YD(KK+1)=AA3
C
      GO TO 100
C
   30 CONTINUE
      IF(A1.LE.UB0.AND.A2.LE.0.0) GO TO 100
      IF(A1.LE.UB0.AND.A2.GE.0.0) GO TO 80
C
   80 CONTINUE
      DTT=-YV(KK)/YA(KK)
      YYD=YD(KK)+DTT*YV(KK)+(DTT*DTT*YA(KK))/2.0
      YYV=0.0
      YYA=-(AC*YYV+AK2*YYD-(AK1-AK2)*U1+AM*Z(KK))/AM
C
      UA0=YYD+2.0*U1
      UB0=YYD
      BB=-(AK1-AK2)*(YYD+U1)
C
      DTA=DT-DTT
      B1=DTA/2.0
      B2=DTA*DTA/3.0
      B3=DTA*DTA/6.0
      B4=AM*Z(KK+1)
      B5=AC*(YYV+B1*YYA)
      B6=AK1*(YYD+DTA*YYV+B2*YYA)
      B7=AM+B1*AC+B3*AK1
C
      AA1=-(B4+B5+B6+BB)/B7
      AA2=YYV+B1*YYA+B1*AA1
      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
      YA(KK+1)=AA1
      YV(KK+1)=AA2
      YD(KK+1)=AA3
C
      GO TO 100
C
  100 CONTINUE
      RETURN
      END
C
C     ******************  SUBROUTINE VERS  ************************
C     *                                                           *
C     *  SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM  WITH   *
C     *  A BOUC-WEN'S HYSTERETIC BEHAVOIR                         *
C     *                 CALLED BY THE MAIN PROGRAM                *
C     *************************************************************
      SUBROUTINE VERS(YD,YV,YA,Z,XD,AM,AC,AK1,AA,BE,GA,AZ,N1,DT,KK,NN,F
     *               ,GN,VV,CA,CN,CV)
      DIMENSION YD(N1),YV(N1),YA(N1),Z(N1),XD(N1)
```

```
      DIMENSION F(N1)
C
C
      DO 10 KK=1,NN
      YYD=YD(KK)
      YYV=YV(KK)
      XXD=XD(KK)
      JJ=KK
C
      CALL RUNGEX(YYD,YYV,YYA,Z,XXD,AM,AC,AK1,AA,BE,GA,AZ,N1,DT,JJ
     *            ,GN,VV,CA,CN,CV)
C
      YD(KK+1)=YYD
      YV(KK+1)=YYV
      YA(KK+1)=YYA
      XD(KK+1)=XXD
      F(KK+1)=XXD*AK1
C
   10 CONTINUE
      RETURN
      END
C
C     ****************  SUBROUTINE RUNGEX **************************
C     *                                                            *
C     *  SUBROUTINE FOR  A SINGLE DEGREE OF FREEDOM SYSTEM WITH    *
C     *  A BOUC-WEN'S HYSTERETIC BEHAVOIR                          *
C     *                 CALLED BY SUBROUTINE VERS                  *
C     **************************************************************
      SUBROUTINE RUNGEX(YYD,YYV,YYA,Z,XXD,AM,AC,AK1,AAA,BE,GA
     *                  ,AZ,N1,DT,KK,GNN,VVV,CA,CN,CV)
      DIMENSION Z(N1)
      DIMENSION Y1(5),Y2(5),Y3(5),BK1(5),BK2(5),BK3(5)
      DIMENSION R1(5),R2(5),R3(5),Q1(5),Q2(5),Q3(5)
      DIMENSION Y4(5),BK4(5),R4(5),Q4(5)
C
      Y1(1)=YYD
      Y2(1)=YYV
      Y3(1)=XXD
      Y4(1)=ZZE
C
      IF(KK.NE.1) GO TO 100
      AA=AAA
      GN=GNN
      VV=VVV
      Q1(1)=0.0
      Q2(1)=0.0
      Q3(1)=0.0
      Q4(1)=0.0
  100 CONTINUE
C
      BK1(1)=DT*Y2(1)
      BK2(1)=-DT*(AM*Z(KK)+AC*Y2(1)+AK1*Y3(1))/AM
      YZ2=ABS(Y2(1))
      YZ3=ABS(Y3(1))
C
      IF(KK.EQ.1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
```

```
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(1)-VV*BE*YZ2*ZZ1*Y3(1))
      BK3(1)=(BB1-VV*DT*GA*Y2(1)*ZZ2)/GN
      BK4(1)=DT*AK1*Y3(1)*Y2(1)
C
      R1(1)=BK1(1)/2.0-Q1(1)
      R2(1)=BK2(1)/2.0-Q2(1)
      R3(1)=BK3(1)/2.0-Q3(1)
      R4(1)=BK4(1)/2.0-Q4(1)
C
      Y1(2)=Y1(1)+R1(1)
      Y2(2)=Y2(1)+R2(1)
      Y3(2)=Y3(1)+R3(1)
      Y4(2)=Y4(1)+R4(1)
C
      Q1(2)=Q1(1)+3.0*R1(1)-BK1(1)/2.0
      Q2(2)=Q2(1)+3.0*R2(1)-BK2(1)/2.0
      Q3(2)=Q3(1)+3.0*R3(1)-BK3(1)/2.0
      Q4(2)=Q4(1)+3.0*R4(1)-BK4(1)/2.0
C
C
      BK1(2)=DT*Y2(2)
      ZZ=(Z(KK)+Z(KK+1))/2.0
      BK2(2)=-DT*(AM*ZZ+AC*Y2(2)+AK1*Y3(2))/AM
      YZ2=ABS(Y2(2))
      YZ3=ABS(Y3(2))
C
      IF(KK.EQ.1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(2)-VV*BE*YZ2*ZZ1*Y3(2))
      BK3(2)=(BB1-VV*DT*GA*Y2(2)*ZZ2)/GN
      BK4(2)=DT*Y3(2)*Y2(2)*AK1
C
      DA1=0.2928932
      R1(2)=DA1*(BK1(2)-Q1(2))
      R2(2)=DA1*(BK2(2)-Q2(2))
      R3(2)=DA1*(BK3(2)-Q3(2))
      R4(2)=DA1*(BK4(2)-Q4(2))
C
      Y1(3)=Y1(2)+R1(2)
      Y2(3)=Y2(2)+R2(2)
      Y3(3)=Y3(2)+R3(2)
      Y4(3)=Y4(2)+R4(2)
C
      Q1(3)=Q1(2)+3.0*R1(2)-DA1*BK1(2)
      Q2(3)=Q2(2)+3.0*R2(2)-DA1*BK2(2)
      Q3(3)=Q3(2)+3.0*R3(2)-DA1*BK3(2)
      Q4(3)=Q4(2)+3.0*R4(2)-DA1*BK4(2)
C
C
      BK1(3)=DT*Y2(3)
      ZZ=(Z(KK)+Z(KK+1))/2.0
```

