



**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

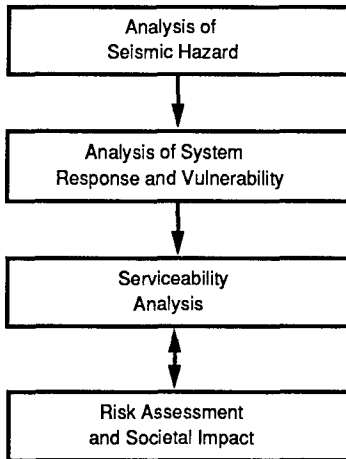
This technical report pertains to Program 3, Lifeline Systems, and more specifically to water delivery systems.

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 trans-

formed 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 Hystereic 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

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

where Z, \dot{Z}, \ddot{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 $\{1\} = \{1 \ 1 \ \dots \ 1\}^T$

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

$$Z = \Phi\eta \quad (2.1.2)$$

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

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

with

$$\delta_j = \sum_{k=1}^n m_k \phi_{kj} \quad (2.1.4)$$

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

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

where $u_{ij} = \phi_{ij}\eta_j$, ϕ_{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

$$Z_i = u_{i1} + u_{i2} + \dots + u_{in} \quad (2.1.6)$$

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

$$\mathbf{X} = \left\{ \mathbf{X}_1^T \ \mathbf{X}_2^T \ \dots \ \mathbf{X}_n^T \right\}^T \quad (2.2.1)$$

where \mathbf{X}_j contains the quantities corresponding to the j-th mode as

$$\begin{aligned} \mathbf{X}_j &= \{x_{1j} \ x_{2j} \ x_{3j} \ x_{4j} \ x_{5j}\}^T \\ &= \{u_{ij} \ \dot{u}_{ij} \ h_j \ \omega_j \ p_{ij}\}^T \end{aligned} \quad (2.2.2)$$

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

$$\frac{d\mathbf{X}_j}{dt} = \begin{Bmatrix} \dot{x}_{1j} \\ \dot{x}_{2j} \\ \dot{x}_{3j} \\ \dot{x}_{4j} \\ \dot{x}_{5j} \end{Bmatrix} = \begin{Bmatrix} x_{2j} \\ -2x_{3j}x_{4j}x_{2j} - x_{4j}^2x_{1j} - x_{5j}\ddot{f}(t) \\ 0 \\ 0 \\ 0 \end{Bmatrix} = \mathbf{g}_j(t) \quad (2.2.3)$$

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

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

where $\mathbf{w}(t)$ is the system noise vector with covariance matrix $\mathbf{Q}(t)$ and \mathbf{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 $\mathbf{Y}(k)$ can be written as

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

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

On Program EXKAL2

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]

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

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

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

$$\mathbf{X} = \left\{ \mathbf{X}_1^T \quad \mathbf{X}_2^T \quad \dots \quad \mathbf{X}_n^T \right\}^T \quad (2.3.3)$$

with

$$\begin{aligned} \mathbf{X}_j &= \{x_{1j} \quad x_{2j} \quad x_{3j} \quad x_{4j} \quad x_{5j} \quad x_{6j}\}^T \\ &= \{u_{ij} \quad \dot{u}_{ij} \quad \ddot{u}_{ij} \quad h_j \quad w_j \quad p_{ij}\}^T \end{aligned} \quad (2.3.4)$$

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

$$\begin{aligned}
X_j(k+1) &= \begin{Bmatrix} x_{1j}(k+1) \\ x_{2j}(k+1) \\ x_{3j}(k+1) \\ x_{4j}(k+1) \\ x_{5j}(k+1) \\ x_{6j}(k+1) \end{Bmatrix} = \begin{Bmatrix} D_{11}x_{1j}(k) + D_{12}x_{2j}(k) + D_{13}x_{3j}(k) + D_{14}x_{6j}(k) \ddot{f}(k+1) \\ D_{21}x_{1j}(k) + D_{22}x_{2j}(k) + D_{23}x_{3j}(k) + D_{24}x_{6j}(k) \ddot{f}(k+1) \\ D_{31}x_{1j}(k) + D_{32}x_{2j}(k) + D_{33}x_{3j}(k) + D_{34}x_{6j}(k) \ddot{f}(k+1) \\ x_{4j}(k) \\ x_{5j}(k) \\ x_{6j}(k) \end{Bmatrix} \\
&= g_j(k) \tag{2.3.5}
\end{aligned}$$

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

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

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

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

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

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

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

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

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.

On Program EXKAL2

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

$$H_{ij}(\omega) = \frac{-P_{ij}}{(\omega_j^2 - \omega^2) + i(2h_j\omega_j\omega)} \quad (2.4.1)$$

and

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

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

$$\mathbf{X} = \left\{ \mathbf{X}_1^T \quad \mathbf{X}_2^T \quad \dots \quad \mathbf{X}_n^T \right\}^T \quad (2.4.3)$$

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

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

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

$$\mathbf{Y}_j(k) = \begin{Bmatrix} \text{Re}[H_{ij}(k)] \\ \text{Im}[H_{ij}(k)] \end{Bmatrix} = \begin{Bmatrix} \frac{-x_{3j}(k)\{x_{2j}^2(k)-(k\Delta\omega)^2\}}{\{x_{2j}^2(k)-(k\Delta\omega)^2\}^2 + \{2x_{1j}(k)x_{2j}(k)(k\Delta\omega)\}^2} \\ \frac{2x_{3j}(k)x_{1j}(k)x_{2j}(k)(k\Delta\omega)}{\{x_{2j}^2(k)-(k\Delta\omega)^2\}^2 + \{2x_{1j}(k)x_{2j}(k)(k\Delta\omega)\}^2} \end{Bmatrix} + \mathbf{w}(k) \quad (2.4.5)$$

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

$$\begin{Bmatrix} \mathbf{X}_1(k+1) \\ \mathbf{X}_2(k+1) \\ \cdot \\ \cdot \\ \mathbf{X}_n(k+1) \end{Bmatrix} = \begin{Bmatrix} \mathbf{X}_1(k) \\ \mathbf{X}_2(k) \\ \cdot \\ \cdot \\ \mathbf{X}_n(k) \end{Bmatrix} \quad (2.4.6)$$

and

$$\mathbf{Y}(k) = \begin{Bmatrix} \text{Re}[H_{i1}(k)] + \text{Re}[H_{i2}(k)] + \dots \\ \text{Im}[H_{i1}(k)] + \text{Im}[H_{i2}(k)] + \dots \end{Bmatrix} + \mathbf{w}(k) \quad (2.4.7)$$

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

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

$$H_i(\omega) = \frac{\widehat{\dot{Z}}_i(\omega)}{i(\omega\widehat{\dot{f}}(\omega))} \quad (2.4.9)$$

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

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.

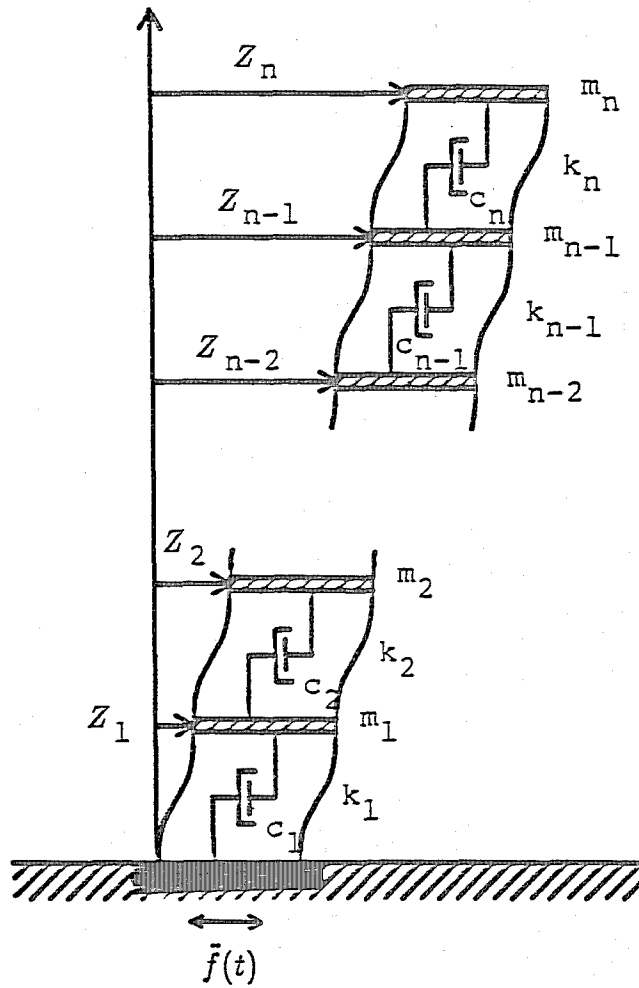


FIGURE 2-1 Example Structural Model for Linear MDOF System

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

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

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.

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

Then the equation of motion is obtained as

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

By defining the state vector as

$$\mathbf{X} = \left\{ Z, \dot{Z}, a_1, a_2, a_3, a_4 \right\}^T \quad (3.2.3)$$

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

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

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

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

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

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

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

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

Then, by using a state vector defined as

$$\mathbf{X} = \{Z, \dot{Z}, h, \omega, Z_e, \alpha\}^T \quad (3.3.3)$$

a continuous state equation is constructed from Eq. 3.3.2 as

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

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

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

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

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

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

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

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

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

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

$$\nu(t) = 1.0 + \delta_\nu \epsilon(t) \quad (3.4.4)$$

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

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

By defining a state vector as

$$\mathbf{X} = \{Z \quad \dot{Z} \quad \phi \quad \epsilon \quad h \quad \omega \quad \beta \quad \gamma \quad A_0 \quad \delta_A \quad \delta_\nu \quad \delta_\eta\}^T \quad (3.4.5)$$

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

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

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

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

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.

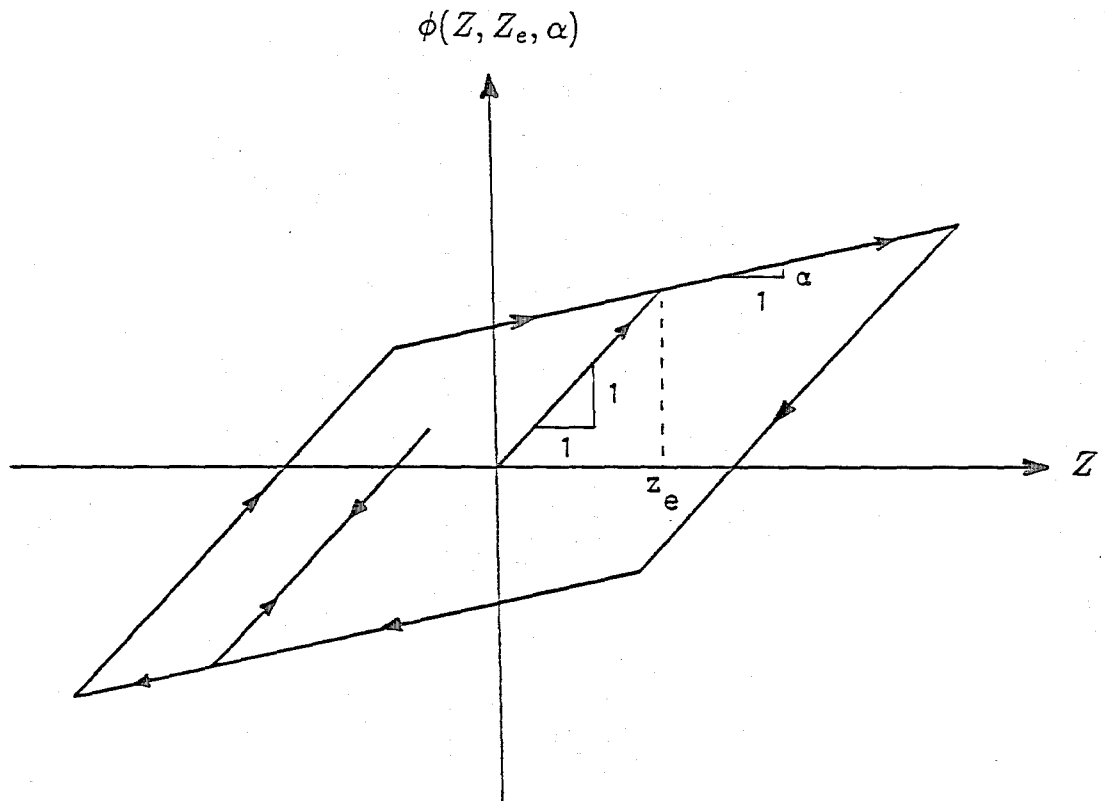


FIGURE 3-1 Bilinear Hysteresis



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

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

with observation at $t = k\Delta t$

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

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

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

$$\begin{aligned}\hat{\mathbf{X}}(k+1/k) &= E\{\mathbf{X}(k+1) | \mathbf{Y}(1), \mathbf{Y}(2), \dots, \mathbf{Y}(k)\} \\ &= \hat{\mathbf{X}}(k/k) + \int_{k\Delta t}^{(k+1)\Delta t} \mathbf{g}(\mathbf{X}(t/k), f; t) dt\end{aligned}\quad (4.1.3)$$

where

$$\mathbf{P}(k+1/k) = \Phi(k+1, k)\mathbf{P}(k/k)\Phi^T(k+1, k) + \mathbf{Q}_k \quad (4.1.4)$$

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

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

for small Δt .

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

$$\begin{aligned}\hat{\mathbf{X}}(k+1/k+1) &= E\{\mathbf{X}(k+1) | \mathbf{Y}(1), \mathbf{Y}(2), \dots, \mathbf{Y}(k+1)\} \\ &= \hat{\mathbf{X}}(k+1/k) + \mathbf{K}(k+1) \left[\mathbf{Y}(k+1) - \mathbf{h}(\hat{\mathbf{X}}(k+1/k); k) \right]\end{aligned}\quad (4.1.6)$$

$$\begin{aligned}\mathbf{P}(k+1/k+1) &= [\mathbf{I} - \mathbf{K}(k+1)\mathbf{M}(k+1)]\mathbf{P}(k+1/k)[\mathbf{I} - \mathbf{K}(k+1)\mathbf{M}(k+1)]^T \\ &\quad + \mathbf{K}(k+1)\mathbf{R}_k\mathbf{K}^T(k+1)\end{aligned}\quad (4.1.7)$$

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

$$\mathbf{K}(k+1) = \mathbf{P}(k+1/k)\mathbf{M}(k+1)^T \left[\mathbf{M}(k+1)\mathbf{P}(k+1/k)\mathbf{M}(k+1)^T + \mathbf{R}_k \right]^{-1} \quad (4.1.8)$$

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

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

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 $\hat{X}(0/0)$ 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

$$\hat{X}_{(2)}(0/0) = \begin{Bmatrix} \xi_{(1)}(0/0) \\ \theta_{(1)}(N/N) \end{Bmatrix} \quad (4.2.1)$$

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

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

$$\mathbf{X}(k+1) = \mathbf{X}(k) \quad (4.2.3)$$

$$\mathbf{Y}(k) = \mathbf{M}(k)\mathbf{X}(k) + \mathbf{v}(k) \quad (4.2.4)$$

where $\mathbf{X}(k)$ is a state vector with constant values, $\mathbf{Y}(k)$ is an observation vector, $\mathbf{M}(k)$ 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 $\hat{\mathbf{X}}_{(1)}(N/N)$ and the error covariance matrix $\mathbf{P}_{(1)}(N/N)$ at $t = t_N$ can be obtained as

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

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

Then, performing weighted global iteration J times, one obtains

$$\begin{aligned} \hat{\mathbf{X}}_{(J)}(N/N) = & \left[\left(\frac{1+w+w^2+\dots+w^{J-1}}{w^{J-1}} \right) \sum_{i=1}^N \mathbf{M}^T(i) \mathbf{R}_i^{-1} \mathbf{Y}(i) \right. \\ & \left. + \frac{1}{w^{J-1}} \mathbf{P}_{(1)}^{-1}(0/0) \hat{\mathbf{X}}_{(1)}(0/0) \right] \end{aligned} \quad (4.2.7)$$

$$\begin{aligned} \mathbf{P}_{(J)}(N/N) = & \left[\left(\frac{1+w+w^2+\dots+w^{J-1}}{w^{J-1}} \right) \sum_{i=1}^N \mathbf{M}^T(i) \mathbf{R}_i^{-1} \mathbf{M}(i) \right. \\ & \left. + \frac{1}{w^{J-1}} \mathbf{P}_{(1)}^{-1}(0/0) \right] \end{aligned} \quad (4.2.8)$$

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

$$\lim_{j \rightarrow \infty} \hat{\mathbf{X}}_{(j)}(N/N) = \left[\sum_{i=1}^N \mathbf{M}^T(i) \mathbf{R}_i^{-1} \mathbf{M}(i) \right]^{-1} \left[\sum_{i=1}^N \mathbf{M}^T(i) \mathbf{R}_i^{-1} \mathbf{Y}(i) \right] \quad (4.2.9)$$

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:

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

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	ICON		
Unit	4	5	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_v
30	—	—	δ_n
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