```
      BK2(3)=-DT*(AM*ZZ+AC*Y2(3)+AK1*Y3(3))/AM
      YZ2=ABS(Y2(3))
      YZ3=ABS(Y3(3))
      IF(KK.EQ.1) THEN
      ZZ1=0.0
      ZZ2=0.0
      ELSE
      ZZ1=YZ3**(AZ-1.0)
      ZZ2=YZ3**AZ
      END IF
C
      BB1=DT*(AA*Y2(3)-VV*BE*YZ2*ZZ1*Y3(3))
      BK3(3)=(BB1-VV*DT*GA*Y2(3)*ZZ2)/GN
      BK4(3)=DT*Y3(3)*Y2(3)*AK1
C
      DA1=0.17071068E+01
      R1(3)=DA1*(BK1(3)-Q1(3))
      R2(3)=DA1*(BK2(3)-Q2(3))
      R3(3)=DA1*(BK3(3)-Q3(3))
      R4(3)=DA1*(BK4(3)-Q4(3))
C
      Y1(4)=Y1(3)+R1(3)
      Y2(4)=Y2(3)+R2(3)
      Y3(4)=Y3(3)+R3(3)
      Y4(4)=Y4(3)+R4(3)
C
      Q1(4)=Q1(3)+3.0*R1(3)-DA1*BK1(3)
      Q2(4)=Q2(3)+3.0*R2(3)-DA1*BK2(3)
      Q3(4)=Q3(3)+3.0*R3(3)-DA1*BK3(3)
      Q4(4)=Q4(3)+3.0*R4(3)-DA1*BK4(3)
C
C
      BK1(4)=DT*Y2(4)
      BK2(4)=-DT*(AM*Z(KK+1)+AC*Y2(4)+AK1*Y3(4))/AM
      YZ2=ABS(Y2(4))
      YZ3=ABS(Y3(4))
C
      BB1=DT*(AA*Y2(4)-VV*BE*YZ2*(YZ3**(AZ-1.0))*Y3(4))
      BK3(4)=(BB1-VV*DT*GA*Y2(4)*(YZ3**AZ))/GN
      BK4(4)=DT*Y3(4)*Y2(4)*AK1
C
      R1(4)=(BK1(4)-2.0*Q1(4))/6.0
      R2(4)=(BK2(4)-2.0*Q2(4))/6.0
      R3(4)=(BK3(4)-2.0*Q3(4))/6.0
      R4(4)=(BK4(4)-2.0*Q4(4))/6.0
C
       Y1(5)=Y1(4)+R1(4)
       Y2(5)=Y2(4)+R2(4)
       Y3(5)=Y3(4)+R3(4)
      Y4(5)=Y4(4)+R4(4)
C
       Q1(5)=Q1(4)+3.0*R1(4)-BK1(4)/2.0
       Q2(5)=Q2(4)+3.0*R2(4)-BK2(4)/2.0
       Q3(5)=Q3(4)+3.0*R3(4)-BK3(4)/2.0
      Q4(5)=Q4(4)+3.0*R4(4)-BK4(4)/2.0
C
       YY1=Y1(5)
       YY2=Y2(5)
       YY3=Y3(5)
      YY4=Y4(5)
```

```
C
      YYD=YY1
      YYV=YY2
      XXD=YY3
      ZZE=YY4
C
      Q1(1)=Q1(5)
      Q2(1)=Q2(5)
      Q3(1)=Q3(5)
      Q4(1)=Q4(5)
C
C
      AA=AAA-CA*ZZE
      GN=GNN+CN*ZZE
      VV=VVV+CV*ZZE
C
      YYA=-(AM*Z(KK+1)+AC*YYV+AK1*XXD)/AM
C
      RETURN
      END
C
C     ********************* SUBROUTINE RES1 ***********************
C     *                                                            *
C     *   SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH    *
C     *   A BILINEAR SPRING (NON-HYSTERETIC)                       *
C     *                 CALLED BY SUBROUTINE NOSP                  *
C     **************************************************************
      SUBROUTINE RES1(YY3,U1,AK1,AK2,F,KK,N1)
      DIMENSION F(N1)
C
      XX1=ABS(YY3)
C
      IF(XX1.LE.U1) GO TO 10
      IF(YY3.GT.U1) GO TO 20
      IF(YY3.LT.-U1) GO TO 30
C
   10 CONTINUE
      AA1=AK1*YY3
      F(KK+1)=AA1
      GO TO 40
C
   20 CONTINUE
      AA1=AK2*YY3+(AK1-AK2)*U1
      F(KK+1)=AA1
      GO TO 40
C
   30 CONTINUE
      AA1=AK2*YY3-(AK1-AK2)*U1
      F(KK+1)=AA1
C
   40 CONTINUE
C
      RETURN
      END
C
C     ********************* SUBROUTINE RES2 ***********************
C     *                                                            *
C     *   SUBROUTINE FOR SINGLE DEGREE OF FREEDOM SYSTEM WITH      *
C     *   A BILINEAR HYSTERETIC  BEHAVOIR                          *
C     *                 CALLED BY SUBROUTINE BILI                  *
```

```
C     ******************************************************************
      SUBROUTINE RES2(DD1,VV1,BB,U1,UA0,UB0,AK1,AK2,F,KK,N1)
      DIMENSION F(N1)
C
      IF(DD1.GE.UB0.AND.DD1.LE.UA0) GO TO 10
      IF(DD1.GT.UA0.AND.VV1.GE.0.0) GO TO 20
      IF(DD1.LT.UB0.AND.VV1.LE.0.0) GO TO 30
C
   10 CONTINUE
      AA1=AK1*DD1+BB
      F(KK+1)=AA1
      GO TO 40
C
   20 CONTINUE
      AA1=AK2*DD1+(AK1-AK2)*U1
      F(KK+1)=AA1
      GO TO 40
C
   30 CONTINUE
      AA1=AK2*DD1-(AK1-AK2)*U1
      F(KK+1)=AA1
      GO TO 40
C
   40 CONTINUE
      RETURN
      END
C
C
C     ***************** SUBROUTINE NOISE1 ****************
C     *                                                  *
C     *  SUBROUTINE FOR GENERATING OBSERVATIONAL NOISE   *
C     *            CALLED BY THE MAIN PROGRAM            *
C     ****************************************************
C
      SUBROUTINE NOISE1(Y1,Y2,PA,YD,YV,YA,N1,NN,DT,KCOM)
      DIMENSION YD(N1),YV(N1),YA(N1)
C
      CALL AUC(1,NN,DT,YD,YV,YA,1,N1,PA,Y1,Y2,KCOM)
C
      RETURN
      END
C
C     ***************** SUBROUTINE AUC  *****************
C     *                                                  *
C     *  SUBROUTINE FOR GENERATING OBSERVATINAL NOISE    *
C     *           CALLED BY SUBROUTINE  NOISE1           *
C     ****************************************************
C
      SUBROUTINE AUC(N,NN,DT,YD,YV,YA,M1,M2,PA,Z1,Z2,KCOM)
      DIMENSION Y1(3,1,3000),X1(3000),YD(M2),YV(M2),YA(M2)
      DIMENSION X2(3000)
C
      DO 11 I=1,NN
      Y1(1,1,I)=YD(I)
      Y1(2,1,I)=YV(I)
      Y1(3,1,I)=YA(I)
   11 CONTINUE
C
      IF(PA.EQ.0.0) GO TO 20
      B=0.0
```

```
      CALL STGU(NN,DT,X1,3000,Z1,Z2)
      X1(1)=0.0
C
      IF(KCOM.EQ.2) THEN
      DO 112 I=1,NN
      X2(I)=X1(I)*X1(I)*X1(I)
  112 CONTINUE
      DO 113 I=1,NN
      X1(I)=X2(I)
  113 CONTINUE
      END IF
C
      DO 100 K=1,NN
  100 B=B+X1(K)*X1(K)
   20 CONTINUE
C
C
      DO 200 I=1,N
      DO 300 J=1,3
      A=0.0
      DO 400 K=1,NN
      A=A+Y1(J,I,K)*Y1(J,I,K)
  400 CONTINUE
C
      IF(PA.EQ.0.0) GO TO 40
      A1=A*PA/B
      A2=SQRT(A1)
      DO 500 K=1,NN
  500 Y1(J,I,K)=X1(K)*A2+Y1(J,I,K)
      C=0.0
      DO 600 K=1,NN
  600 C=C+Y1(J,I,K)*Y1(J,I,K)
   40 CONTINUE
  300 CONTINUE
  200 CONTINUE
C
      DO 12 I=1,NN
      YD(I)=Y1(1,1,I)
      YV(I)=Y1(2,1,I)
      YA(I)=Y1(3,1,I)
   12 CONTINUE
C
      RETURN
      END
C
C     ***************** SUBROUTINE STGU ******************
C     *                                                  *
C     *  SUBROUTINE FOR GENERATING OBSERVATIONAL NOISE   *
C     *           CALLED BY SUBROUTINE AUC               *
C     ****************************************************
C
      SUBROUTINE STGU(NDATA,DELT,X,M2,Y1,Y2)
      IMPLICIT REAL*4 (Z)
C
      DIMENSION A(5001),X(M2),AA(5001),AA1(5001)
      DIMENSION Y(5001),OME(5001),PHI(5001)
      DIMENSION Z(5001),ZZ(5001)
C
C
      OHL=Y1
```

```
      OHH=Y2
      NSUM=200
      IX=1
      OL=OHL*6.283186
      OH=OHH*6.283186
      OS=OH-OL
      DEO=OS/FLOAT(NSUM)
      S=0.5/OS
C
      SDE=SQRT(4.0*S*DEO)
C
      CALL RNDFL (1.D0,5001,Z)
      CALL RNDNOR(1.D0,5001,ZZ)
C
      DO 55 I=1,5001
      A(I)=Z(I)
      AA(I)=ZZ(I)
   55 CONTINUE
C
      DO 60 I=1,NDATA
      AA1(I)=AA(I)*SDE
   60 CONTINUE
C
      DO 10 K=1,NSUM
      OME(K)=DEO*(FLOAT(K)-0.5)+OL
      PHI(K)=A(K)*6.283186
C
   10 CONTINUE
C
      DO 20 J=1,NDATA
      T=DELT*FLOAT(J-1)
      SUM=0.0
      DO 50 K=1,NSUM
      Y(K)=AA1(K)*SIN(OME(K)*T+PHI(K))
   50 SUM=SUM+Y(K)
      X(J)=SUM
   20 CONTINUE
      RETURN
      END
C
C     **************** SUBROUTINE WRITEB ******************
C     *                                                    *
C     *  SUBROUTINE FOR GENERATING OUTPUT FILES  TO BE     *
C     *  USED FOR IDENTIFICATION AND PLOTTING              *
C     *          CALLED BY THE MAIN PROGRAM                *
C     ******************************************************
      SUBROUTINE WRITEB(Z,YD,YV,YA,F,N1,NN,DT,NCOM)
      DIMENSION Z(N1),YD(N1),YV(N1),YA(N1),F(N1)
      DIMENSION TIME(3000)
C
      II1=5
      II2=6
      IF(NCOM.EQ.1) GO TO 10
      IF(NCOM.EQ.2) GO TO 20
      IF(NCOM.EQ.3) GO TO 30
C
   10 CONTINUE
C
      WRITE(8,*) 'OBSERVED INPUT EXCIATION / OUTPUT RESPONSE'
      NRSP=3
```

```
      WRITE(8,101) NRSP
  101 FORMAT(I5)
C
      WRITE(8,*) 'OBSERVED INPUT EXCIATION'
      WRITE(8,100) (Z(KK),KK=1,NN)
C
      WRITE(8,*) 'DISPLACEMENT RESPONSE'
      JDX=1
      WRITE(8,101) JDX
      WRITE(8,100) (YD(KK),KK=1,NN)
C
      WRITE(8,*) 'VELOCITY RESPONSE'
      JDX=2
      WRITE(8,101) JDX
      WRITE(8,100) (YV(KK),KK=1,NN)
C
      WRITE(8,*) 'ACCELERATION RESPONSE'
      JDX=3
      WRITE(8,101) JDX
      WRITE(8,100) (YA(KK),KK=1,NN)
      GO TO 40
C
   20 CONTINUE
      DO 1000 I=1,NN
      TIME(I)=DT*FLOAT(I-1)
 1000 CONTINUE
C
      WRITE(31,150) II1,II1,NN
      WRITE(31,100) (TIME(KK),KK=1,NN)
      WRITE(31,150) II1,II2,NN
      WRITE(31,100) (Z(KK),KK=1,NN)
      REWIND 21
C
      WRITE(32,150) II1,II1,NN
      WRITE(32,100) (TIME(KK),KK=1,NN)
      WRITE(32,150) II1,II2,NN
      WRITE(32,100) (YD(KK),KK=1,NN)
      REWIND 22
C
      WRITE(33,150) II1,II1,NN
      WRITE(33,100) (TIME(KK),KK=1,NN)
      WRITE(33,150) II1,II2,NN
      WRITE(33,100) (YV(KK),KK=1,NN)
      REWIND 23
C
      WRITE(34,150) II1,II1,NN
      WRITE(34,100) (TIME(KK),KK=1,NN)
      WRITE(34,150) II1,II2,NN
      WRITE(34,100) (YA(KK),KK=1,NN)
      REWIND 24
      GO TO 40
C
   30 CONTINUE
      WRITE(35,150)  II1,II1,NN
      WRITE(35,100) (YD(KK),KK=1,NN)
      WRITE(35,150) II1,II2,NN
      WRITE(35,100) (F(KK),KK=1,NN)
      GO TO 40
C
```