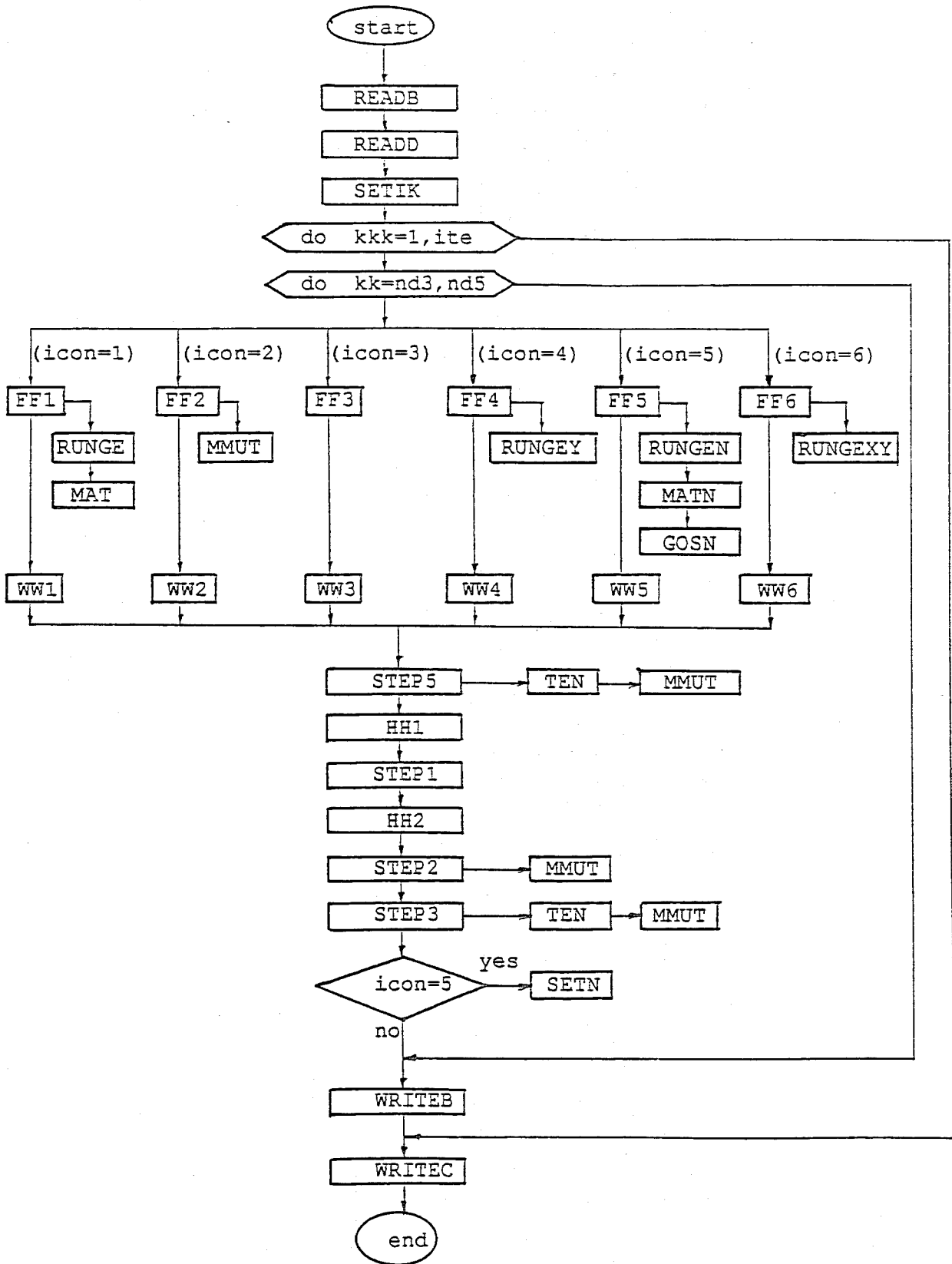


FIGURE 5-1 Subroutine Tree of Program EXKAL2

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 $H(Z, \dot{Z}), \phi(Z, Z_e, \alpha)$ or $\phi(Z)$ (see Eqs. 3.2.1, 3.3.2 and 3.4.2).

PROGRAM SRESP

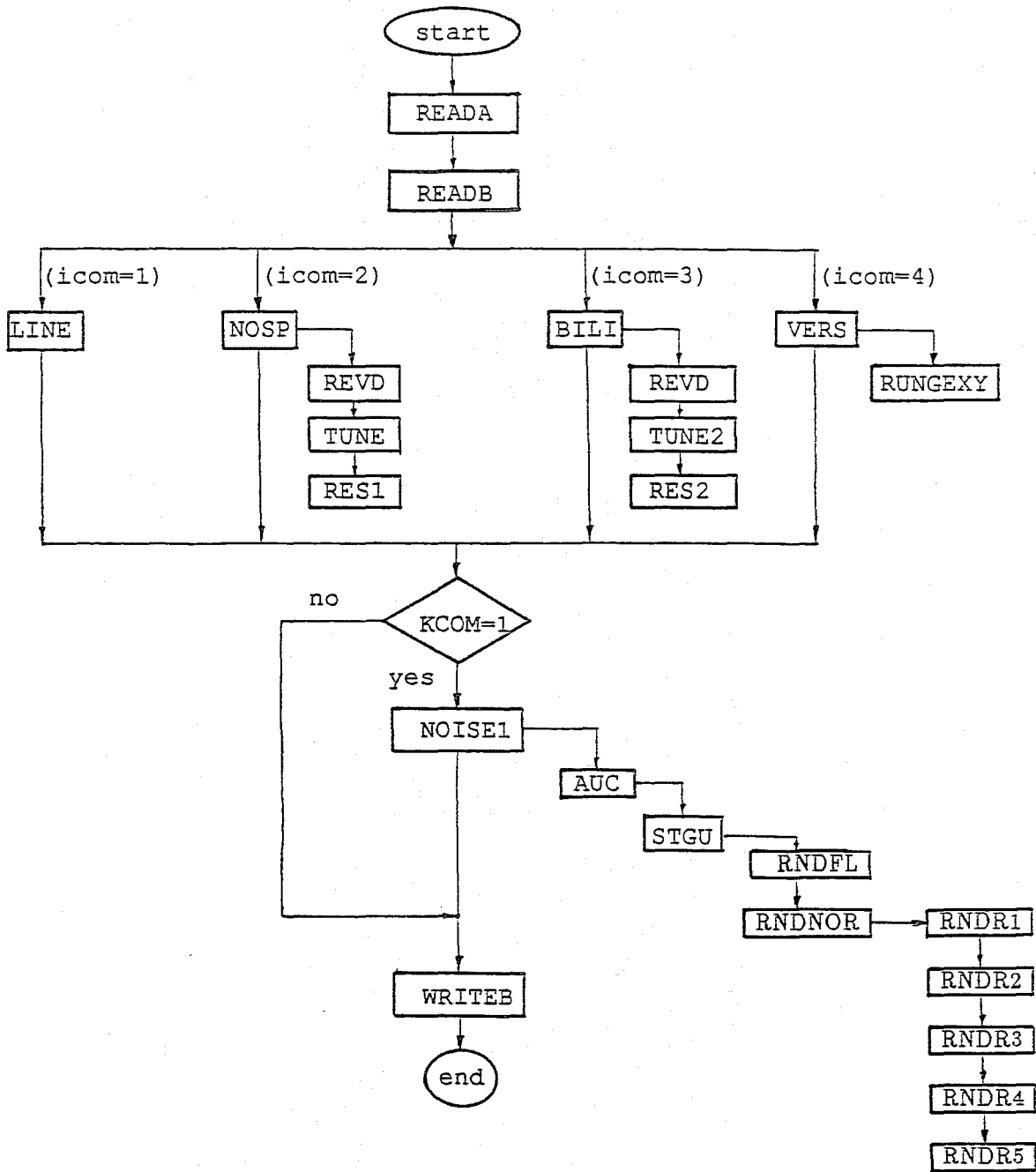


FIGURE 6-1 Subroutine Tree of Program SRESP



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 input 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 $\text{ICON}=1$. 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 ($\text{ICON}=4$)

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 ($\text{ICON}=5$)

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 convergence 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		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	0.18	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		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	0.175	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	Step II	Step III	Step I	Step II	Step III
			$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$
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	Step II	Step III	Step I	Step II	Step III
			$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$	$\bar{\theta}_{10}$
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 $\delta_A = \delta_\nu = \delta_\tau = 0.0$ and $A_0 = 1.0$.
 (4) Units : ω is in *rad/sec* and β and γ are in *1/cm*.

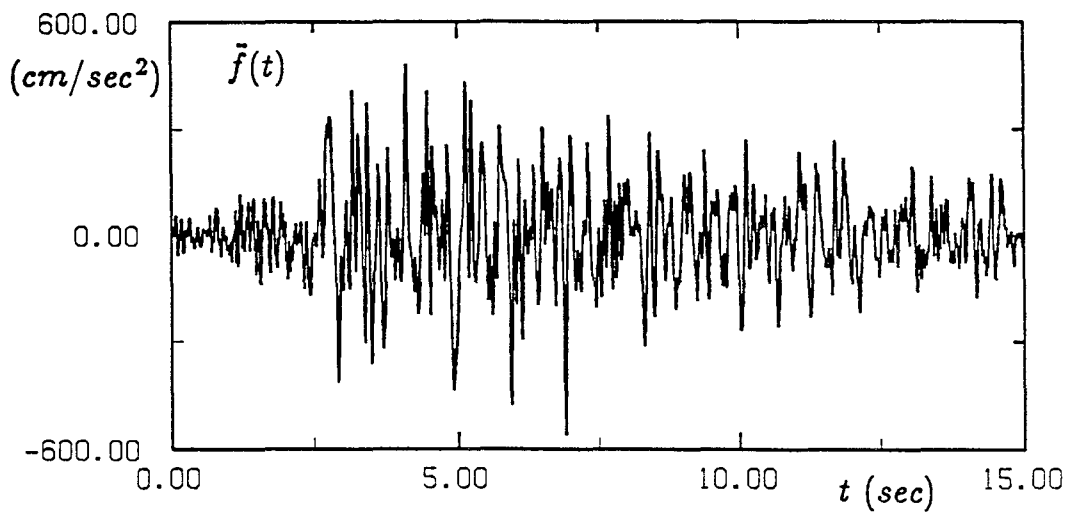


FIGURE 7-1 Input Ground Acceleration

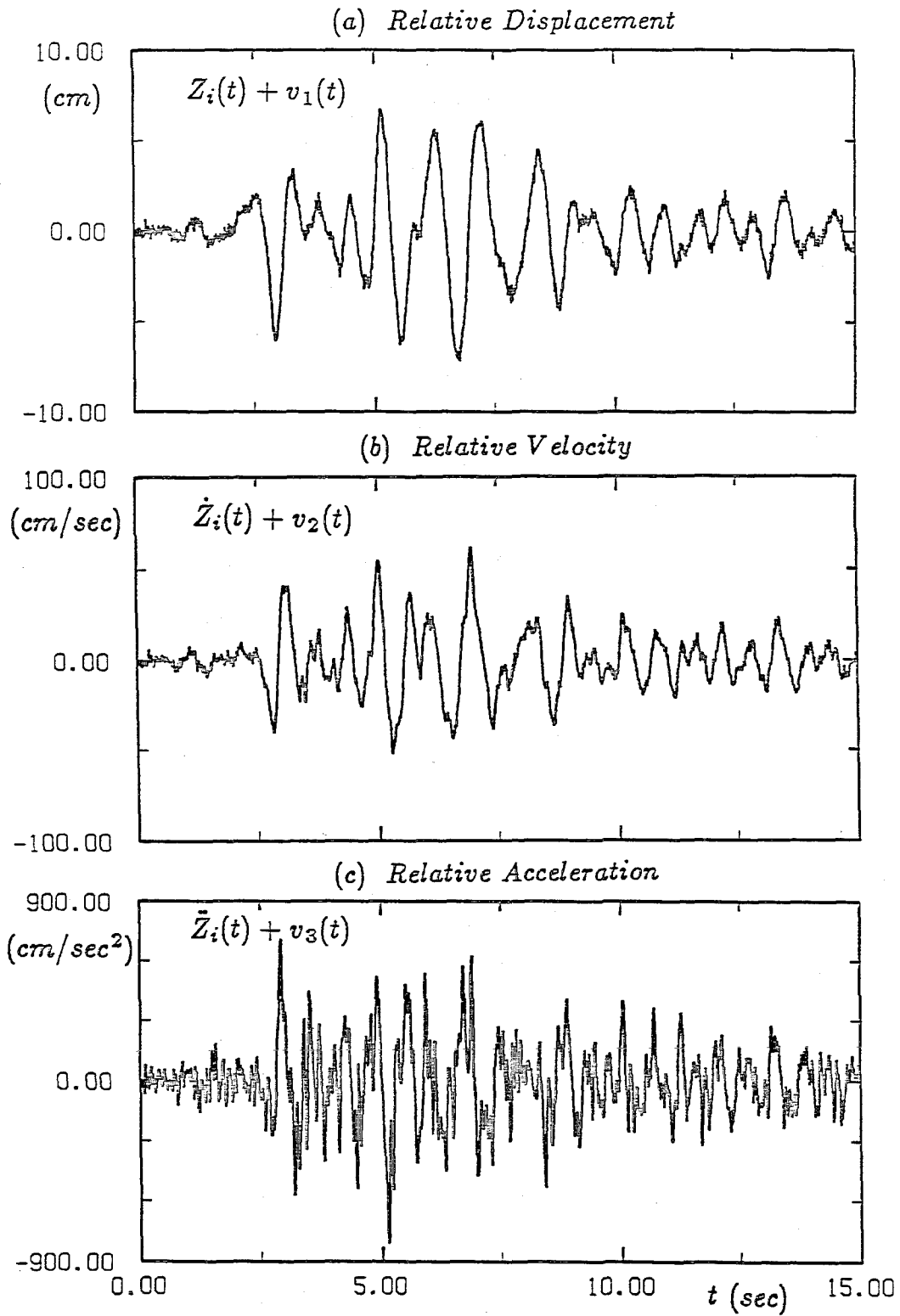


FIGURE 7-2 Response Observations of Linear MDOF Structure
(at Node *i*; ICON=1,2 and 3; 10% Observational Noise in RMS)

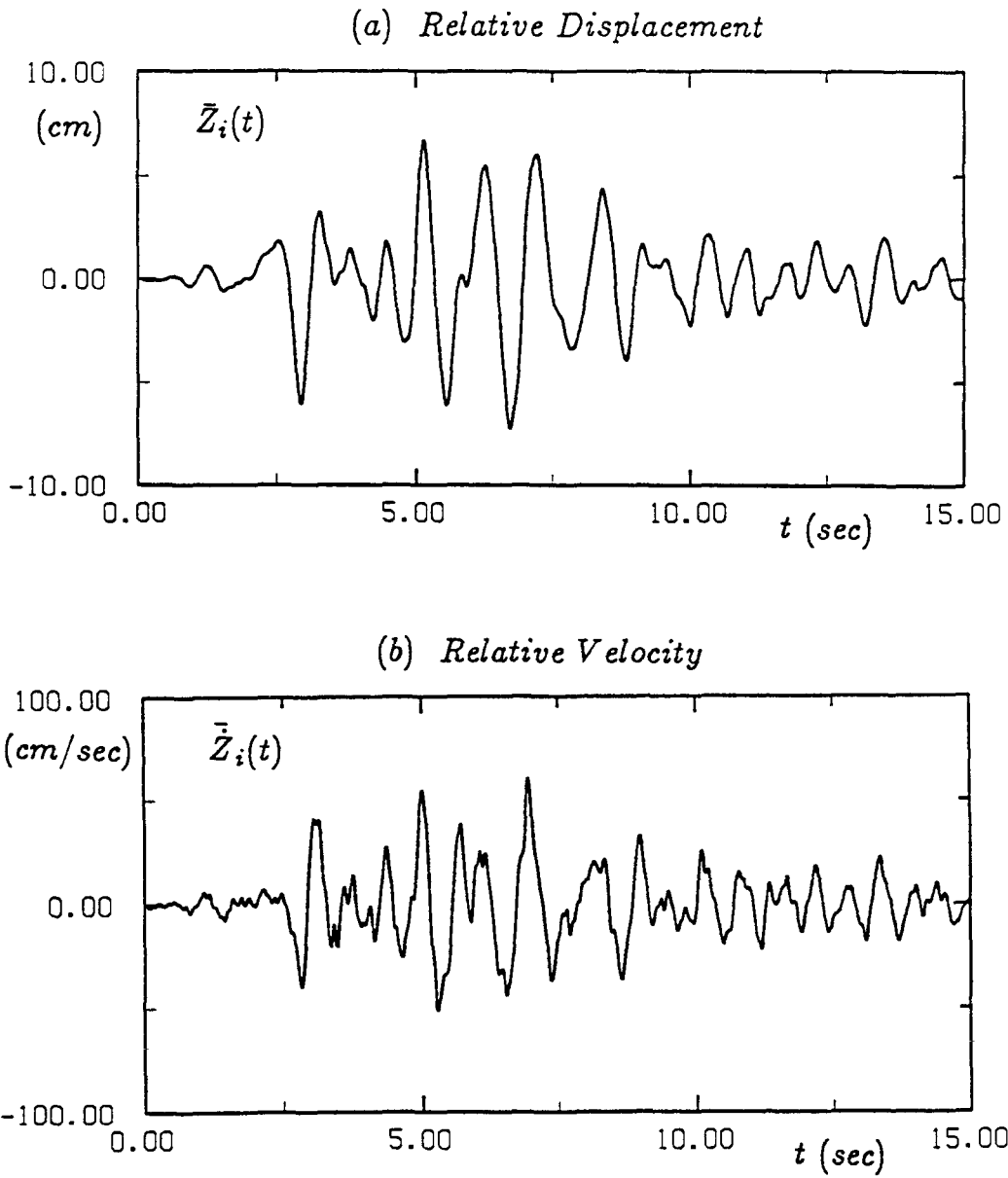


FIGURE 7-3 Estimated Response Based on the Identified Parameters (ICON=1; 10% Observational Noise in RMS)

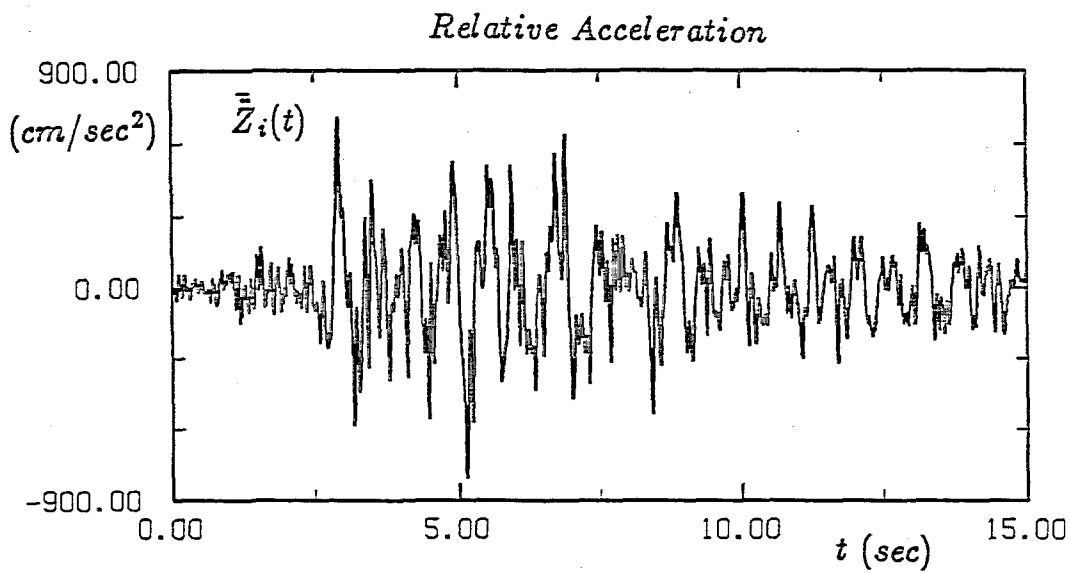


FIGURE 7-4 Estimated Acceleration Based on the Identified Parameters
(ICON=2; 10% Observational Noise in RMS)

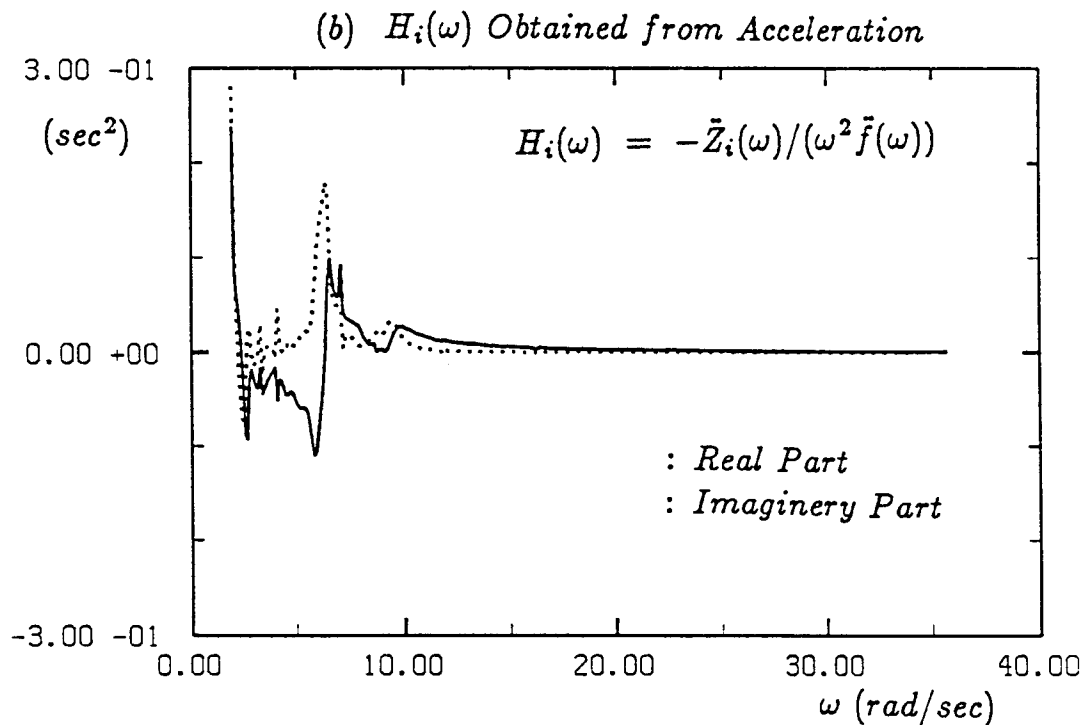
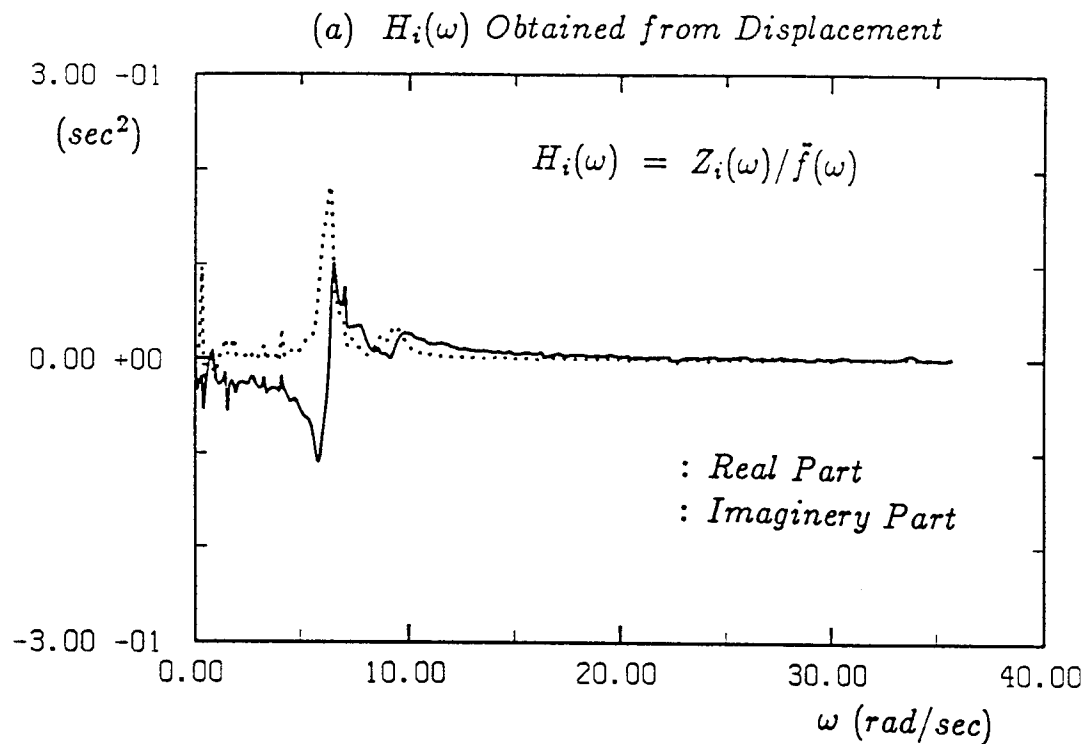


FIGURE 7-5 Frequency Response Function Used for Parameter Estimation in Frequency Domain (ICON=3; 10% Observational Noise in RMS)

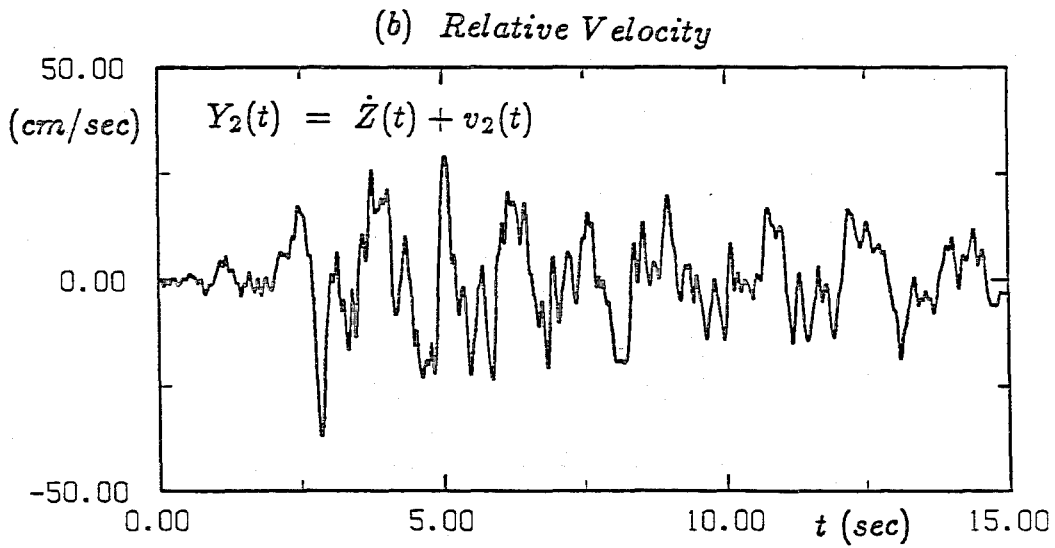
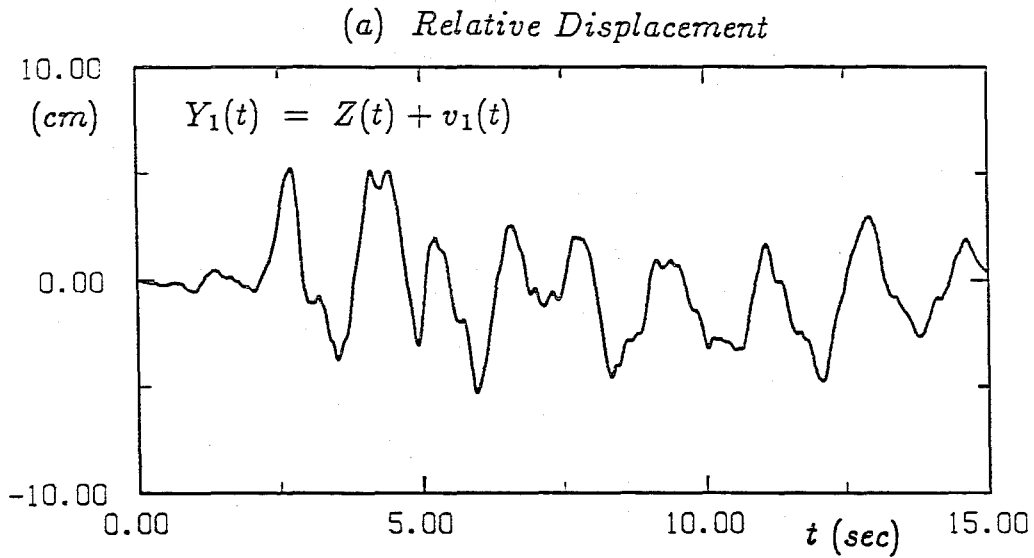


FIGURE 7-6 Response Observations of Nonlinear SDOF Structure with Bilinear Hysteresis (ICON=5; No Observational Noise Condition)

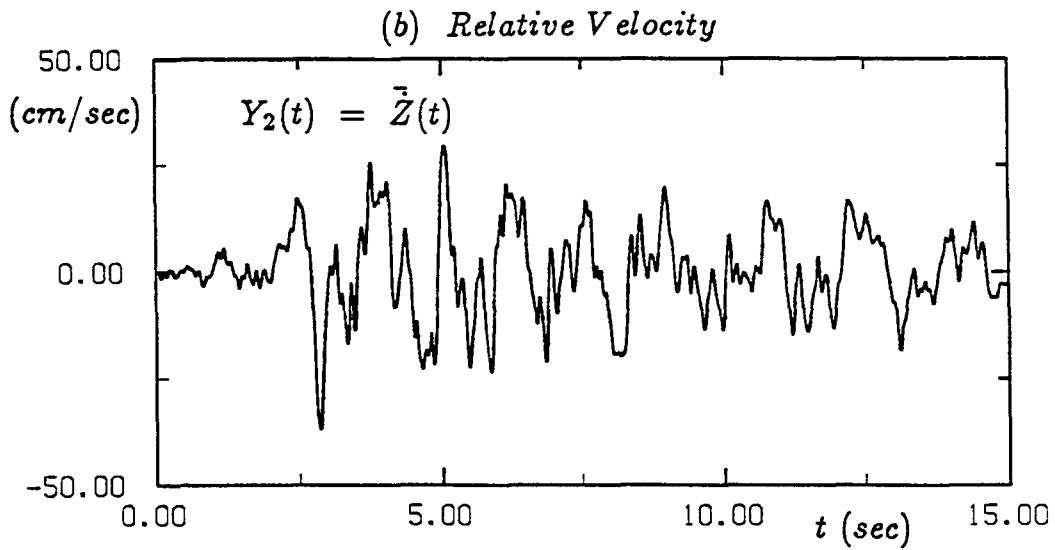
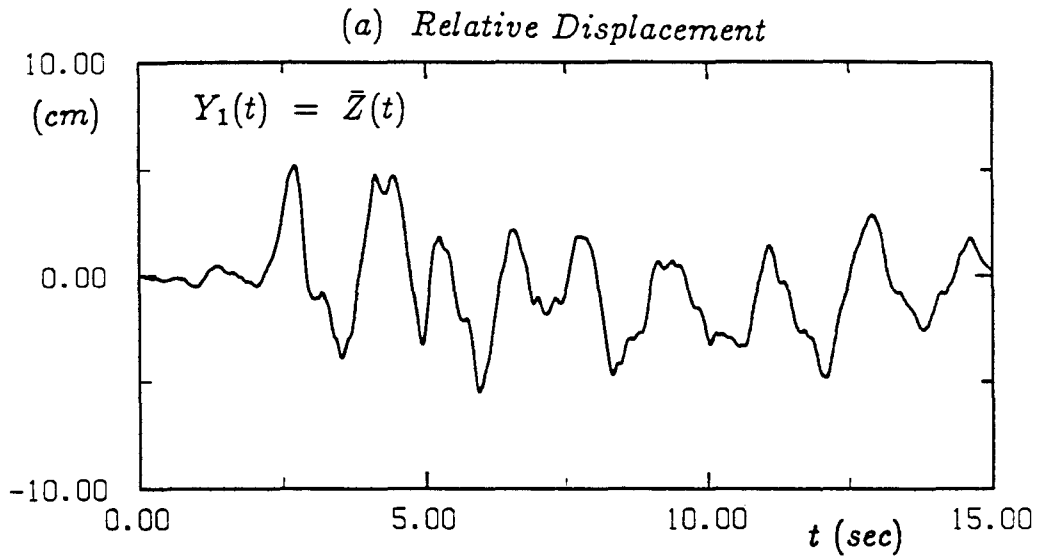


FIGURE 7-7 Estimated Response Based on the Identified Parameters
(ICON=5; No Observational Noise Condition)

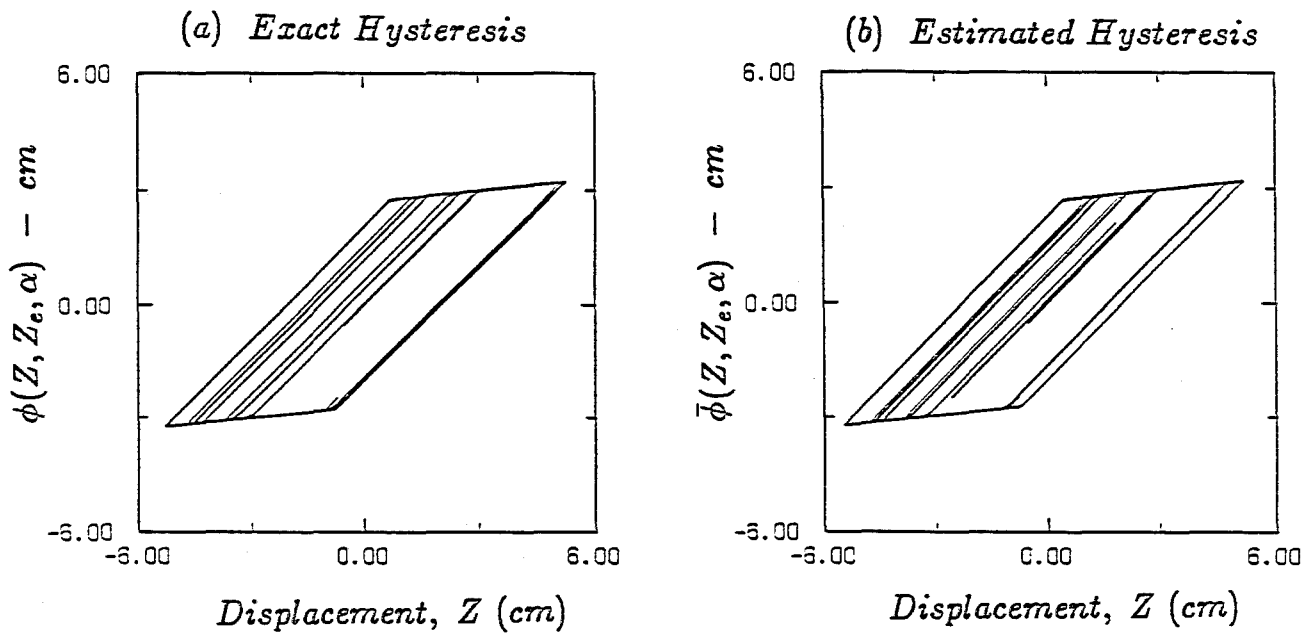


FIGURE 7-8 Exact and Estimated Bilinear Hystereses
(ICON=5; No Observational Noise Condition)