```
   40 CONTINUE
C
  100 FORMAT(8(1PE10.3))
  150 FORMAT(3I5)
C
      RETURN
      END
C---------------------------------------------
C              SUBROUTINE RNDNOR
C---------------------------------------------
      SUBROUTINE RNDNOR  (DSEED,NR,R)
C
      REAL                 R(NR),X
      DOUBLE PRECISION     DSEED
      INTEGER              NR, IER
C
      CALL RNDFL(DSEED,NR,R)
      DO 5 I=1,NR
         X=R(I)
         CALL RNDR1(X,R(I),IER)
    5 CONTINUE
      RETURN
      END
C------------------------------------------
C             SUBROUTINE RNDFL
C------------------------------------------
      SUBROUTINE RNDFL (DSEED,NR,R)
C
      REAL                 R(NR)
      INTEGER              I,NR
      DOUBLE PRECISION     D2P31M,D2P31,DSEED
      DATA                 D2P31M/2147483647.D0/
      DATA                 D2P31/2147483711.D0/
      DO 5 I=1,NR
         DSEED = DMOD(16807.D0*DSEED,D2P31M)
    5 R(I) = DSEED / D2P31
      RETURN
      END
C----------------------------------
C             SUBROUTINE RNDR1
C----------------------------------
      SUBROUTINE RNDR1  (P,Y,IER)
      INTEGER              IER
      REAL                 P,Y
      REAL                 EPS,G0,G1,G2,G3,H0,H1,H2,A,W,WI,SN,SD
      REAL                 SIGMA,SQRT2,X,XINF
      DATA                 XINF/.3402823E+39/
      DATA                 SQRT2/1.414214/
      DATA                 EPS/1.192093E-07/
      DATA                 G0/.1851159E-3/,G1/-.2028152E-2/
      DATA                 G2/-.1498384/,G3/.1078639E-1/
      DATA                 H0/.9952975E-1/,H1/.5211733/
      DATA                 H2/-.6888301E-1/
      IER = 0
      IF (P .GT. 0.0 .AND. P .LT. 1.0) GO TO 5
      IER = 129
      SIGMA = SIGN(1.0,P)
      Y = SIGMA * XINF
      GO TO 9000
    5 IF(P.LE.EPS) GO TO 10
```

```
      X = 1.0 -(P + P)
      CALL RNDR2 (X,Y,IER)
      Y = -SQRT2 * Y
      GO TO 9005
   10 A = P+P
      W = SQRT(-ALOG(A+(A-A*A)))
      WI = 1./W
      SN = ((G3*WI+G2)*WI+G1)*WI
      SD = ((WI+H2)*WI+H1)*WI+H0
      Y = W + W*(G0+SN/SD)
      Y = -Y*SQRT2
      GO TO 9005
 9000 CONTINUE
      CALL RNDR3(IER,'RNDR1')
 9005 RETURN
      END
C-------------------------------------
C           SUBROUTINE RNDR2
C-------------------------------------
C
      SUBROUTINE RNDR2 (P,Y,IER)
      REAL                P,Y
      INTEGER             IER
      REAL                A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,
     *                    B2,B3,C0,C1,C2,C3,D0,D1,D2,E0,E1,E2,E3,F0,F1,
     *                    F2,G0,G1,G2,G3,H0,H1,H2,SIGMA
      DATA                A1/-.5751703/,A2/-1.896513/,A3/-.5496261E-1/
      DATA                B0/-.1137730/,B1/-3.293474/,B2/-2.374996/
      DATA                B3/-1.187515/
      DATA                C0/-.1146666/,C1/-.1314774/,C2/-.2368201/
      DATA                C3/.5073975E-1/
      DATA                D0/-44.27977/,D1/21.98546/,D2/-7.586103/
      DATA                E0/-.5668422E-1/,E1/.3937021/,E2/-.3166501/
      DATA                E3/.6208963E-1/
      DATA                F0/-6.266786/,F1/4.666263/,F2/-2.962883/
      DATA                G0/.1851159E-3/,G1/-.2028152E-2/
      DATA                G2/-.1498384/,G3/.1078639E-1/
      DATA                H0/.9952975E-1/,H1/.5211733/
      DATA                H2/-.6888301E-1/
      DATA                RINFM/.3402823E+39/
      IER = 0
      X = P
      SIGMA = SIGN(1.0,X)
      IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30
      Z = ABS(X)
      IF (Z.LE. .85) GO TO 20
      A = 1.-Z
      B = Z
    5 W = SQRT(-ALOG(A+A*B))
      IF (W.LT.2.5) GO TO 15
      IF (W.LT.4.) GO TO 10
      WI = 1./W
      SN = ((G3*WI+G2)*WI+G1)*WI
      SD = ((WI+H2)*WI+H1)*WI+H0
      F = W + W*(G0+SN/SD)
      GO TO 25
   10 SN = ((E3*W+E2)*W+E1)*W
      SD = ((W+F2)*W+F1)*W+F0
      F = W + W*(E0+SN/SD)
      GO TO 25
```

```
   15 SN = ((C3*W+C2)*W+C1)*W
      SD = ((W+D2)*W+D1)*W+D0
      F = W + W*(C0+SN/SD)
      GO TO 25
   20 Z2 = Z*Z
      F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))
   25 Y = SIGMA*F
      IER = 0
      GO TO 9005
   30 IER = 129
      Y = SIGMA * RINFM
 9000 CONTINUE
      CALL RNDR3(IER,'RNDR2 ')
 9005 RETURN
      END
C-----------------------------------------------------------------------
C       SUBROUTINE RNDR3
C-----------------------------------------------------------------------
C
      SUBROUTINE RNDR3 (IER,NAME)
      INTEGER              IER
      CHARACTER            NAME*(*)
      INTEGER              I,IEQDF,IOUNIT,LEVEL,LEVOLD,NIN,NMTB
      CHARACTER            IEQ,NAMEQ(6),NAMSET(6),NAMUPK(6)
      DATA                 NAMSET/'U','E','R','S','E','T'/
      DATA                 NAMEQ/6*' '/
      DATA                 LEVEL/4/,IEQDF/0/,IEQ/'='/
      CALL RNDR5 (NAME,6,NAMUPK,NMTB)
      CALL RNDR4(1,NIN,IOUNIT)
      IF (IER.GT.999) GO TO 25
      IF (IER.LT.-32) GO TO 55
      IF (IER.LE.128) GO TO 5
      IF (LEVEL.LT.1) GO TO 30
      IF (IEQDF.EQ.1) WRITE(IOUNIT,35) IER,NAMEQ,IEQ,NAMUPK
      IF (IEQDF.EQ.0) WRITE(IOUNIT,35) IER,NAMUPK
      GO TO 30
    5 IF (IER.LE.64) GO TO 10
      IF (LEVEL.LT.2) GO TO 30
      IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAMUPK
      IF (IEQDF.EQ.0) WRITE(IOUNIT,40) IER,NAMUPK
      GO TO 30
   10 IF (IER.LE.32) GO TO 15
      IF (LEVEL.LT.3) GO TO 30
      IF (IEQDF.EQ.1) WRITE(IOUNIT,45) IER,NAMEQ,IEQ,NAMUPK
      IF (IEQDF.EQ.0) WRITE(IOUNIT,45) IER,NAMUPK
      GO TO 30
   15 CONTINUE
      DO 20 I=1,6
         IF (NAMUPK(I).NE.NAMSET(I)) GO TO 25
   20 CONTINUE
      LEVOLD = LEVEL
      LEVEL = IER
      IER = LEVOLD
      IF (LEVEL.LT.0) LEVEL = 4
      IF (LEVEL.GT.4) LEVEL = 4
      GO TO 30
   25 CONTINUE
      IF (LEVEL.LT.4) GO TO 30
      IF (IEQDF.EQ.1) WRITE(IOUNIT,50) IER,NAMEQ,IEQ,NAMUPK
      IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAMUPK
```