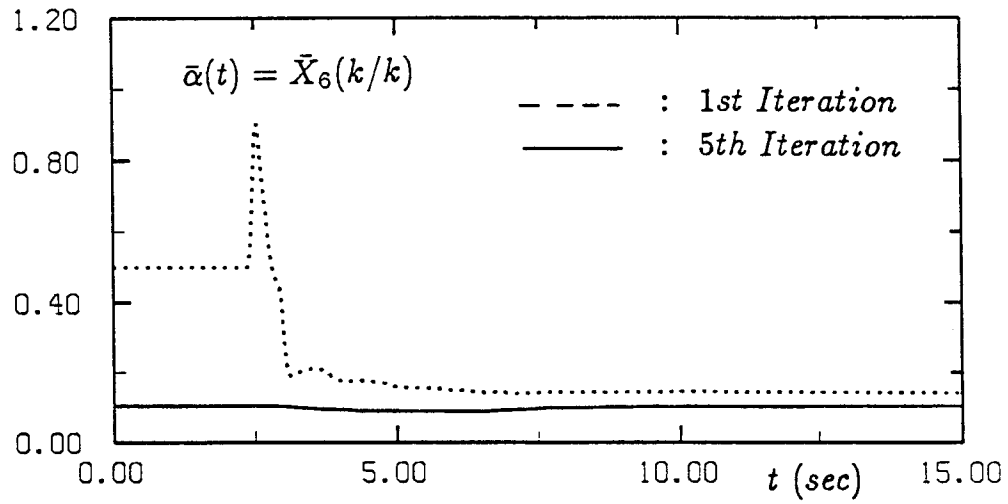
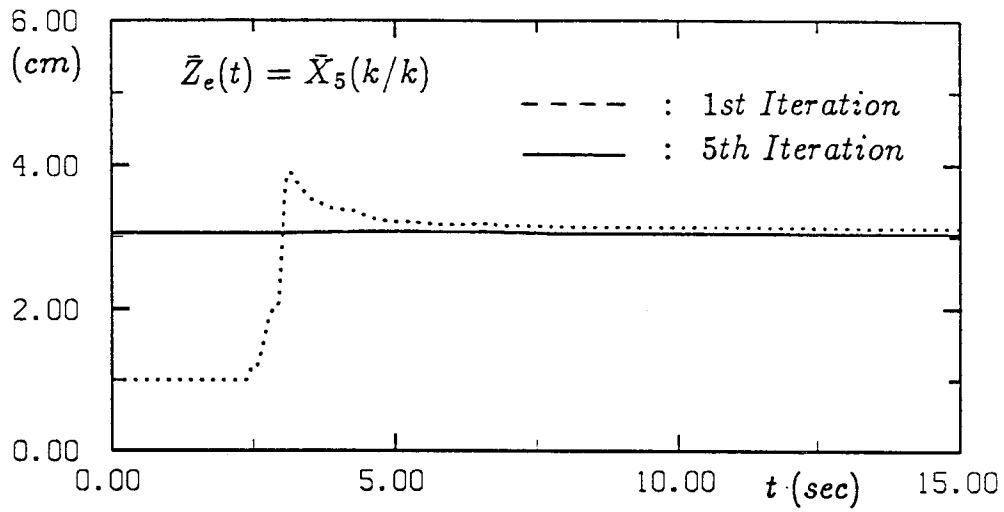


FIGURE 7-9 Convergency Processes of Estimated Parameters as Augmented State Variables (ICON=5; Step II in Table 7-IV)

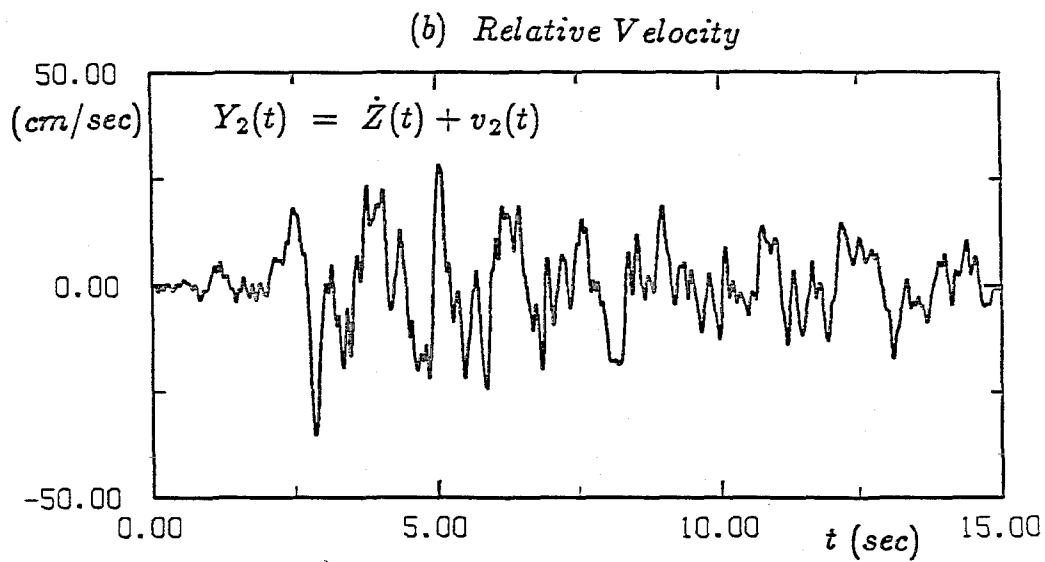
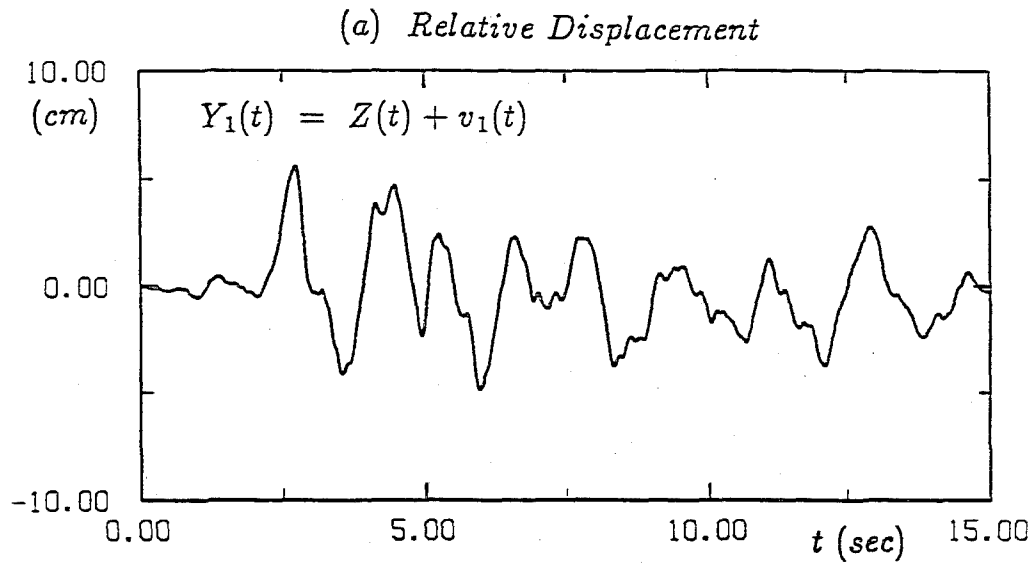
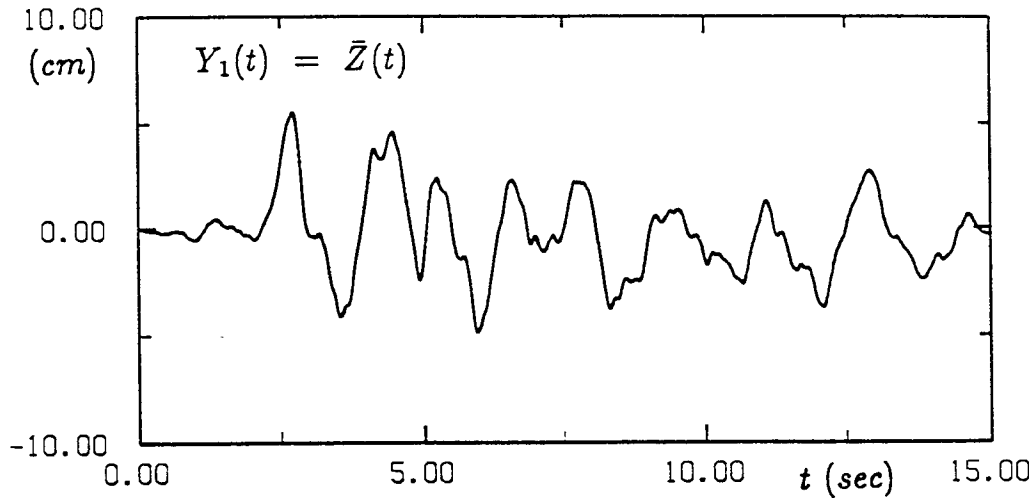


FIGURE 7-10 Response Observations of Nonlinear SDOF Structure with Bouc-Wen's Hysteresis (ICON=6; No Observational Noise Condition)

(a) *Relative Displacement*



(b) *Relative Velocity*

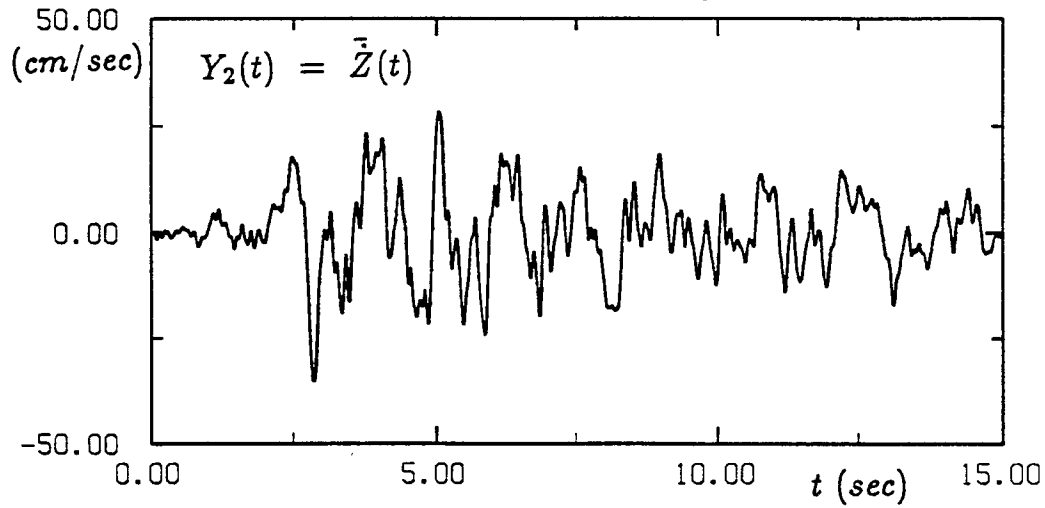


FIGURE 7-11 Estimated Response Based on the Identified Parameters (ICON=6; No Observational Noise Condition)

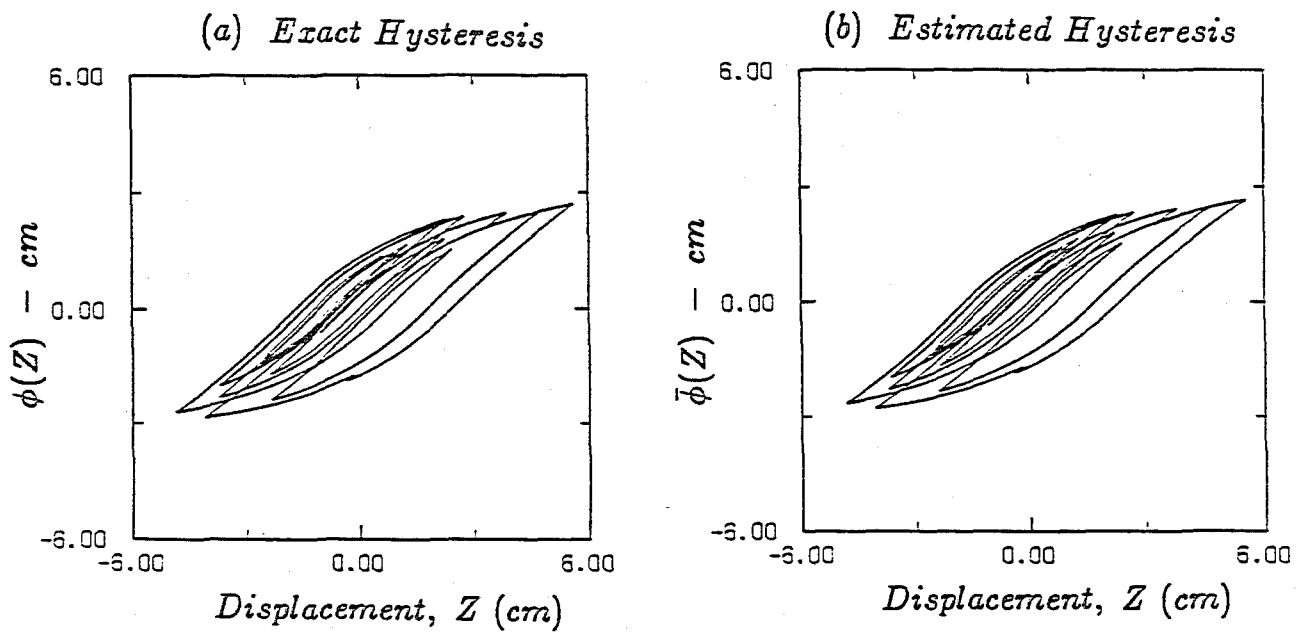


FIGURE 7-12 Exact and Estimated Hystereses of Bouc-Wen's Model
(ICON=6; No Observational Noise Condition)

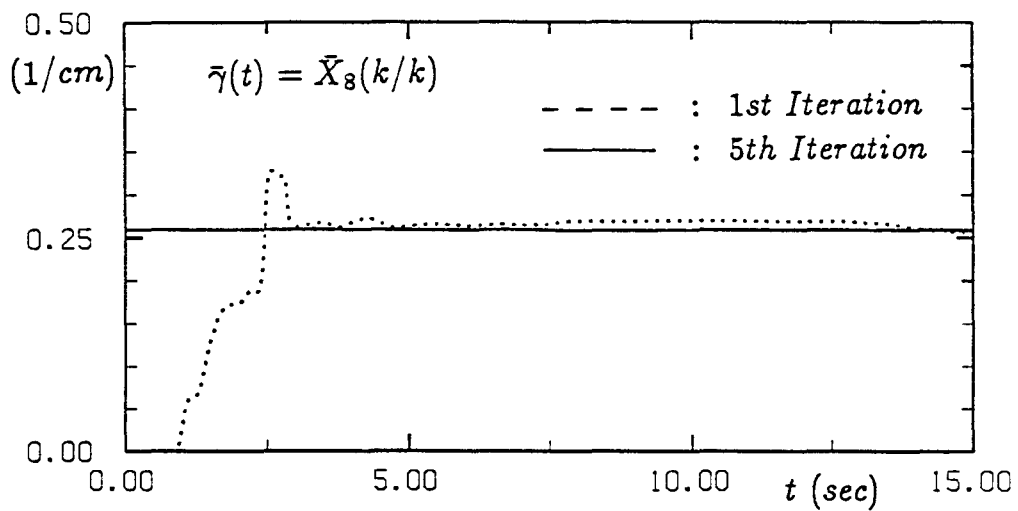
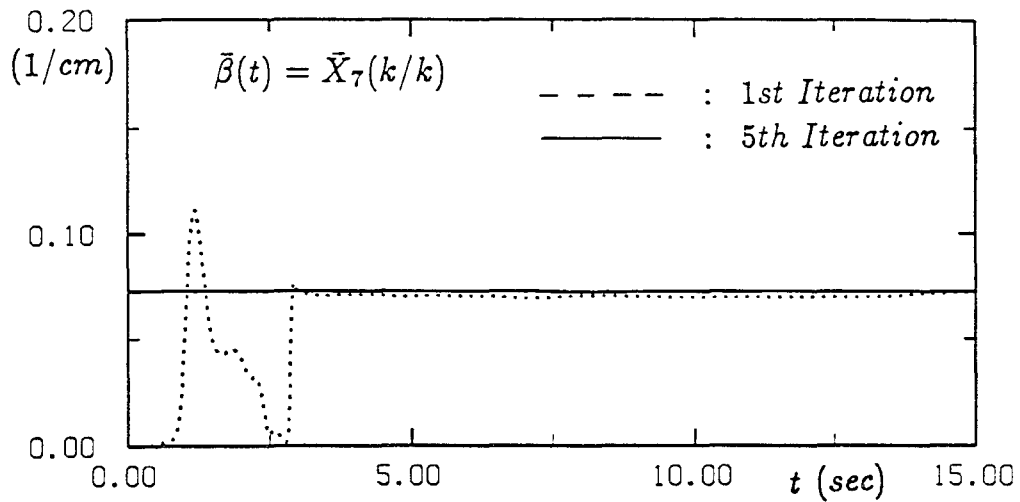


FIGURE 7-13 Convergency Processes of Estimated Parameters as Augmented State Variables (ICON=6; Step II in Table 7-V)

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

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1          PROGRAM EXKAL2
2 C *****
3 C          PROGRAM EXKAL2
4 C *****
5 C    A COMPUTER PROGRAM FOR SYSTEM IDENTIFICATION UNDER SEISMIC EXCIATION
6 C    BY THE EXTENDED KALMAN FILTERING WITH WEIGHTED GLOBAL ITERATION.
7 C    (EK-WGI PROCEDURE)
8 C *****
9 C    EACH PROGRAM IS ORIGINALLY CODED BY DR.E.SAITO AND O.MARUYAMA
10 C    UNDER THE GUIDANCE OF PROF. M.HOSHIYA
11 C    DEPARTMENT OF CIVIL ENGINEERING
12 C    MUSASHI INSTITUTE OF TECHNOLOGY
13 C    1-28-1, TAMAZUTSUMI SETAGAYA-KU,
14 C    TOKYO 158,JAPAN
15 C -----
16 C    LATER SUMMARIZED BY DR.O.MARUYAMA
17 C    UNDER THE SUPERVISION OF PROF. M.SHINOZUKA
18 C    DEPARTMENT OF CIVIL ENGINEERING AND OPERATIONS RESEARCH
19 C    SCHOOL OF ENGINEERING/APPLIED SCIENCE
20 C    PRINCETON UNIVERSITY PRINCETON, N.J. 08544, U.S.A.
21 C
22 C    THIS IS VERSION *** EXKAL2 *****
23 C    (04, JANUARY 1989)
24 C *****
25 C    THIS PROGRAM IS FOR IDENTIFICATION OF
26 C    (1) LINEAR MULTI-DEGREE OF FREEDOM SYSTEM IN TIME DOMAIN.
27 C    (2) LINEAR MULTI-DEGREE OF FREEDOM SYSTEM IN FREQUENCY DOMAIN.
28 C    (3) NONLINEAR SINGLE DEGREE OF FREEDOM SYSTEM IN TIME DOMAIN.
29 C
30 C *****
31 C
32 C    INPUT DATA FILES:
33 C
34 C    GENERAL INPUT DATA: UNIT=3
35 C    SEE THE DESCRIPTION OF INPUT DATA IN UNIT 3
36 C
37 C    EXCITATION/RESPONSE OBSERVATIONS: UNIT=8
38 C    SEE THE DESCRIPTION OF INPUT DATA IN UNIT 8
39 C
40 C    OUTPUT DATA FILES:
41 C
42 C    GENERAL OUTPUT: UNIT=6
43 C
44 C    ESTIMATED HYSTERESIS AND CONVERGENCY PROCESS OF PARAMETERS:
45 C    UNIT=22-30
46 C
47 C *****
48 C    < DESCRIPTION OF INPUT DATA IN UNIT 3 >
49 C    *** FREE FORMAT ***
50 C *****
51 C
52 C    1. HEADING CARD
53 C
54 C    2. MASTER CONTROL CARD; ICON,NCON,ITE,PITE
55 C
56 C    ICON: ANALYSIS CASE
57 C    ICON=1 : LINEAR (MDOF) RUNGE-KUTTA METHOD
58 C    ICON=2 : LINEAR (MDOF) LINEAR ACCLERATION METHOD
59 C    ICON=3 : LINEAR (MDOF) FREQUENCY DOMAIN
60 C    ICON=4 : NONLINEAR (SDOF) NONPARAMETRIC MODEL

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61 C ICON=5 : NONLINEAR (SDOF) BILINEAR HYSTRESIS
62 C ICON=6 : NONLINEAR (SDOF) BOUC-WEN'S MODEL
63 C
64 C NCON : OUTPUT COTROL
65 C
66 C IF(ICON.LE.3), NO OUTPUT DATA FILES EXCEPT UNIT 6 ARE GENERATED AND
67 C ANY POSITIVE INTEGER VALUE MAY BE INPUT FOR NCON.
68 C
69 C IF(ICON.GE.4 AND NCON=1), UNIT 22-30 ARE GENERATED FOR PLOTTING.
70 C UNIT=22 : ESTIMATED HYSTERESIS
71 C UNIT=23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
72 C
73 C ITE : TOTAL NUMBER OF GLOBAL ITERATIONS (ITE.GE.1)
74 C
75 C PITE : WEIGHT FOR EK-WGI PROCEDURE (PITE.GT.1.0)
76 C

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

78 C
79 C N : NUMBER OF DEGREES OF FREEDOM(OR MODES) TO BE IDENTIFIED
80 C

81 C I1 : DIMENSION OF EXTENDED STATE VECTOR (I1.LE.30)
82 C

83 C TABLE 5-I COMPONENTS OF STATE VECTOR

ICON	I1	COMPONENTS OF STATE VECTOR
1	5*N	U _{ij} , dU _{ij} /dt, h _j , w _j , P _{ij} for each mode j=1,...,N
2	6*N	U _{ij} , dU _{ij} /dt, ddU _{ij} /dtdt, h _j , w _i , P _{ij} for each mode j=1,...,N
3	3*N	h _j , w _j , P _{ij} for each mode j=1,...,N
4	6	Z, dZ/dt, a ₁ , a ₂ , a ₃ , a ₄
5	6	Z, dZ/dt, h, w, Z _e , alfa
6	12	Z, dZ/dt, phi, e, h, w, be, ga, A ₀ , ca, cv, cn

101 C
102 C NOTE :

103 C FOR ICON=6, (SEE SECTION 3.4)

104 C phi = hysteretic function,

105 C e = dissipated hysteretic energy,

106 C h = damping ratio, w = natural frequency,

107 C be = beta, ga = gamma,

108 C A₀ = A₀, ca = delta A, cv = delta nu, cn = delta eta
109 C

110 C I2 : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING

111 C IF ICON IS 1,4,5 OR 6, I2 IS RECOMMENED AS 2.

112 C IF ICON IS 3, I2 MUST BE 2.
113 C

114 C MC2 : CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED

115 C (REQUIRED ONLY FOR ICON=2)
116 C

117 C TABLE 5-II RESPONSE OBSERVATIONS* USED

ICON	I2	MC2	RESPONSE COMPONENTS USED

121	C	1	1		DISPLACEMENT ONLY
122	C		2		DISPLACEMENT AND VELOCITY
123	C	-----			
124	C	2	1	1	DISPLACEMENT RESPONSE
125	C			2	VELOCITY RESPONSE
126	C			3	ACCELERATION RESPONSE
127	C	-----			
128	C		2	1	DISPLACEMENT AND VELOCITY RESPONSE
129	C			2	ACCELERATION AND VELOCITY RESPONSE
130	C	-----			
131	C	3	2		REAL AND IMAGINARY PARTS OF FREQUENCY
132	C				RESPONSE FUNCTION WILL BE USED.
133	C	-----			
134	C	4	1		DISPLACEMENT ONLY
135	C		2		DISPLACEMENT AND VELOCITY
136	C	-----			
137	C	5	1		DISPLACEMENT ONLY
138	C		2		DISPLACEMENT AND VELOCITY
139	C	-----			
140	C	6	1		DISPLACEMENT ONLY
141	C		2		DISPLACEMENT AND VELOCITY
142	C	-----			

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

- 145 C
- 146 C 4. OBSERVATION DATA CARD; NN,DT,NM1,NM2
- 147 C
- 148 C NN : TOTAL NUMBER OF OBSERVATION DATA POINTS OF EACH RECORD
- 149 C DT : TIME INCREMENT (SEC) OR FREQUENCY INCREMENT (RAD/SEC) IN DATA
- 150 C NM1 : STRATING DATA POINT USED FOR FILTERING
- 151 C NM2 : ENDING DATA POINT USED FOR FILTERING
- 152 C
- 153 C 5. INITIAL GUESS FOR FILTERED STATE VECTOR; Y2(I,1), I=1,I1
- 154 C
- 155 C DATA MUST BE SUPPLIED FOR Y2(I,1), I=1,I1.
- 156 C FOR DEFINITION OF STATE VECTOR Y2(I), SEE TABLE 5-I.
- 157 C
- 158 C 6. INITIAL GUESS FOR ERROR COVARIANCE MATRIX OF THE FILTERED STATE;
- 159 C P11(I), I=1,I1
- 160 C
- 161 C INITIAL VALUES FOR THE ERROR COVARIANCE MATRIX OF THE FILTERED
- 162 C STATE VECTOR IS ASSUMED AS DIAGONAL. INITIAL VALUES OF THE
- 163 C DIAGONAL MEMBERS MUST BE SUPPLIED; P11(I), I=1,I1.
- 164 C
- 165 C 7. SYSTEM NOISE COVARIANCE MATRIX; QR1(I), I=1,I1
- 166 C
- 167 C COVARIANCE MATRIX OF SYSTEM NOISE IS ASSUMED TO BE DIAGONAL.
- 168 C VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPLIED; QR1(I), I=1,I1
- 169 C
- 170 C 8. SYSTEM NOISE COEFFICIENT MATRIX; G11(I), I=1,I1
- 171 C
- 172 C COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
- 173 C DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
- 174 C MUST BE PROVIDED; G11(I), I=1,I1
- 175 C
- 176 C 9. OBSERVATION NOISE COVARIANCE MATRIX; QR2(I), I=1,I2
- 177 C
- 178 C COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
- 179 C DIAGONAL. DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
- 180 C QR2(I), I=1,I2.

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181 C
182 C *****
183 C *****
184 C < DESCRIPTION OF INPUT DATA IN UNIT 8 >
185 C *****
186 C
187 C ***** IF ICON = 1,2,4,5 AND 6 *****
188 C
189 C 1. HEADING CARD (72A)
190 C
191 C 2. MASTER CONTROL DATA ; NRSP (I5)
192 C
193 C NRSP : NUMBER OF RESPONSE COMPONENT RECORDS AT A CERTAIN NODE
194 C TO BE SUPPLIED IN THIS DATA FILE (NRSP.LE.3)
195 C
196 C 3. GROUND ACCELERATION DATA
197 C
198 C 3-A. TITLE CARD (72A)
199 C
200 C 3-B. GROUND ACCELERATION DATA ( 8(1PE10.3) )
201 C NUMBER OF DATA POINTS (NN) AND TIME INTERVAL (DT) MUST BE
202 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
203 C
204 C 4. RESPONSE OBSERVATION DATA
205 C
206 C NRSP COMPONENTS OF RESPONSE OBSERVATIONS MUST BE PROVIDED.
207 C (FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
208 C TO THE GROUND MOTION MUST BE USED.)
209 C
210 C FOR EACH COMPONENT, FOLLOWING SET OF DATA MUST BE SUPPLIED.
211 C
212 C 4-A. TITLE OF RESPONSE COMPONENT ( 72A )
213 C
214 C 4-B. RESPONSE COMPONENT INDICATOR ( I5 )
215 C = 1, FOR DISPLACEMENT
216 C 2, FOR VELOCITY
217 C 3, FOR ACCELERATION
218 C
219 C 4-C. OBSERVED RESPONSE DATA ( 8(1PE10.3) )
220 C NUMBER OF DATA POINTS (NN) AND TIME INTERVAL (DT) MUST BE
221 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
222 C
223 C ***** IF ICON = 3 *****
224 C
225 C 1. HEADING CARD ( 72A )
226 C
227 C 2. MASTER CONTROL CARD ; NRSP ( I5 )
228 C NRSP = 2 (REAL & IMAGINARY PARTS OF FREQUENCY RESPONSE FUNCTION)
229 C
230 C 3. REAL PARTS OF FREQUENCY RESPONSE FUNCTION
231 C
232 C 3-A. TITLE CARD ( 72A )
233 C
234 C 3-B RESPONSE COMPONENT INDICATOR ( I5 )
235 C = 1 (REAL PARTS)
236 C
237 C 3-C. REAL PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
238 C NUMBER OF DATA POINTS (NN) AND FREQ. INTERVAL (DW) MUST BE
239 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
240 C

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241 C 4. IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION
242 C
243 C 4-A. TITLE CARD ( 72A )
244 C
245 C 4-B RESPONSE COMPONENT INDICATOR ( I5 )
246 C = 2 (IMAGINERY PARTS)
247 C
248 C 4-C. IMAGINERY PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
249 C NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
250 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
251 C
252 C *****
253 C
254 C PARAMETER (J1=30, J2=10, J3=3000, J5=3)
255 C DIMENSION AK(J1, J2), P1(J1, J1), H1(J2, J1), H2(J1, J2),
256 C * R(J2, J2), P2(J1, J1), W1(J1, J1), W2(J1, J1),
257 C * G1(J1, J1), G2(J1, J1), Q(J1, J1), P11(J1),
258 C * G11(J1), DY(J3), Y(J2, J3), Z(J2, 1), Y3(J1, J3),
259 C * Y1(J1, 1), Y2(J1, 1), QR1(J1), QR2(J2), AHH(J2, 1),
260 C * F(J1, 1), GG1(J3), Y4(J1, J3), P3(J1, J1), YC(J2, J3),
261 C * DYC(J3), MC(J5)
262 C
263 C ---- READ GENERAL INPUT AND
264 C INITIAL GUESS FOR EK-WGI METHOD (UNIT=3)-----
265 C CALL READB(QR1, QR2, Y2, P11, G11, N, NN, I1, I2,
266 C * DT, J1, J2, J5, ITE, PITE, NM1, NM2, MC, ICON, NCON, AAZ)
267 C
268 C ---- OBSERVATION DATA FOR INPUT EXCITATION
269 C AND OUTPUT RESPONSE (UNIT=8)-----
270 C CALL READD(DY, Y, NN, I2, J2, J3, ICON, MC)
271 C
272 C ND=NM2-NM1+1
273 C ND3=NM1
274 C ND5=NM2
275 C CALL SETIK(ICON, IK1, Y, NM1, J2, J3)
276 C
277 C ----- SET INITIAL GUESS FOR EK-WGI METHOD -----
278 C CALL INIT(Q, P2, G1, R, H1, QR1, QR2, P11, G11, I1, I2, J1, J2, F)
279 C
280 C ----- START WITH THE FILTERED STATE VECTOR [Y2]
281 C AND ITS ERROR COVARIANCE MATRIX [P2] -----
282 C WRITE(6,1200) (Y2(I,1), I=1, I1)
283 C WRITE(6,1200) (P2(I,I), I=1, I1)
284 C 1200 FORMAT(1H , 6(1X, E11.5))
285 C
286 C *****
287 C * EXTENDED KALMAN FILTER WEIGHTED GLOBAL ITERATION METHOD *
288 C *****
289 C
290 C DO 9500 KKK=1, ITE
291 C
292 C WRITE(6,8000)
293 C 8000 FORMAT(1H , ' ')
294 C WRITE(6,1300) KKK
295 C 1300 FORMAT(1H , 3X, '***** NUMBER OF ITERATIONS=', I5, '*****')
296 C
297 C
298 C IF(ICON.NE.3) THEN
299 C IF(ICON.EQ.1.OR.ICON.EQ.2) THEN
300 C IF(ICON.EQ.1) IQ=5

```

```

301      IF (ICON.EQ.2) IQ=6
302      DO 131 I=1,N
303      II=IQ*(I-1)
304      DO 132 IK=1,IK1
305      Y2 (II+IK,1)=0.0
306      132 CONTINUE
307      131 CONTINUE
308      ELSE
309      DO 130 IK=1,IK1
310      Y2 (IK,1)=0.0
311      130 CONTINUE
312      END IF
313      END IF
314      C
315      DO 135 I=1,I1
316      DO 135 J=1,I1
317      135 P3 (I,J)=0.0
318      C
319      IF (KKK.EQ.1) GO TO 140
320      C ----- WEIGHTED GLOBAL ITERATIONS -----
321      C      *PITE=WEIGHT OF GLOBAL ITERATIONS
322      C
323      DO 150 I=1,I1
324      DO 160 J=1,I1
325      P3 (I,J)=P2 (I,J)*PITE
326      P2 (I,J)=P3 (I,J)
327      160 CONTINUE
328      150 CONTINUE
329      C -----
330      140 CONTINUE
331      C
332      WRITE (6,8000)
333      WRITE (6,1800)
334      1800 FORMAT (1H , 'INITIAL GUESS OF THE STATE VECTOR =')
335      WRITE (6,1400) (Y2 (I,1),I=1,I1)
336      1400 FORMAT (1H , 6(1X,F11.5))
337      C
338      NZ=1
339      XK=0.0
340      XXX=0.0
341      C
342      WRITE (6,8000)
343      WRITE (6,1500) ND3,ND5
344      1500 FORMAT (1H , 'ND3=' , I5, 5X, 'ND5=' , I5)
345      C
346      C *****
347      C * EXTENDED KALMAN FILTER *
348      C *****
349      C
350      DO 9000 KK=ND3,ND5
351      C
352      KQ=KK-ND3+1
353      C
354      C ----- COMPUTE THE PREDICTED STATE VECTOR [Y1]
355      C      AND ITS STATE TRANSITION MATRIX [W1] -----
356      IF (ICON.EQ.1) GO TO 3100
357      IF (ICON.EQ.2) GO TO 3200
358      IF (ICON.EQ.3) GO TO 3300
359      IF (ICON.EQ.4) GO TO 3400
360      IF (ICON.EQ.5) GO TO 3500

```

```

361         IF (ICON.EQ.6) GO TO 3600
362     C
363     3100 CONTINUE
364     C
365     C ***** LINEAR-MDOF (ICON=1) *****
366     C (CONTINUOUS STATE EQUATION WITH RUNGE-KUTTA METHOD)
367     C
368     CALL FF1 (N, F, Y2, Y1, I1, DY, DT, J1, J3, KK)
369     CALL WW1 (N, W1, Y2, I1, J1, J3, DT, DY, KK)
370     GO TO 4000
371     C
372     3200 CONTINUE
373     C
374     C ***** LINEAR-MDOF (ICON=2) *****
375     C (DISCRETE STATE EQUATION WITH LINEAR ACCELERATION METHOD)
376     C
377     CALL FF2 (F, Y2, Y1, I1, DY, DT, J1, J3, KK, N, MC)
378     CALL WW2 (W1, Y2, DY, I1, J1, DT, KK, J3, N, MC)
379     GO TO 4000
380     C
381     3300 CONTINUE
382     C
383     C ***** LINEAR-MDOF (ICON=3) *****
384     C (FREQUENCY DOMAIN FORMULATION)
385     C
386     CALL FF3 (F, Y2, Y1, J1, I1)
387     CALL WW3 (W1, Y2, I1, J1)
388     GO TO 4000
389     C
390     3400 CONTINUE
391     C
392     C ***** NONLINEAR-SDOF (ICON=4) *****
393     C (NONPARAMETRIC RESTORING FORCE MODEL)
394     C
395     CALL FF4 (F, Y2, Y1, DY, DT, J1, J3, KK, NM1)
396     CALL WW4 (W1, Y2, I1, J1, DT)
397     BB1=Y2 (3, 1)*Y2 (1, 1)+Y2 (4, 1)*Y2 (1, 1)*Y2 (1, 1)*Y2 (1, 1)
398     BB2=Y2 (5, 1)*Y2 (2, 1)+Y2 (6, 1)*Y2 (2, 1)*Y2 (2, 1)*Y2 (2, 1)
399     C ***** GG1: ESTIMATED HYSTERESIS *****
400     GG1 (KQ)=BB1+BB2
401     GO TO 4000
402     C
403     3500 CONTINUE
404     C
405     C ***** NONLINEAR-SDOF (ICON=5) *****
406     C (BILINEAR HYSTERETIC RESTORING FORCE MODEL)
407     C
408     CALL FF5 (F, Y2, Y1, DY, DT, J1, J3, KK, NZ, XX, XXX, AK1)
409     CALL WW5 (W1, Y2, DT, I1, J1, XX, NZ, XXX)
410     C ***** GG1: ESTIMATED HYSTERESIS *****
411     GG1 (KQ)=AK1
412     GO TO 4000
413     C
414     3600 CONTINUE
415     C
416     C ***** NONLINEAR-SDOF (ICON=6) *****
417     C (BOUC-WEN'S HYSTERETIC RESTORING FORCE MODEL)
418     C
419     CALL FF6 (F, Y2, Y1, DY, DT, J1, J3, KK, AAZ, NM1)
420     CALL WW6 (W1, Y2, I1, J1, DT, KK, AAZ, NM1)

```