```
   30 IEQDF = 0
      RETURN
   35 FORMAT(19H *** TERMINAL ERROR,10X,7H(IER = ,I3,
     1       23H) IN RANDOM GENERATION ,6A1,A1,6A1)
   40 FORMAT(27H *** WARNING WITH FIX ERROR,2X,7H(IER = ,I3,
     1       23H) IN RANDOM GENERATION ,6A1,A1,6A1)
   45 FORMAT(18H *** WARNING ERROR,11X,7H(IER = ,I3,
     1       23H) IN RANDOM GENERATION ,6A1,A1,6A1)
   50 FORMAT(20H *** UNDEFINED ERROR,9X,7H(IER = ,I5,
     1       23H) IN RANDOM GENERATION ,6A1,A1,6A1)
   55 IEQDF = 1
      DO 60 I=1,6
   60 NAMEQ(I) = NAMUPK(I)
   65 RETURN
      END
C---------------------------------------------
C          SUBROUTINE RNDR4
C---------------------------------------------
C
      SUBROUTINE RNDR4(IOPT,NIN,NOUT)
      INTEGER              IOPT,NIN,NOUT,NIND,NOUTD
      DATA                 NIND/5/,NOUTD/6/
      IF (IOPT.EQ.3) GO TO 10
      IF (IOPT.EQ.2) GO TO 5
      IF (IOPT.NE.1) GO TO 9005
      NIN = NIND
      NOUT = NOUTD
      GO TO 9005
    5 NIND = NIN
      GO TO 9005
   10 NOUTD = NOUT
 9005 RETURN
      END
C-----------------------------------------------------------------------
C      SUBROUTINE RNDR5
C-----------------------------------------------------------------------
      SUBROUTINE RNDR5  (PACKED,NCHARS,UNPAKD,NCHMTB)
      INTEGER             NC,NCHARS,NCHMTB
      CHARACTER           UNPAKD(1),IBLANK
      CHARACTER*(1)       PACKED(1)
      DATA                IBLANK /' '/
      NCHMTB = 0
      IF(NCHARS.LE.0) RETURN
      NC = MIN0 (129,NCHARS)
      DO 5 I=1,NC
         UNPAKD(I) = PACKED(I)
    5 CONTINUE
  150 FORMAT (129A1)
      DO 200 N = 1,NC
         NN = NC - N + 1
         IF(UNPAKD(NN) .NE. IBLANK) GO TO 210
  200 CONTINUE
      NN = 0
  210 NCHMTB = NN
      RETURN
      END
```

APPENDIX III–2

DESCRIPTION OF INPUT DATA IN UNIT 2

(free format)

1. HEADING CARD

2. MASTER CONTROL CARD ; ICOM, NCOM, KCOM

ICOM: ANALYSIS CASE

- ICOM=1 : LINEAR MULTI-DEGREE OF FREEDOM SYSTEM
- ICOM=2 : SINGLE-DEGREE OF FREEDOM SYSTEM WITH BILINEAR SPRING (NON-HYSTERETIC)
- ICOM=3 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BILINEAR HYSTERESIS
- ICOM=4 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BOUC AND WEN'S HYSTERETIC MODEL

NCOM: OUTPUT CONTROL

- NCOM=1 : GENERATING OUTPUT DATA FILE (UNIT=8) FOR SYSTEM IDENTIFICATION BY USING PROGRAM EXKAL2.
  UNIT 8 INCLUDES INPUT EXCITATION AND RELATIVE DISPLACEMENT, VELOCITY AND ACCELERATION OF STRUCTURE TO GROUND MOTION.

- NCOM=2 : GENERATING OUTPUT DATA FILES (UNIT= 31-34) FOR PLOTTING EXCITATION/RESPONSE OBSERVATIONS.
  - UNIT=31 : INPUT EXCIATION
  - UNIT=32 : RELATIVE DISPLACEMENT OF STRUCTURE
  - UNIT=33 : RELATIVE VELOCITY OF STRUCTURE
  - UNIT=34 : RELATIVE ACCELERATION OF STRUCTURE

- NCOM=3 : GENERATING OUTPUT DATA FILE (UNIT= 35) FOR PLOTTING HYSTERETIC BEHAVOIR

KCOM: NOISE CONTROL

- KCOM=1 : NOISE IMPOSED RESPONSE OBSERVATIONS
- OTHERWISE : NOISE FREE

3. CONTROL CARD : N,NN,DT,XN

- N : NUMBER OF MODES USED FOR IDENTIFICATION OF LINEAR MDOF SYSTEM OR NUMBER OF MOF (=1) FOR NONLINEAR SMDOF SYSTEM
- NN : TOTAL NUMBER OF DATA POINTS IN INPUT EXCITATION RECORD AS WELL AS OUTPUT RESPONSE RECORDS TO BE GENERATED
- DT : TIME INCREMENT IN DATA (SEC)
- XN : SCALE FACTOR FOR INPUT EXCIATION IN UNIT=7

```
4. LINEAR PARAMETER CARDS : BETA1(I),OME(I),PA1(I), I=1,N
   ( N-CARDS MUST BE SUPPLIED FOR MDOF SYSTEM ANALYZED USING N-MODES.)
    BETA1(I): MODAL DAMPING RATIO FOR I-TH MODE
    OME1(I) : NATURAL CIRCULAR FREQUENCY FOR I-TH MODE (RAD/SEC)
    PA1(I)  :
        IF ICOM=1, PATICIPATION FACTOR FOR I-TH MODE AT THE NODE
                   WHERE RESPONSE OBSERVATION IS MADE,
        OTHERWISE, MAY BE OMITTED.


5. NONLINEAR PARAMETER CARD : REQUIRED ONLY FOR ICOM= 2, 3 OR 4

   IF ICOM =2 OR 3 (BILINEAR SPRING,NON-HYSTERETIC OR HYSTERESIS);
        U1  : YIELDING DISPLACEMENT
       AA2  : RATIO OF POST-YIELDING STIFFNESS TO
              PRE-YIELDING STIFFNESS

   IF ICOM =4 (BOUC-WEN'S HYSTERESIS,SECTION 3-4);
       BE,GA,CA,CV,CN: PARAMETERS FOR BOUC-WEN'S MODEL

      NOTE :
          BE=BETA; GA=GAMMA; CA=DELTA A; CV= DELTA NU; CN=DELTA ETA.
          PARAMETER A0 AND N HAVE BEEN FIXED AS A0=1.0 AND N=1.