```

421 C ***** GG1: ESTIMATED HYSTERESIS *****
422 GG1(KQ)=Y2(3,1)
423 C
424 4000 CONTINUE
425 C
426 DYC(KQ)=DY(KK)
427 DO 170 JC=1, I2
428 170 YC(JC, KQ)=Y(JC, KK)
429 C
430 DO 180 I=1, I1
431 180 Y4(I, KQ)=P2(I, I)
432 C
433 C --- COMPUTE THE ERROR COVARIANCE MATRIX
434 C OF THE PREDICTED STATE [P1]-----
435 CALL STEP5(P1, W1, P2, W2, G1, Q, G2, I1, J1)
436 C
437 DO 190 I=1, I1
438 190 Y3(I, KQ)=Y2(I, 1)
439 C
440 C
441 IF(KK.EQ.ND5) GO TO 9000
442 CALL HH1(H1, I2, DT, J1, J2, KK, ICON, Y1, N)
443 C
444 C --- COMPUTE THE KALMAN GAIN MATRIX [AK] -----
445 CALL STEP1(AK, P1, H1, H2, R, I1, I2, J1, J2)
446 C
447 DO 100 I=1, I2
448 Z(I, 1)=Y(I, KK+1)
449 100 CONTINUE
450 C
451 CALL HH2(N, AHH, Y1, KK, DT, I2, J1, J2, ICON)
452 C
453 C --- COMPUTE THE FILTERED STATE VECTOR [Y2] -----
454 CALL STEP2(Y2, Y1, AK, Z, AHH, I1, I2, J1, J2)
455 C
456 C --- COMPUTE THE ERROR COVARIANCE MATRIX
457 C OF THE FILTERED STATE [P2] -----
458 CALL STEP3(P2, AK, H1, P1, R, I1, I2, J1, J2)
459 C
460 IF(ICON.EQ.5.AND.KK.NE.1) THEN
461 CALL SETN(Y3, J1, J3, KK, NZ, XX, XXX)
462 END IF
463 C
464 9000 CONTINUE
465 C
466 C
467 C*****
468 C
469 IF(ICON.EQ.1.OR.ICON.EQ.2) THEN
470 DO 510 J=1, I2
471 DO 520 JJ=1, KQ
472 AA=0.0
473 DO 530 I=1, N
474 IF(ICON.EQ.1) IQ=5
475 IF(ICON.EQ.2) IQ=6
476 II=IQ*(I-1)
477 AA=AA+Y3(J+II, JJ)
478 530 CONTINUE
479 Y3(J, JJ)=AA
480 520 CONTINUE

```

```

481     510 CONTINUE
482     END IF
483 C*****
484 C     PRINT GENERAL OUTPUT (UNIT=6)
485     CALL WRITEB(YC,DYC,Y3,I2,I1,J1,J2,J3,ND,Y4)
486 C*****
487 C
488     9500 CONTINUE
489 C
490 C
491 C     *****
492 C     GENERATE OUTPUT FILE (UNIT=22-UNIT=30) FOR PLOTTING
493     CALL WRITEC(ICON,NCON,DT,N,ND,Y3,GG1,J1,J3)
494 C*****
495     STOP
496     END
497 C
498 C     ***** SUBROUTINE READB *****
499 C     *
500 C     * SUBROUTINE FOR READING GENERAL INPUT DATA FROM UNIT 3 *
501 C     *     CALLED BY THE MAIN PROGRAM     *
502 C     *****
503 C
504 C     PURPOSE:
505 C     TO READ GENERAL INPUT DATA AND INITIAL GUESS FROM UNIT=3
506 C
507 C     USAGE:
508 C     CALL READB(QR1,QR2,Y2,P11,G11,N,NN,I1,I2,DT,
509 C     *     J1,J2,J5,ITE,PITE,NM1,NM2,MC,ICON,NCON,AAZ)
510 C
511 C     *****
512 C     < DESCRIPTION OF INPUT DATA IN UNIT 3 >
513 C     *** FREE FORMAT ***
514 C     *****
515 C
516 C     1. HEADING CARD
517 C
518 C     2. MASTER CONTROL CARD; ICON,NCON,ITE,PITE
519 C
520 C     ICON: ANALYSIS CASE
521 C     ICON=1 : LINEAR (MDOF) RUNGE-KUTTA METHOD
522 C     ICON=2 : LINEAR (MDOF) LINEAR ACCLERATION METHOD
523 C     ICON=3 : LINEAR (MDOF) FREQUENCY DOMAIN
524 C     ICON=4 : NONLINEAR (SDOF) NONPARAMETRIC MODEL
525 C     ICON=5 : NONLINEAR (SDOF) BILINEAR HYSTRESIS
526 C     ICON=6 : NONLINEAR (SDOF) BOUC-WEN'S MODEL
527 C
528 C     NCON : OUTPUT COTROL
529 C
530 C     IF(ICON.LE.3), NO OUTPUT DATA FILES EXCEPT UNIT 6 ARE GENERATED AND
531 C     ANY POSITIVE INTEGER VALUE MAY BE INPUT FOR NCON.
532 C
533 C     IF(ICON.GE.4 AND NCON=1), UNIT 22-30 ARE GENERATED FOR PLOTTING.
534 C     UNIT=22 : ESTIMATED HYSTERESIS
535 C     UNIT=23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
536 C
537 C     ITE : TOTAL NUMBER OF GLOBAL ITERATIONS (ITE.GE.1)
538 C
539 C     PITE : WEIGHT FOR EK-WGI PROCEDURE (PITE.GT.1.0)
540 C

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541 C 3. CONTROL CARD; N,I1,I2,MC2
 542 C
 543 C N : NUMBER OF DEGREES OF FREEDOM(OR MODES) TO BE IDENTIFIED
 544 C
 545 C I1 : DIMENSION OF EXTENDED STATE VECTOR (I1.LE.30)
 546 C

547 C TABLE 5-I COMPONENTS OF STATE VECTOR

ICON	I1	COMPONENTS OF STATE VECTOR
1	5*N	U _{ij} , dU _{ij} /dt, h _j , w _j , P _{ij} for each mode j=1,...,N
2	6*N	U _{ij} , dU _{ij} /dt, ddU _{ij} /dt ² , h _j , w _i , P _{ij} for each mode j=1,...,N
3	3*N	h _j , w _j , P _{ij} for each mode j=1,...,N
4	6	Z, dZ/dt, a ₁ , a ₂ , a ₃ , a ₄
5	6	Z, dZ/dt, h, w, Z _e , alfa
6	12	Z, dZ/dt, phi, e, h, w, b _e , g _a , A ₀ , c _a , c _v , c _n

565 C
 566 C NOTE :

567 C FOR ICON=6, (SEE SECTION 3.4)

568 C phi = hysteretic function,

569 C e = dissipated hysteretic energy,

570 C h = damping ratio, w = natural frequency,

571 C b_e = beta, g_a = gamma,

572 C A₀ = A₀, c_a = delta A, c_v = delta nu, c_n = delta eta

573 C
 574 C I2 : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING

575 C IF ICON IS 1,4,5 OR 6, I2 IS RECOMMENED AS 2.

576 C IF ICON IS 3, I2 MUST BE 2.

577 C
 578 C MC2 : CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED

579 C (REQUIRED ONLY FOR ICON=2)

580 C 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

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601 C      | 5 | 1 |      | DISPLACEMENT ONLY      |
602 C      |   | 2 |      | DISPLACEMENT AND VELOCITY |
603 C      |-----|-----|-----|
604 C      | 6 | 1 |      | DISPLACEMENT ONLY      |
605 C      |   | 2 |      | DISPLACEMENT AND VELOCITY |
606 C      |-----|-----|-----|
607 C      NOTE :
608 C          FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
609 C          TO THE GROUND MOTION MUST BE USED.
610 C
611 C      4. OBSERVATION DATA CARD; NN,DT,NM1,NM2
612 C
613 C          NN : TOTAL NUMBER OF OBSERVATION DATA POINTS OF EACH RECORD
614 C          DT : TIME INCREMENT (SEC) OR FREQUENCY INCREMENT (RAD/SEC) IN DATA
615 C          NM1 : STRATING DATA POINT USED FOR FILTERING
616 C          NM2 : ENDING DATA POINT USED FOR FILTERING
617 C
618 C      5. INITIAL GUESS FOR FILTERED STATE VECTOR; Y2(I,1), I=1,I1
619 C
620 C          DATA MUST BE SUPPLIED FOR Y2(I,1), I=1,I1.
621 C          FOR DEFINITION OF STATE VECTOR Y2(I), SEE TABLE 5-I.
622 C
623 C      6. INITIAL GUESS FOR ERROR COVARIANCE MATRIX OF THE FILTERED STATE;
624 C          P11(I), I=1,I1
625 C
626 C          INITIAL VALUES FOR THE ERROR COVARIANCE MATRIX OF THE FILTERED
627 C          STATE VECTOR IS ASSUMED AS DIAGONAL. INITIAL VALUES OF THE
628 C          DIAGONAL MEMBERS MUST BE SUPPLIED; P11(I), I=1,I1.
629 C
630 C      7. SYSTEM NOISE COVARIANCE MATRIX; QR1(I), I=1,I1
631 C
632 C          COVARIANCE MATRIX OF SYSTEM NOISE IS ASSUMED TO BE DIAGONAL.
633 C          VALUES OF THE DIAGONAL MEMBERS MUST BE SUPPLIED; QR1(I), I=1,I1
634 C
635 C      8. SYSTEM NOISE COEFFICIENT MATRIX; G11(I), I=1,I1
636 C
637 C          COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
638 C          DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
639 C          MUST BE PROVIDED; G11(I), I=1,I1
640 C
641 C      9. OBSERVATION NOISE COVARIANCE MATRIX; QR2(I), I=1,I2
642 C
643 C          COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
644 C          DIAGONAL. DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
645 C          QR2(I), I=1,I2.
646 C
647 C *****
648 C
649 C      REMARKS:
650 C          (1) PARAMETER I1 MUST BE LESS THAN 30
651 C          (2) PARAMETER I2 MUST BE LESS THAN 10
652 C
653 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
654 C          NONE
655 C *****
656 C
657 C          SUBROUTINE READB(QR1,QR2,Y2,P11,G11,N,NN,I1,I2,DT,
658 C          *          J1,J2,J5,ITE,PITE,NM1,NM2,MC,ICON,NCON,AAZ)
659 C          CHARACTER*72 TEXT
660 C          DIMENSION QR1(J1),QR2(J2),Y2(J1,1)

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661     DIMENSION MC(J5),P11(J1),G11(J1)
662   C
663     READ(3,1200) TEXT
664   1200 FORMAT(72A)
665   C
666     READ(3,*) ICON,NCON,ITE,PITE
667   C
668     IF(ICON.NE.2) READ(3,*) N,I1,I2
669     IF(ICON.EQ.2) READ(3,*) N,I1,I2,MC2
670   C
671     READ(3,*) NN,DT,NM1,NM2
672   C
673     READ(3,*) (Y2(I,1),I=1,I1)
674   C
675     READ(3,*) (P11(I),I=1,I1)
676   C
677     READ(3,*) (QR1(I),I=1,I1)
678   C
679     READ(3,*) (G11(I),I=1,I1)
680   C
681     READ(3,*) (QR2(I),I=1,I2)
682   C
683   C
684     AAZ=1.0
685     MC(1)=1
686     MC(2)=MC2
687     IF(I2.EQ.2.AND.MC(2).EQ.2) MC(2)=3
688   C
689     WRITE(6,1210) TEXT
690   1210 FORMAT(2X,72A/)
691   C
692     WRITE(6,8000)
693     WRITE(6,1201) ICON
694   1201 FORMAT(1H,'ANALYSIS CASE : ICON====>',I5)
695   C
696     WRITE(6,8000)
697     WRITE(6,1202) NCON
698   1202 FORMAT(1H,'OUTPUT CONTROL : NCON====>',I5)
699   C
700     WRITE(6,8000)
701     WRITE(6,1203) ITE
702   1203 FORMAT(1H,'NO. OF GLOBAL ITERATIONS : ITE====>',I5)
703   C
704     WRITE(6,8000)
705     WRITE(6,1204) PITE
706   1204 FORMAT(1H,'WEIGHT FOR GLOBAL ITERATION : PITE====>',2X,E15.4)
707   C
708     WRITE(6,8000)
709     WRITE(6,1205) N
710   1205 FORMAT(1H,'NO. OF DOF OF SYSTEM : N====>',I5)
711   C
712     WRITE(6,8000)
713     WRITE(6,1206) I1
714   1206 FORMAT(1H,'DIMENSION OF STATE VECTOR : I1====>',I5)
715   C
716     WRITE(6,8000)
717     WRITE(6,1207) I2
718   1207 FORMAT(1H,'NO. OF RESPONSE OBSERVATIONS USED : I2====>',I5)
719   C
720     IF(ICON.EQ.2) THEN

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```

721      WRITE(6,8000)
722      WRITE(6,1208) MC2
723 1208 FORMAT(1H , 'CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED '
724 1      , ' : MC2 ==>', 2X, I5)
725      END IF
726  C
727      WRITE(6,8000)
728      WRITE(6,1020) NN,DT,NM1,NM2
729 1020 FORMAT(1H , 'DATA OF OBSERVED RECORDS TO BE USED :'/
730 1      1H , ' NN=', I5, '      DT=', F10.4, '      NM1=', I5, '      NM2=', I5)
731  C
732      WRITE(6,8000)
733      WRITE(6,1041)
734 1041 FORMAT(1H , 'INITIAL GUESS OF STATE VECTOR : Y2==>')
735      WRITE(6,1040) (Y2(I,1), I=1, I1)
736 1040 FORMAT(1H , 6(2X, E10.3))
737  C
738      WRITE(6,8000)
739      WRITE(6,1051)
740 1051 FORMAT(1H , 'INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) '
741 1      , ' : P11==>')
742      WRITE(6,1050) (P11(I), I=1, I1)
743 1050 FORMAT(1H , 6(2X, E10.3))
744  C
745      WRITE(6,8000)
746      WRITE(6,1055)
747 1055 FORMAT(1H , 'COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) :'
748 1      , ' QR1==>')
749      WRITE(6,1050) (QR1(I), I=1, I1)
750  C
751      WRITE(6,8000)
752      WRITE(6,1061)
753 1061 FORMAT(1H , 'COEFFICIENT MATRIX OF SYSTEM NOISE : G11==>')
754      WRITE(6,1060) (G11(I), I=1, I1)
755 1060 FORMAT(1H , 6(2X, E10.3))
756  C
757      WRITE(6,8000)
758      WRITE(6,1070) (QR2(I), I=1, I2)
759 1070 FORMAT(1H , 'COVARIANCE MATRIX OF OBSERVATION NOISE (DIAGONAL) '
760 1      , ' : QR2==>', /, 6(2X, E10.3))
761  C
762      WRITE(6,8000)
763  C
764 8000 FORMAT(1H , ' ')
765      RETURN
766      END
767  C
768  C ***** SUBROUTINE READD *****
769  C *
770  C * SUBROUTINE FOR READING OBSERVED INPUT EXCITATION AND *
771  C * RESPONSE OBSERVATION DATA FROM UNIT 8 *
772  C * CALLED BY THE MAIN PROGRAM *
773  C *****
774  C PURPOSE:
775  C TO READ OBSERVATION DATA FOR INPUT EXCITATION
776  C AND RESPONSE OBSERVATION FROM UNIT=8
777  C
778  C USAGE:
779  C READD(DY, Y, NN, I2, J2, J3, ICON, MC)
780  C

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781 C      DESCRIPTION OF PARAMETERS
782 C      DY(J3) : OBSERVED INPUT EXCITATION
783 C      Y(J2,J3) : OBSERVATION DATA
784 C      I2 : NUMBER OF RESPONSE OBSERVATIONS
785 C      J2,J3 : DIMENSION OF [DY] OR [Y] IN CALLING PROGRAM
786 C      ICON : PARAMETER FOR STATE VECTOR EQUATION
787 C      AND OBSERVATION EQUATION
788 C      MC : PARAMETERS FOR OBSERVATION DATA
789 C      IN (ICON.EQ.2)
790 C      REMARKS
791 C
792 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
793 C      NONE
794 C *****
795 C *****
796 C      < DESCRIPTION OF INPUT DATA IN UNIT 8 >
797 C *****
798 C
799 C ***** IF ICON = 1,2,4,5 AND 6 *****
800 C
801 C 1. HEADING CARD (72A)
802 C
803 C 2. MASTER CONTROL DATA ; NRSP (I5)
804 C
805 C      NRSP : NUMBER OF RESPONSE COMPONENT RECORDS AT A CERTAIN NODE
806 C      TO BE SUPPLIED IN THIS DATA FILE (NRSP.LE.3)
807 C
808 C 3. GROUND ACCELERATION DATA
809 C
810 C 3-A. TITLE CARD (72A)
811 C
812 C 3-B. GROUND ACCELERATION DATA ( 8(1PE10.3) )
813 C      NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
814 C      SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
815 C
816 C 4. RESPONSE OBSERVATION DATA
817 C
818 C      NRSP COMPONENTS OF RESPONSE OBSERVATIONS MUST BE PROVIDED.
819 C      (FOR EARTHQUAKE GROUND EXCITATION, RELATIVE RESPONSE RECORDS
820 C      TO THE GROUND MOTION MUST BE USED.)
821 C
822 C      FOR EACH COMPONENT, FOLLOWING SET OF DATA MUST BE SUPPLIED.
823 C
824 C 4-A. TITLE OF RESPONSE COMPONENT ( 72A )
825 C
826 C 4-B. RESPONSE COMPONENT INDICATOR ( I5 )
827 C      = 1, FOR DISPLACEMENT
828 C      2, FOR VELOCITY
829 C      3, FOR ACCELERATION
830 C
831 C 4-C. OBSERVED RESPONSE DATA ( 8(1PE10.3) )
832 C      NUMBER OF DATA POINTS(NN) AND TIME INTERVAL(DT) MUST BE
833 C      SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
834 C
835 C ***** IF ICON = 3 *****
836 C
837 C 1. HEADING CARD ( 72A )
838 C
839 C 2. MASTER CONTROL CARD ; NRSP ( I5 )
840 C      NRSP = 2 (REAL & IMAGINARY PARTS OF FREQUENCY RESPONSE FUNCTION)