6. OBSERVATION NOISE DATA CARD : REQUIRED ONLY FOR KCOM =1

         Y1 : LOWER RANGE OF GAUSSIAN WHITE NOISE IN HZ
         Y2 : UPPER RANGE OF GAUSSIAN WHITE NOISE IN HZ
         PA : NOISE RATIO TO STRUCTURAL RESPONSE IN VARIANCE
```

APPENDIX IV

INPUT DATA FILES FOR PROGRAM SRESP

IV – 1 General Control Input Data Files (Unit = 2)

IV-1-1 Linear MDOF Structure : ICOM=1

(line no.)

```
1        GEN. OBS. DATA FOR 2-D LIN. CASE;  W/ 1 % NOISE IN VARIANCE
2        1  1  1
3        2  1000  0.015  980.0
4        0.05   6.28  0.724
5        0.05   9.42  0.276
6        0.1   100.0  0.01
```

IV-1-2 Nonlinear SDOF Structure with Bilinear Hysteresis : ICOM=3

(line no.)

```
1        GEN. OBS. DATA FOR 1-D BILIN. CASE, ICOM=3;  W/O  NOISE
2        3  1  3
3        1  1000  0.015  980.0
4        0.1   3.14   1.0
5        3.0   0.1
```

IV-1-3 Nonlinear SDOF Structure with Bouc-Wen's Hysteresis : ICOM=4

(line no.)

```
1        GEN. OBS. DATA FOR 1-D BOUC-WEN NONLIN., ICOM=4;  W/O  NOISE
2        4   1   3
3        1  1000  0.015  980.0
4        0.1   3.14
5        0.1   0.2  0.0  0.0  0.0
```

IV – 2 Input Ground Acceleration Record (Unit = 7)

Used for all example cases (ICOM=1,2,3 and 4)

(line no.)

```
1    GROUND ACCEL. IN G ; NN =1000, DT = 0.015
2     1.000e-03-1.500e-03 1.500e-03 6.900e-03 1.460e-02 5.020e-02 5.640e-02-2.260e-02
3    -5.700e-02-1.440e-02-8.700e-03 1.360e-02 4.780e-02 4.200e-03-4.810e-02-5.000e-02
4    -1.000e-03 1.730e-02-2.300e-03 3.400e-03 2.280e-02 5.100e-02 3.740e-02 4.900e-03
5    -2.080e-02-4.200e-03-1.340e-02-3.940e-02-1.930e-02-1.170e-02 8.900e-03 2.420e-02
6     7.700e-03-1.880e-02-3.220e-02-2.800e-02-1.460e-02 1.330e-02 1.930e-02 1.040e-02
7     1.430e-02 8.900e-03-3.000e-03 1.060e-02 3.320e-02 5.940e-02 1.980e-02-4.760e-02
8    -2.010e-02-5.200e-03-1.960e-02 4.800e-02 7.800e-02 7.750e-02 6.610e-02-7.200e-03
9    -2.850e-02-1.120e-02-6.090e-02-4.240e-02 2.500e-02 1.330e-02-1.390e-02-8.000e-04
10   -3.500e-03-4.110e-02-4.240e-02-3.570e-02-5.750e-02-1.760e-02-5.650e-02-7.780e-02
11    2.900e-03-1.440e-02 5.520e-02 7.380e-02-7.970e-02-4.560e-02-8.990e-02 1.040e-02
12    1.176e-01 5.940e-02 8.890e-02-3.620e-02-3.100e-02 1.580e-02-4.580e-02 3.170e-02
13    5.350e-02 1.880e-02 9.580e-02 2.990e-02-4.660e-02 3.410e-02 1.780e-02 8.190e-02
14    1.074e-01-4.140e-02-4.360e-02-1.142e-01-4.630e-02 4.310e-02-2.500e-03 1.730e-02
15   -1.431e-01-8.770e-02-8.700e-03 4.830e-02 1.064e-01 2.470e-02 9.380e-02 1.760e-02
16    3.540e-02 1.530e-02-8.820e-02-5.550e-02-1.100e-01 3.660e-02 9.730e-02 1.111e-01
17    8.590e-02-5.080e-02-5.650e-02-7.630e-02-9.510e-02-6.500e-03-2.080e-02 4.450e-02
18    9.700e-02 1.950e-02 6.240e-02-7.000e-03 1.530e-02 3.840e-02-7.630e-02-4.900e-02
19   -1.280e-01-7.630e-02-1.490e-02-1.062e-01-3.690e-02-7.550e-02-5.150e-02 1.330e-02
20   -2.280e-02 3.320e-02 3.020e-02-3.050e-02-1.000e-03-1.710e-02-2.080e-02 3.840e-02
21    2.890e-02-4.090e-02-1.226e-01-1.545e-01-9.510e-02-4.530e-02 3.930e-02-1.540e-02
22   -9.730e-02-1.644e-01-1.738e-01-1.543e-01-1.055e-01-1.510e-02-8.900e-03-4.700e-03
23    8.400e-03-3.050e-02-3.070e-02 2.050e-02 6.410e-02 1.626e-01 1.287e-01 6.530e-02
24    4.200e-03-6.610e-02-3.150e-02 5.490e-02 1.914e-01 2.703e-01 2.996e-01 3.206e-01
25    2.820e-01 3.374e-01 3.416e-01 3.109e-01 2.379e-01 1.074e-01 2.770e-02-2.060e-02
26   -9.290e-02-1.862e-01-3.615e-01-4.229e-01-3.429e-01-1.775e-01-5.800e-02-1.082e-01
27   -1.595e-01-1.565e-01-8.770e-02 5.820e-02 1.015e-01 9.460e-02-1.310e-02-8.640e-02
28   -1.555e-01-1.377e-01 2.230e-02 2.067e-01 4.162e-01 3.367e-01 1.233e-01-4.360e-02
29   -1.060e-01 1.210e-02 1.847e-01 2.951e-01 2.490e-01 1.740e-01 1.017e-01 1.780e-02
30   -1.275e-01-2.523e-01-3.090e-01-1.800e-01 1.478e-01 3.808e-01 3.303e-01 1.473e-01
31   -9.010e-02-2.833e-01-3.704e-01-2.550e-01-1.659e-01-1.072e-01-1.035e-01-3.540e-02
32    3.360e-02 1.478e-01 2.055e-01 1.305e-01 1.310e-02-1.659e-01-2.699e-01-3.254e-01
33   -2.924e-01-2.399e-01-1.518e-01 4.200e-03 1.659e-01 2.520e-01 1.921e-01 2.550e-02
34   -6.320e-02-6.390e-02-1.020e-02-1.490e-02-8.990e-02-1.307e-01-1.055e-01-3.500e-03
35    2.080e-02-1.190e-02-7.060e-02-1.320e-01-1.345e-01-1.045e-01 5.900e-03 1.171e-01
36    2.614e-01 4.224e-01 4.887e-01 2.837e-01 1.235e-01-6.500e-03-2.950e-02-4.510e-02
37   -7.230e-02-1.208e-01-1.644e-01-1.600e-01-6.390e-02-1.164e-01-1.926e-01-2.261e-01
38   -2.038e-01-1.493e-01-3.890e-02 7.990e-02 1.728e-01 1.807e-01 8.040e-02-3.200e-03
39    3.640e-02 2.642e-01 4.144e-01 2.555e-01-2.160e-02-2.313e-01-1.092e-01 1.376e-01
40    2.552e-01 1.550e-01 8.220e-02 5.150e-02 8.440e-02 5.440e-02-1.290e-02-7.600e-02
41   -1.020e-01-4.460e-02 2.870e-02 1.030e-01 6.190e-02-3.000e-02-1.330e-01-8.370e-02
42    9.950e-02 2.619e-01 2.367e-01 1.265e-01-2.330e-02-1.607e-01-2.937e-01-3.734e-01
43   -4.454e-01-4.204e-01-3.783e-01-3.392e-01-3.063e-01-2.350e-01-1.597e-01-7.210e-02
44   -2.500e-02 1.480e-02 3.290e-02 7.250e-02 1.574e-01 2.887e-01 4.392e-01 4.087e-01
45    1.725e-01-6.710e-02-1.236e-01-6.220e-02 1.319e-01 3.857e-01 3.246e-01 9.230e-02
46   -7.550e-02-1.164e-01-1.389e-01-9.960e-02-7.880e-02-4.900e-02-1.270e-02 1.057e-01
47    2.065e-01 2.590e-01 2.659e-01 2.441e-01 2.070e-01 1.146e-01 4.400e-03-1.139e-01
48   -1.874e-01-1.416e-01-7.180e-02-5.670e-02-1.439e-01-2.310e-01-2.065e-01-7.500e-02
49    3.860e-02-1.760e-02-1.206e-01-1.258e-01-9.400e-03 1.785e-01 3.132e-01 3.114e-01
50    2.612e-01 2.233e-01 1.958e-01 1.703e-01 1.579e-01 1.565e-01 1.413e-01 9.080e-02
51    1.580e-02-8.820e-02-2.536e-01-4.628e-01-4.873e-01-3.303e-01-7.360e-02 4.500e-02
52   -1.070e-02-1.481e-01-2.021e-01-1.030e-01 9.310e-02 2.203e-01 1.361e-01-5.600e-02
53   -2.684e-01-2.996e-01-1.874e-01-4.060e-02 7.080e-02 1.017e-01 4.210e-02-2.110e-02
54   -5.600e-02-4.190e-02 9.100e-03 2.370e-02-1.640e-02 8.400e-03 1.139e-01 2.018e-01
55    1.614e-01-2.030e-02-1.352e-01-1.976e-01-1.986e-01-1.723e-01-1.327e-01-6.610e-02
56    3.880e-02 1.933e-01 3.112e-01 2.956e-01 1.208e-01-2.600e-02 5.700e-03 9.410e-02
57    1.522e-01 6.560e-02 1.780e-02 5.620e-02 1.272e-01 1.347e-01 7.330e-02-4.680e-02
58   -1.605e-01-2.040e-01-9.930e-02 3.590e-02 1.413e-01 1.763e-01 1.975e-01 2.235e-01
59    2.018e-01 9.550e-02-7.430e-02-2.793e-01-4.930e-01-5.719e-01-2.914e-01-7.060e-02
60    2.320e-02 7.770e-02 1.671e-01 2.877e-01 2.676e-01 2.025e-01 7.700e-02-5.300e-02
61   -1.550e-01-1.590e-01-9.880e-02-4.310e-02-5.670e-02-9.310e-02-1.357e-01-1.637e-01
62   -1.102e-01-7.000e-03 4.030e-02 4.080e-02 1.200e-03 1.460e-02 1.334e-01 2.671e-01
63    2.240e-01 1.255e-01 4.900e-03-5.180e-02-1.119e-01-1.211e-01-1.449e-01-1.511e-01
```

(Appendix IV-2 Continued)

64	-2.092e-01	-1.741e-01	-8.150e-02	4.200e-03	2.130e-02	-5.350e-02	-1.659e-01	-1.775e-01