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841 C
842 C 3. REAL PARTS OF FREQUENCY RESPONSE FUNCTION
843 C
844 C 3-A. TITLE CARD ( 72A )
845 C
846 C 3-B RESPONSE COMPONENT INDICATOR ( I5 )
847 C = 1 (REAL PARTS)
848 C
849 C 3-C. REAL PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
850 C NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
851 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
852 C
853 C 4. IMAGINERY PARTS OF FREQUENCY RESPONSE FUNCTION
854 C
855 C 4-A. TITLE CARD ( 72A )
856 C
857 C 4-B RESPONSE COMPONENT INDICATOR ( I5 )
858 C = 2 (IMAGINERY PARTS)
859 C
860 C 4-C. IMAGINERY PARTS OF FREQUENCY RESPONSE DATA ( 8(1PE10.3) )
861 C NUMBER OF DATA POINTS(NN) AND FREQ. INTERVAL(DW) MUST BE
862 C SAME TO THOSE SPECIFIED IN DATA FILE UNIT 3.
863 C
864 C *****
865 C
866 C SUBROUTINE READD(DY,Y,NN,I2,J2,J3,ICON,MC)
867 C IMPLICIT REAL*8(A-H,O-Z)
868 C CHARACTER*72 DUMMY
869 C DIMENSION DY(J3),Y(J2,J3)
870 C DIMENSION MC(3),A(3,3000)
871 C
872 C READ(8,101) DUMMY
873 C READ(8,102) NRSP
874 C 102 FORMAT(I5)
875 C
876 C DO 300 I=1,3
877 C DO 310 J=1,NN
878 C A(I,J)=0.0
879 C Y(I,J)=0.0
880 C DY(J)=0.0
881 C 310 CONTINUE
882 C 300 CONTINUE
883 C
884 C IF(ICON.EQ.3) GO TO 3000
885 C
886 C READ(8,101) DUMMY
887 C READ(8,5) (DY(I),I=1,NN)
888 C
889 C DO 100 J=1,NRSP
890 C READ(8,101) DUMMY
891 C READ(8,102) JDX
892 C READ(8,5) (A(JDX,I),I=1,NN)
893 C 100 CONTINUE
894 C 5 FORMAT(8(1PE10.3))
895 C 101 FORMAT(72A)
896 C
897 C IF(ICON.EQ.2) GO TO 2000
898 C
899 C DO 210 J=1,I2
900 C DO 220 K=1,NN

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901      Y(J,K)=A(J,K)
902      220 CONTINUE
903      210 CONTINUE
904      C
905      GO TO 1000
906      C
907      2000 CONTINUE
908      DO 510 I=1,3
909      M=I
910      IF(I.EQ.MC(1)) M=MC(2)
911      IF(I.EQ.MC(2)) M=MC(1)
912      DO 520 K=1,NN
913      Y(M,K)=A(I,K)
914      520 CONTINUE
915      510 CONTINUE
916      C
917      GO TO 1000
918      C
919      3000 CONTINUE
920      DO 600 I=1,2
921      READ(8,101) DUMMY
922      READ(8,102) JDX
923      READ(8,5) (Y(JDX, KK), KK=1, NN)
924      600 CONTINUE
925      C
926      1000 CONTINUE
927      C
928      RETURN
929      END
930      C
931      C ***** SUBROUTINE SETIK *****
932      C * * * * *
933      C * SUBROUTINE FOR SETTING UP INITIAL GUESS *
934      C * CALLED BY THE MAIN PROGRAM *
935      C *****
936      C
937      C
938      SUBROUTINE SETIK(ICON, IK, Y, NML, J2, J3)
939      C IMPLICIT REAL*8 (A-H, O-Z)
940      DIMENSION Y(J2, J3)
941      C
942      IK=2
943      IF(ICON.EQ.3) GO TO 200
944      IF(ICON.EQ.1) IK=2
945      IF(ICON.EQ.2) IK=3
946      IF(ICON.EQ.6) IK=4
947      C
948      DO 100 I=1, IK
949      Y(I, NML)=0.0
950      100 CONTINUE
951      200 CONTINUE
952      C
953      C
954      RETURN
955      END
956      C
957      C ***** SUBROUTINE INIT *****
958      C * * * * *
959      C * SUBROUTINE FOR SETTING UP INITIAL GUESS *
960      C * CALLED BY THE MAIN PROGRAM *

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961 C *****
962 C
963 C PURPOSE:
964 C TO SET UP INITIAL GUESS FOR EK-WGI PROCEDURE
965 C
966 C USAGE:
967 C CALL INIT(Q,P2,G1,R,H1,QR1,QR2,P11,G11,I1,I2,J1,J2,F)
968 C
969 C DESCRIPTION OF PARAMETERS
970 C Q(J1,J1) : SYSTEM NOISE COVARIANCE MATRIX
971 C P2(J1,J1) : ERROR COVARIANCE MATRIX OF THE FILTERED
972 C STATE
973 C G1(J1,J1) : SYSTEM NOISE COEFFICIENT MATRIX
974 C R(J2,J2) : OBSERVATION NOISE COVARIANCE MATRIX
975 C H1(J2,J1) : LINEARIZED MATRIX OF THE OBSERVATION EQ.
976 C REGARDING EACH PARAMETER
977 C QR1(J1) : SYSTEM NOISE COVARIANCE MATRIX
978 C QR2(J1) : OBSERVATION NOISE COVARIANCE MATRIX
979 C P11(J1) : INITIAL GUESS FOR DIAGONAL ELEMENTS OF
980 C FILTERED ERROR COVARIANCE MATRIX
981 C G11(J1) : INITIAL GUESS FOR DIAGONAL ELEMENTS OF
982 C SYSTEM NOISE COEFFICIENT MATRIX
983 C I1 : DIMENSION OF EXTENDED STATE VECTOR
984 C (I1.LE.30)
985 C I2 : NUMBER OF RESPONSE OBSERVATIONS
986 C (I2.LE.10)
987 C J1,J2: DIMENSION OF [Q],[P2],[G1],[R],[H1],[QR1],[QR2],
988 C [P11],[G11] OR [F]
989 C F(J1,1) : PREDICTED STATE VECTOR
990 C
991 C REMARK:
992 C (1) PARAMETER I1 MUST BE LESS THAN 30
993 C (2) PARAMETER I2 MUST BE LESS THAN 10
994 C
995 C SUBROUTINES AND FUNCTION SUBROUTINES REQUIRED
996 C NONE
997 C *****
998 C
999 C
1000 C SUBROUTINE INIT(Q,P2,G1,R,H1,QR1,QR2,P11,G11,
1001 C * I1,I2,J1,J2,F)
1002 C IMPLICIT REAL*8(A-H,O-Z)
1003 C DIMENSION P2(J1,J1),G1(J1,J1),R(J2,J2)
1004 C DIMENSION P11(J1),G11(J1),H1(J2,J1)
1005 C DIMENSION Q(J1,J1),F(J1,1),QR1(J1),QR2(J2)
1006 C
1007 C DO 10 I=1,I1
1008 C DO 10 J=1,I1
1009 C Q(I,J)=0.0
1010 C P2(I,J)=0.0
1011 C G1(I,J)=0.0
1012 C F(I,1)=0.0
1013 C 10 CONTINUE
1014 C
1015 C DO 20 I=1,I2
1016 C DO 20 J=1,I2
1017 C 20 R(I,J)=0.0
1018 C
1019 C DO 30 I=1,I1
1020 C P2(I,I)=P11(I)

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```

1021      G1(I,I)=G11(I)
1022      Q(I,I)=QR1(I)
1023      30 CONTINUE
1024      C
1025      DO 40 I=1,I2
1026      40 R(I,I)=QR2(I)
1027      C
1028      DO 50 I=1,I1
1029      DO 50 J=1,I2
1030      50 H1(J,I)=0.0
1031      C
1032      RETURN
1033      END
1034      C
1035      C *****          SUBROUTINE FF1          *****
1036      C *
1037      C *      SUBROUTINE FOR THE PREDICTED STATE VETCOR      *
1038      C * OF LINEAR MULTI-DEGREE OF FREEDOM SYSTEM BY SOLVING *
1039      C * DIFFERENTIAL EQUATION USING RUNGE-KUTTA METHOD.    *
1040      C *      ( ICON = 1 )                                  *
1041      C *      CALLED BY THE MAIN PROGRAM                    *
1042      C *****
1043      C
1044      C      PURPOSE:
1045      C      TO COMPUTE THE PREDICTED STATE VECTOR OF LINEAR MULTI-
1046      C      DEGREE OF FREEDOM SYSTEM (ICON.EQ.1).
1047      C
1048      C      USAGE:
1049      C      CALL FF1(N,F,Y2,Y1,I1,DY,DT,J1,J3,KK)
1050      C
1051      C      DESCRIPTION OF PARAMETERS
1052      C      N : NUMBER OF DEGREE OF STRUCTURE
1053      C      F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
1054      C      Y2(J1,1): FILTERED STATE VECTOR
1055      C      I1 : DIMENSION OF EXTENDED STATE VECTOR
1056      C      DY(J3) : OBSERVED INPUT EXCIATION
1057      C      DT : TIME INCREMENT IN DATA IN SEC
1058      C      J1,J3 : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
1059      C      PROGRAM
1060      C      KK : TIME IN DATA PROCESSING
1061      C
1062      C      REMARK:
1063      C
1064      C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1065      C      RUNGE
1066      C *****
1067      C
1068      C      SUBROUTINE FF1(N,F,Y2,Y1,I1,DY,DT,J1,J3,KK)
1069      C      IMPLICIT REAL*8(A-H,O-Z)
1070      C      DIMENSION Y2(J1,1),DY(J3),F(J1,1)
1071      C      DIMENSION QT(1,2),YY(1),Q(1,2)
1072      C      DIMENSION YT(1,2),ACK(1,2)
1073      C      DIMENSION Y(1,2),Y1(J1,1)
1074      C
1075      C
1076      C      DO 100 I=1,N
1077      C      II=5*(I-1)
1078      C
1079      C      F(3+II,1)=Y2(3+II,1)
1080      C      F(4+II,1)=Y2(4+II,1)

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1081      F(5+II,1)=Y2(5+II,1)
1082      C
1083      ACK(1,1)=Y2(4+II,1)*Y2(4+II,1)
1084      ACK(1,2)=Y2(4+II,1)*Y2(3+II,1)*2.0
1085      ARPA=Y2(5+II,1)
1086      C
1087      C
1088      DO 200 J=1,2
1089      QT(1,J)=0.0
1090      YT(1,J)=Y2(J+II,1)
1091      200 CONTINUE
1092      C
1093      DDT=DY(KK)
1094      DDY=DY(KK+1)
1095      CALL RUNGE(1,ACK,DT,DDY,DDYT,Y,YY,YT,
1096      *      Q,QT,1,5,ARPA)
1097      F(1+II,1)=Y(1,1)
1098      F(2+II,1)=Y(1,2)
1099      C
1100      100 CONTINUE
1101      C
1102      DO 300 I=1,I1
1103      Y1(I,1)=F(I,1)
1104      300 CONTINUE
1105      C
1106      RETURN
1107      END
1108      C
1109      C      *****      SUBROUTINE RUNGE      *****
1110      C      *
1111      C      *      SUBROUTINE FOR THE PREDICTED STATE VECTOR OF LINEAR      *
1112      C      *      MDOF SYSTEM BY SOLVING DEFFERENTIAL EQUATION USING      *
1113      C      *      RUNGE-KUTTA METHOD
1114      C      *      ( ICON = 1 )
1115      C      *      CALLED BY SUBROUTINE FF1
1116      C      *****
1117      C
1118      C
1119      SUBROUTINE RUNGE(N,ACK,DT,DDY,DDYT,
1120      * Y,YY,YT,Q,QT,M1,NK,ARPA)
1121      C      IMPLICIT REAL*8(A-H,O-Z)
1122      DIMENSION ACK(M1,2),Y(M1,2),YY(M1),YT(M1,2),Q(M1,2)
1123      DIMENSION QT(M1,2)
1124      DIMENSION P1(4),P2(4),P3(4),P4(4),P5(4)
1125      DIMENSION Z(10,2),T(10,2),R(10,2)
1126      DATA P1/0.5,1.0,1.0,0.5/
1127      DATA P2/1.0,0.2928932,1.7071068,0.3333333/
1128      DATA P3/0.0,0.7071068,-0.7071068,0.0/
1129      DATA P4/1.0,0.5,0.5,0.0/
1130      DATA P5/0.0,0.5,0.5,1.0/
1131      DO 11 I=1,N
1132      DO 10 L=1,2
1133      Q(I,L)=QT(I,L)
1134      Y(I,L)=YT(I,L)
1135      10 CONTINUE
1136      11 CONTINUE
1137      DO 15 JJ=1,4
1138      DDYG=P4(JJ)*DDYT+P5(JJ)*DDY
1139      DO 12 I=1,N
1140      Z(I,1)=Y(I,2)*DT

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1141      CALL MAT(ACK, Y, N, I, DDYG, Z12, M1, NK, ARPA)
1142      Z(I, 2)=Z12*DT
1143 12 CONTINUE
1144      DO 14 I=1, N
1145      DO 13 L=1, 2
1146      T(I, L)=P1(JJ)*Z(I, L)-Q(I, L)
1147      R(I, L)=P2(JJ)*T(I, L)
1148      Y(I, L)=Y(I, L)+R(I, L)
1149      Q(I, L)=3.0*R(I, L)-T(I, L)+P3(JJ)*Z(I, L)
1150 13 CONTINUE
1151 14 CONTINUE
1152 15 CONTINUE
1153      DO 17 I=1, N
1154      CALL MAT(ACK, Y, N, I, DDY, Z12, M1, NK, ARPA)
1155 17 YY(I)=Z12
1156      RETURN
1157      END
1158 C
1159 C ***** SUBROUTINE MAT *****
1160 C *
1161 C * SUBROUTINE FOR THE PREDICTED STATE VECTOR OF *
1162 C * LINEAR MDOF SYSTEM *
1163 C * ( ICON = 1 ) *
1164 C * CALLED BY SUBROUTINE RUNCE *
1165 C *****
1166 C
1167 SUBROUTINE MAT(ACK, Y, N, I, DDYG, Z12, M1, NK, ARPA)
1168 C IMPLICIT REAL*8(A-H, O-Z)
1169 DIMENSION ACK(M1, 2), Y(M1, 2)
1170 IF(NK.EQ.5) GO TO 100
1171 Z12=-(ACK(I, 1)*Y(I, 1)+ACK(I, 2)*Y(I, 2))-DDYG
1172 Z12=Z12-ACK(I, 1)*ARPA
1173 RETURN
1174 100 Z12=-(ACK(I, 1)*Y(I, 1)+ACK(I, 2)*Y(I, 2))-ARPA*DDYG
1175 RETURN
1176 END
1177 C
1178 C ***** SUBROUTINE FF2 *****
1179 C *
1180 C * SUBROUTINE FOR THE PREDICTED STATE VETCOR *
1181 C * OF LINEAR MULTI-DEGREE OF FREEDOM SYSTEM BY SOLVING *
1182 C * DIFFERENTIAL EQUATION USING LINEAR ACCELERATION METHOD *
1183 C * ( ICON = 2 ) *
1184 C * CALLED BY THE MAIN PROGRAM *
1185 C *****
1186 C
1187 C PURPOSE:
1188 C TO COMPUTE THE PREDICTED STATE VECTOR OF
1189 C LINEAR MULTI-DEGREE OF FREEDOM SYSTEM (ICON.EQ.2).
1190 C
1191 C USAGE:
1192 C CALL FF2(F, Y2, Y1, I1, DY, DT, J1, J3, KR, N, MC)
1193 C
1194 C DESCRIPTION OF PARAMETERS
1195 C F(J1, 1), Y1(J1, 1): PREDICTED STATE VECTOR
1196 C Y2(J1, 1): FILTERED STATE VECTOR
1197 C I1 : DIMENSION OF EXTENDED STATE VECTOR
1198 C DY(J3) : OBSERVED INPUT EXCIATION
1199 C DT : TIME INCREMENT IN DATA IN SEC
1200 C J1, J3 : DIMENSION OF [F], [Y2] OR [DY] IN CALLING