65	-9.630e-02	1.780e-02	1.025e-01	6.910e-02	-3.990e-02	-9.460e-02	-1.340e-02	1.874e-01
66	3.436e-01	3.181e-01	1.074e-01	-8.400e-02	-1.577e-01	-5.750e-02	6.260e-02	9.750e-02
67	-1.510e-02	-1.236e-01	-8.540e-02	4.730e-02	1.493e-01	1.359e-01	1.380e-02	-7.210e-02
68	-4.110e-02	7.900e-02	1.517e-01	1.171e-01	8.790e-02	1.154e-01	1.629e-01	1.399e-01
69	8.070e-02	3.400e-03	-1.800e-03	2.180e-02	2.320e-02	6.700e-03	-3.500e-03	4.080e-02
70	7.050e-02	4.730e-02	2.820e-02	8.600e-03	3.070e-02	4.700e-03	-5.720e-02	-1.359e-01
71	-2.149e-01	-2.880e-01	-3.194e-01	-2.233e-01	-1.634e-01	-1.213e-01	4.900e-03	1.017e-01
72	2.317e-01	2.963e-01	1.401e-01	-3.050e-02	-1.818e-01	-2.273e-01	-2.352e-01	-1.657e-01
73	-5.600e-02	7.200e-02	2.089e-01	2.436e-01	2.067e-01	1.040e-01	1.037e-01	1.191e-01
74	8.440e-02	-8.000e-04	-9.960e-02	-1.322e-01	-1.020e-01	1.330e-02	3.560e-02	2.550e-02
75	5.870e-02	6.560e-02	1.089e-01	5.200e-02	-1.560e-02	-1.407e-01	-2.060e-01	-2.144e-01
76	-1.483e-01	-1.226e-01	-1.429e-01	-1.255e-01	-1.347e-01	-9.910e-02	-2.900e-02	3.290e-02
77	1.322e-01	1.708e-01	1.728e-01	1.002e-01	5.390e-02	4.400e-03	4.500e-02	1.238e-01
78	1.812e-01	1.738e-01	1.198e-01	6.560e-02	-2.110e-02	-3.440e-02	-8.820e-02	-1.186e-01
79	-1.887e-01	-1.459e-01	-9.830e-02	-2.450e-02	1.060e-02	-7.000e-03	-4.090e-02	-6.930e-02
80	-3.300e-02	1.233e-01	2.448e-01	1.681e-01	1.190e-02	-1.387e-01	-1.847e-01	-1.666e-01
81	-5.000e-02	1.730e-02	9.750e-02	7.180e-02	9.700e-02	6.110e-02	6.780e-02	5.440e-02
82	1.181e-01	1.305e-01	1.151e-01	4.650e-02	-3.050e-02	-1.075e-01	-1.463e-01	-1.367e-01
83	-6.460e-02	-5.200e-02	-9.730e-02	-1.533e-01	-1.357e-01	-5.150e-02	5.790e-02	8.490e-02
84	1.166e-01	9.730e-02	1.233e-01	7.130e-02	8.590e-02	7.050e-02	1.433e-01	1.225e-01
85	1.116e-01	2.000e-04	-1.010e-01	-2.043e-01	-2.726e-01	-2.709e-01	-2.595e-01	-1.951e-01
86	-1.043e-01	3.170e-02	1.720e-01	2.748e-01	2.602e-01	1.082e-01	-2.430e-02	-9.510e-02
87	-9.460e-02	-4.950e-02	2.570e-02	1.178e-01	1.480e-01	8.790e-02	1.930e-02	-7.010e-02
88	-5.200e-02	-3.960e-02	2.570e-02	3.960e-02	1.780e-02	5.740e-02	4.850e-02	2.370e-02
89	5.870e-02	5.000e-02	1.181e-01	5.840e-02	-5.100e-02	-9.910e-02	-1.392e-01	-3.890e-02
90	-1.340e-02	6.630e-02	1.630e-02	3.790e-02	8.120e-02	1.560e-02	-2.080e-02	-1.847e-01
91	-2.640e-01	-2.476e-01	-1.969e-01	-1.236e-01	-3.620e-02	-2.330e-02	-8.700e-03	4.430e-02
92	6.730e-02	1.151e-01	2.130e-02	-2.820e-02	4.700e-03	3.440e-02	8.470e-02	2.450e-02
93	-4.730e-02	-7.630e-02	-1.023e-01	-4.860e-02	-5.940e-02	-8.700e-03	-1.340e-02	2.320e-02
94	9.800e-02	1.592e-01	2.396e-01	2.347e-01	1.144e-01	9.850e-02	7.400e-02	1.168e-01
95	1.498e-01	1.401e-01	7.380e-02	-1.780e-02	-1.097e-01	-1.770e-01	-2.053e-01	-2.367e-01
96	-2.013e-01	-1.298e-01	-8.770e-02	-4.580e-02	3.910e-02	1.297e-01	2.094e-01	1.718e-01
97	1.768e-01	1.396e-01	9.930e-02	5.540e-02	3.860e-02	-7.700e-03	-3.720e-02	-5.970e-02
98	-6.220e-02	-9.010e-02	-9.310e-02	-9.440e-02	-5.570e-02	-3.640e-02	-6.960e-02	-1.124e-01
99	-1.709e-01	-1.300e-01	1.480e-02	1.971e-01	2.728e-01	1.272e-01	3.740e-02	-5.990e-02
100	-4.810e-02	-3.860e-02	-6.740e-02	1.850e-02	2.180e-02	1.520e-01	1.980e-01	2.228e-01
101	1.612e-01	1.223e-01	1.097e-01	4.880e-02	1.780e-02	-4.460e-02	-1.008e-01	-1.208e-01
102	-1.407e-01	-7.360e-02	-3.200e-02	3.070e-02	-1.040e-02	-5.280e-02	-7.650e-02	-1.384e-01
103	-1.971e-01	-2.206e-01	-1.407e-01	-1.238e-01	-9.930e-02	-1.390e-02	2.820e-02	2.920e-02
104	4.310e-02	-3.000e-04	3.190e-02	4.950e-02	5.960e-02	8.440e-02	5.320e-02	7.800e-02
105	5.050e-02	6.580e-02	8.900e-03	1.660e-02	-7.260e-02	-6.090e-02	-6.590e-02	-7.430e-02
106	-1.201e-01	-1.080e-01	-6.040e-02	9.400e-03	5.540e-02	2.080e-02	2.570e-02	1.380e-02
107	7.870e-02	4.780e-02	-4.500e-03	-4.760e-02	-7.800e-02	-3.990e-02	-4.580e-02	-4.760e-02
108	-7.850e-02	-3.370e-02	2.000e-03	7.470e-02	-1.490e-02	-3.440e-02	-9.110e-02	-2.380e-02
109	6.930e-02	5.490e-02	9.180e-02	5.300e-02	4.060e-02	6.660e-02	4.360e-02	1.111e-01
110	5.320e-02	5.300e-02	1.700e-03	-3.050e-02	2.920e-02	5.620e-02	1.634e-01	1.983e-01
111	1.760e-01	8.490e-02	-1.240e-02	-1.280e-01	-1.624e-01	-1.117e-01	-3.390e-02	-2.500e-02
112	-6.440e-02	-1.260e-01	-8.320e-02	-4.210e-02	-4.240e-02	-9.310e-02	-7.550e-02	-8.570e-02
113	-5.330e-02	-4.460e-02	-2.870e-02	6.190e-02	1.347e-01	1.718e-01	1.381e-01	-4.000e-03
114	-5.940e-02	-1.980e-02	-1.120e-02	7.850e-02	1.480e-02	-7.500e-02	-2.130e-02	-3.910e-02
115	8.660e-02	8.810e-02	2.990e-02	3.660e-02	-2.380e-02	6.390e-02	1.045e-01	1.012e-01
116	9.800e-02	-1.860e-02	-1.910e-02	-7.630e-02	-7.680e-02	-4.360e-02	-8.350e-02	-4.580e-02
117	-8.000e-02	8.400e-03	-3.390e-02	-2.210e-02	-3.910e-02	-9.660e-02	-4.610e-02	-6.140e-02
118	2.000e-02	5.070e-02	3.560e-02	3.240e-02	-5.970e-02	-7.970e-02	-6.320e-02	4.480e-02
119	1.176e-01	1.661e-01	1.082e-01	1.037e-01	1.339e-01	1.537e-01	8.760e-02	-3.490e-02
120	-1.114e-01	-1.783e-01	-1.355e-01	-8.990e-02	3.860e-02	2.280e-02	3.860e-02	4.780e-02
121	-5.990e-02	-3.940e-02	-6.220e-02	-8.170e-02	-6.040e-02	-1.159e-01	-7.630e-02	-9.210e-02
122	1.530e-02	4.950e-02	1.572e-01	1.768e-01	1.359e-01	-2.380e-02	-5.800e-02	-1.275e-01
123	-6.340e-02	-6.930e-02	-2.400e-02	2.250e-02	3.070e-02	1.629e-01	1.567e-01	1.255e-01
124	7.750e-02	7.720e-02	1.880e-02	2.280e-02	1.950e-02	-3.420e-02	-1.690e-02	1.200e-03
125	-2.260e-02	5.900e-03	1.190e-02	-4.140e-02	-7.950e-02	-9.110e-02	-3.960e-02	-4.500e-03
126	-1.240e-02	5.700e-03	4.900e-03	-5.200e-03	9.900e-03	1.500e-03	-2.080e-02	-3.320e-02

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