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1201 C          PROGRAM
1202 C          KK : TIME IN DATA PROCESSING
1203 C          N : NUMBER OF DEGREE OF FREEDOM STRUCTURE
1204 C          MC(1),MC(2) : PARAMETERS FOR OBSERVATION DATA
1205 C          IN (ICON.EQ.2)
1206 C  REMARK:
1207 C
1208 C  SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1209 C  MMUT
1210 C  *****
1211 C
1212 C
1213 C  SUBROUTINE FF2(F,Y2,Y1,I1,DY,DT,J1,J3,KK,N,MC)
1214 C  IMPLICIT REAL*8(A-H,O-Z)
1215 C  DIMENSION F(J1,1),Y2(J1,1),DY(J3),Y1(J1,1)
1216 C  DIMENSION A(3,3),B(3,1),A1(3,1)
1217 C  DIMENSION A2(3,3),B1(3,1),A3(3,1),MC(3)
1218 C
1219 C
1220 C  DO 1000 K=1,N
1221 C  K1=6*(K-1)
1222 C
1223 C  DO 300 I=1,3
1224 C  B1(I,1)=0.0
1225 C  B(I,1)=0.0
1226 C  300 CONTINUE
1227 C
1228 C
1229 C  X4=Y2(4+K1,1)
1230 C  X5=Y2(5+K1,1)
1231 C  Z=-1.0/(1.0+DT*X4*X5+DT*DT*X5*X5/6.0)
1232 C  S=X5*X5*Z
1233 C  U=(DT*X4*X5+DT*DT*X5*X5/3.0)*Z
1234 C  T=(2.0*X4*X5+DT*X5*X5)*Z
1235 C
1236 C  DO 100 I=1,3
1237 C  DO 100 J=1,3
1238 C  100 A(I,J)=0.0
1239 C
1240 C  A(1,1)=1.0+S*DT*DT/6.0
1241 C  A(1,2)=DT*(1.0+DT/6.0*T)
1242 C  A(1,3)=DT*DT/6.0*(2.0+U)
1243 C  A(2,1)=DT/2.0*S
1244 C  A(2,2)=1.0+DT/2.0*T
1245 C  A(2,3)=DT/2.0*(1.0+U)
1246 C  A(3,1)=S
1247 C  A(3,2)=T
1248 C  A(3,3)=U
1249 C
1250 C  DO 200 I=1,3
1251 C  DO 200 J=1,3
1252 C  I5=I
1253 C  J5=J
1254 C  IF(I.EQ.MC(1)) I5=MC(2)
1255 C  IF(I.EQ.MC(2)) I5=MC(1)
1256 C  IF(J.EQ.MC(1)) J5=MC(2)
1257 C  IF(J.EQ.MC(2)) J5=MC(1)
1258 C  A2(I5,J5)=A(I,J)
1259 C  200 CONTINUE
1260 C

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1261      B(1,1)=Z*DT*DT/6.0*DY(KK+1)
1262      B(2,1)=DT/2.0*Z*DY(KK+1)
1263      B(3,1)=Z*DY(KK+1)
1264      C
1265      DO 400 M=1,3
1266      M1=M
1267      IF(M.EQ.MC(1)) M1=MC(2)
1268      IF(M.EQ.MC(2)) M1=MC(1)
1269      B1(M1,1)=B(M,1)
1270      400 CONTINUE
1271      C
1272      B(1,1)=B1(1,1)*Y2(6+K1,1)
1273      B(2,1)=B1(2,1)*Y2(6+K1,1)
1274      B(3,1)=B1(3,1)*Y2(6+K1,1)
1275      C
1276      DO 500 I=1,3
1277      A3(I,1)=Y2(I+K1,1)
1278      500 CONTINUE
1279      C
1280      CALL MMUT(A2,A3,A1,3,3,1,3,3,3,1,3,1)
1281      C
1282      C
1283      F(1+K1,1)=A1(1,1)+B(1,1)
1284      F(2+K1,1)=A1(2,1)+B(2,1)
1285      F(3+K1,1)=A1(3,1)+B(3,1)
1286      F(4+K1,1)=Y2(4+K1,1)
1287      F(5+K1,1)=Y2(5+K1,1)
1288      F(6+K1,1)=Y2(6+K1,1)
1289      C
1290      1000 CONTINUE
1291      C
1292      DO 2000 I=1,I1
1293      Y1(I,1)=F(I,1)
1294      2000 CONTINUE
1295      C
1296      RETURN
1297      END
1298      C
1299      C ***** SUBROUTINE MMUT *****
1300      C *
1301      C * SUBROUTINE FOR MATRIX MULTIPLICATION *
1302      C * CALLED BY PROGRAMS STEP2 , STEP5 AND STEP3 *
1303      C *****
1304      C
1305      C
1306      SUBROUTINE MMUT(A,B,C,I1,I2,I3,J1,J2,J3,J4,J5,J6)
1307      C IMPLICIT REAL*8(A-H,O-Z)
1308      DIMENSION A(J1,J2),B(J3,J4),C(J5,J6)
1309      C
1310      C A(I1,I2)*B(I2,I3)=C(I1,I3)
1311      C
1312      DO 100 II=1,I1
1313      DO 200 IJ=1,I3
1314      C(II,IJ)=0.0
1315      200 CONTINUE
1316      100 CONTINUE
1317      C
1318      DO 300 II=1,I1
1319      DO 400 IJ=1,I3
1320      DO 500 IK=1,I2

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1321      C(II, IJ)=C(II, IJ)+A(II, IK)*B(IK, IJ)
1322      500 CONTINUE
1323      400 CONTINUE
1324      300 CONTINUE
1325      1000 CONTINUE
1326      RETURN
1327      END
1328      C
1329      C ***** SUBROUTINE FF3 *****
1330      C *
1331      C * SUBROUTINE FOR THE PREDICTED STATE VETCOR OF LINEAR *
1332      C * MULTI-DEGREE OF FREEDOM SYSTEM IN FREQUENCY DOMAIN *
1333      C * ( ICON = 3 ) *
1334      C * CALLED BY THE MAIN PROGRAM *
1335      C *****
1336      C
1337      C PURPOSE:
1338      C TO COMPUTE THE PREDICTED STATE VECTOR OF LINEAR MDOF
1339      C SYSTEM IN FREQUENCY DOMAIN (ICON.EQ.3)
1340      C STATE VECTOR CONSISTS OF MODAL PARAMETERS IN FREQUENCY
1341      C RESPONSE FUCTION.
1342      C
1343      C USAGE:
1344      C CALL FF3 (F, Y2, Y1, J1, I1)
1345      C
1346      C DESCRIPTION OF PARAMETERS
1347      C F(J1, 1), Y1(J1, 1) : PREDICTED STATE VECTOR
1348      C Y2(J1, 1) : FILTERED STATE VECTOR
1349      C J1 : DIMENSION OF [F] OR [Y2]
1350      C I1 : DIMENSION OF EXTENDED STATE VECTOR
1351      C
1352      C REMARK:
1353      C
1354      C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1355      C NONE
1356      C *****
1357      C
1358      C
1359      C
1360      C SUBROUTINE FF3(F, Y2, Y1, J1, I1)
1361      C IMPLICIT REAL*8 (A-H, O-Z)
1362      C DIMENSION F(J1, 1), Y2(J1, 1), Y1(J1, 1)
1363      C
1364      C DO 100 I=1, I1
1365      C F(I, 1)=Y2(I, 1)
1366      C 100 CONTINUE
1367      C
1368      C DO 200 I=1, I1
1369      C Y1(I, 1)=F(I, 1)
1370      C 200 CONTINUE
1371      C
1372      C
1373      C RETURN
1374      C END
1375      C
1376      C ***** SUBROUTINE FF4 *****
1377      C *
1378      C * SUBROUTINE FOR THE PREDICTED STATE VETCOR *
1379      C * OF NONLINEAR SINGLE DEGREE OF FREEDOM SYSTEM WITH *
1380      C * NONPARAMETRIC RESTORING FORCE MODEL *

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1381 C      *              ( ICON = 4 )              *
1382 C      *              CALLED BY THE MAIN PROGRAM          *
1383 C      *              *****
1384 C
1385 C      PURPOSE:
1386 C      TO COMPUTE THE PREDICTED STATE VECTOR FOR SINGLE DEGREE OF
1387 C      FREEDOM SYSTEM WITH NONPARAMETRIC RESTORING FORCE MODEL
1388 C      (ICON.EQ.4) .
1389 C
1390 C      USAGE:
1391 C      CALL FF4 (F, Y2, Y1, DY, DT, J1, J3, KK, NMI)
1392 C
1393 C      DESCRIPTION OF PARAMETERS
1394 C      F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
1395 C      Y2(J1,1): FILTERED STATE VECTOR
1396 C      DY(J3) : OBSERVED INPUT EXCITATION
1397 C      DT : TIME INCREMENT IN DATA IN SEC
1398 C      J1, J3 : DIMENSION OF [F], [Y2] OR [DY] IN CALLING
1399 C      PROGRAM
1400 C      KK : TIME IN DATA PROCESSING
1401 C      NMI: STARTING TIME IN DATA PROCESSING
1402 C
1403 C      REMARK:
1404 C
1405 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1406 C      RUNGEY
1407 C      *****
1408 C
1409 C      SUBROUTINE FF4 (F, Y2, Y1, DY, DT, J1, J3, KK, NMI)
1410 C      IMPLICIT REAL*8 (A-E, O-Z)
1411 C      DIMENSION Y1 (J1, 1) , Y2 (J1, 1) , DY (J3) , F (J1, 1)
1412 C
1413 C      DO 10 I=3, 6
1414 C      F (I, 1)=Y2 (I, 1)
1415 C      10 CONTINUE
1416 C
1417 C      AM=1.0
1418 C      YYD=Y2 (1, 1)
1419 C      YYV=Y2 (2, 1)
1420 C      A3=Y2 (3, 1)
1421 C      A4=Y2 (4, 1)
1422 C      A5=Y2 (5, 1)
1423 C      A6=Y2 (6, 1)
1424 C
1425 C      CALL RUNGEY (YYD, YYV, A3, A4, A5, A6, DY, DT, J1, J3, KK, AM, NMI)
1426 C
1427 C      F (1, 1)=YYD
1428 C      F (2, 1)=YYV
1429 C
1430 C      DO 100 I=1, 6
1431 C      Y1 (I, 1)=F (I, 1)
1432 C      100 CONTINUE
1433 C
1434 C      RETURN
1435 C      END
1436 C
1437 C      *****      SUBROUTINE RUNGEY      *****
1438 C      *
1439 C      * SUBROUTINE FOR NONLINEAR SDOF SYSTEM WITH NONPARAMETRIC *
1440 C      * RESTORING FORCE MODEL. PREDICTED STATE IS COMPUTED BY *

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1441 C      *  RUNGE-KUTTA METHOD.                                *
1442 C      *                                     ( ICON = 4 )    *
1443 C      *                                     CALLED BY PROGRAM FF4 *
1444 C      * *****
1445 C
1446 C
1447 SUBROUTINE RUNGEY (YY1, YY2, A3, A4, A5, A6, Z, DT, J1, J3, KK, AM, NM1)
1448 C      IMPLICIT REAL*8 (A-H, O-Z)
1449 DIMENSION Z (J3)
1450 DIMENSION X1 (5), X2 (5), BK1 (5), BK2 (5)
1451 DIMENSION R1 (5), R2 (5), Q1 (5), Q2 (5)
1452 C
1453 C      IF (KK.NE.1) GO TO 100
1454 Q1 (1)=0.0
1455 Q2 (1)=0.0
1456 100 CONTINUE
1457 C
1458 ZZ=(Z (KK)+Z (KK+1))/2.0
1459 C
1460 C
1461 X1 (1)=YY1
1462 X2 (1)=YY2
1463 C
1464 BK1 (1)=DT*X2 (1)
1465 C
1466 IF (KK.EQ.NM1) THEN
1467 ZZ1=0.0
1468 ZZ2=0.0
1469 ELSE
1470 ZZ1=X1 (1)*X1 (1)*X1 (1)
1471 ZZ2=X2 (1)*X2 (1)*X2 (1)
1472 END IF
1473 C
1474 BB1=-DT*(AM*Z (KK)+A3*X1 (1)+A4*ZZ1+A5*X2 (1)+A6*ZZ2)/AM
1475 BK2 (1)=BB1
1476 C
1477 R1 (1)=BK1 (1)/2.0-Q1 (1)
1478 R2 (1)=BK2 (1)/2.0-Q2 (1)
1479 C
1480 X1 (2)=X1 (1)+R1 (1)
1481 X2 (2)=X2 (1)+R2 (1)
1482 C
1483 Q1 (2)=Q1 (1)+3.0*R1 (1)-BK1 (1)/2.0
1484 Q2 (2)=Q2 (1)+3.0*R2 (1)-BK2 (1)/2.0
1485 C
1486 BK1 (2)=DT*X2 (2)
1487 C
1488 IF (KK.EQ.NM1) THEN
1489 ZZ1=0.0
1490 ZZ2=0.0
1491 ELSE
1492 ZZ1=X1 (2)*X1 (2)*X1 (2)
1493 ZZ2=X2 (2)*X2 (2)*X2 (2)
1494 END IF
1495 C
1496 BB1=-DT*(AM*ZZ+A3*X1 (2)+A4*ZZ1+A5*X2 (2)+A6*ZZ2)/AM
1497 BK2 (2)=BB1
1498 C
1499 C
1500 DA1=0.2928932

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1501      R1 (2) =DA1*(BK1 (2) -Q1 (2) )
1502      R2 (2) =DA1*(BK2 (2) -Q2 (2) )
1503      C
1504      X1 (3) =X1 (2) +R1 (2)
1505      X2 (3) =X2 (2) +R2 (2)
1506      C
1507      Q1 (3) =Q1 (2) +3.0*R1 (2) -DA1*BK1 (2)
1508      Q2 (3) =Q2 (2) +3.0*R2 (2) -DA1*BK2 (2)
1509      C
1510      BK1 (3) =DT*X2 (3)
1511      C
1512      IF (KK.EQ.NM1) THEN
1513      ZZ1=0.0
1514      ZZ2=0.0
1515      ELSE
1516      ZZ1=X1 (3) *X1 (3) *X1 (3)
1517      ZZ2=X2 (3) *X2 (3) *X2 (3)
1518      END IF
1519      C
1520      BB1=-DT*(AM*ZZ+A3*X1 (3) +A4*ZZ1+A5*X2 (3) +A6*ZZ2) /AM
1521      BK2 (3) =BB1
1522      C
1523      C
1524      DA1=0.17071068E+01
1525      R1 (3) =DA1*(BK1 (3) -Q1 (3) )
1526      R2 (3) =DA1*(BK2 (3) -Q2 (3) )
1527      C
1528      X1 (4) =X1 (3) +R1 (3)
1529      X2 (4) =X2 (3) +R2 (3)
1530      C
1531      Q1 (4) =Q1 (3) +3.0*R1 (3) -DA1*BK1 (3)
1532      Q2 (4) =Q2 (3) +3.0*R2 (3) -DA1*BK2 (3)
1533      C
1534      BK1 (4) =DT*X2 (4)
1535      C
1536      IF (KK.EQ.NM1) THEN
1537      ZZ1=0.0
1538      ZZ2=0.0
1539      ELSE
1540      ZZ1=X1 (4) *X1 (4) *X1 (4)
1541      ZZ2=X2 (4) *X2 (4) *X2 (4)
1542      END IF
1543      C
1544      BB1=-DT*(AM*Z (KK+1) +A3*X1 (4) +A4*ZZ1+A5*X2 (4) +A6*ZZ2) /AM
1545      BK2 (4) =BB1
1546      C
1547      R1 (4) =(BK1 (4) -2.0*Q1 (4) ) /6.0
1548      R2 (4) =(BK2 (4) -2.0*Q2 (4) ) /6.0
1549      C
1550      X1 (5) =X1 (4) +R1 (4)
1551      X2 (5) =X2 (4) +R2 (4)
1552      C
1553      Q1 (5) =Q1 (4) +3.0*R1 (4) -BK1 (4) /2.0
1554      Q2 (5) =Q2 (4) +3.0*R2 (4) -BK2 (4) /2.0
1555      C
1556      YY1=X1 (5)
1557      YY2=X2 (5)
1558      C
1559      C
1560      Q1 (1) =Q1 (5)

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1561      Q2(1)=Q2(5)
1562      C
1563      C
1564      RETURN
1565      END
1566      C
1567      C ***** SUBROUTINE FF5 *****
1568      C *
1569      C *      SUBROUTINE FOR THE PREDICTED STATE VETCOR      *
1570      C *      OF SINGLE DEGREE OF FREEDOM SYSTEM WITH BILINEAR *
1571      C *      HYSTERESIS                                     *
1572      C *      ( ICON = 5 )                                     *
1573      C *      CALLED BY THE MAIN PROGRAM                       *
1574      C *****
1575      C
1576      C      PURPOSE:
1577      C      TO COMPUTE THE PREDICTED STATE VECTOR FOR SDOF SYSTEM
1578      C      WITH BILINEAR HYSTERESIS (ICON.EQ.5) .
1579      C
1580      C      USAGE:
1581      C      CALL FF5 (F, Y2, Y1, DY, DT, J1, J3, KK, NZ, XX, XXX, AK1)
1582      C
1583      C      DESCRIPTION OF PARAMETERS
1584      C      F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
1585      C      Y2(J1,1): FILTERED STATE VECTOR
1586      C      DY(J3) : OBSERVED INPUT EXCIATION
1587      C      DT : TIME INCREMENT IN DATA IN SEC
1588      C      J1, J3 : DIMENSION OF [F], [Y2] OR [DY] IN CALLING
1589      C      PROGRAM
1590      C      KK : TIME IN DATA PROCESSING
1591      C      NZ, XX, XXX, AK1: PARAMETERS FOR BILINEAR HYSTERESIS
1592      C
1593      C      REMARK:
1594      C
1595      C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1596      C      RUNGEN
1597      C *****
1598      C
1599      C      SUBROUTINE FF5 (F, Y2, Y1, DY, DT, J1, J3, KK, NZ, XX, XXX, AK1)
1600      C      IMPLICIT REAL*8 (A-H, O-Z)
1601      C      DIMENSION F (J1, 1), Y2 (J1, 1), DY (J3)
1602      C      DIMENSION QT (30, 2), YT (30, 2), Y (30, 2)
1603      C      DIMENSION Q (30, 2), YY2 (30), Y1 (J1, 1)
1604      C
1605      C      DO 100 I=3, 6
1606      C      100 F(I, 1)=Y2(I, 1)
1607      C      QT(1, 1)=0.0
1608      C      QT(1, 2)=0.0
1609      C      YT(1, 1)=Y2(1, 1)
1610      C      YT(1, 2)=Y2(2, 1)
1611      C      DDYT=DY(KK)
1612      C      DDY=DY(KK+1)
1613      C      CALL RUNGEN(1, DT, DDY, DDYT, Y, YY2,
1614      C      *      YT, Q, QT, J1, Y2, NZ, AR, XE, XX, XXX, AK1)
1615      C
1616      C      F(1, 1)=Y(1, 1)
1617      C      F(2, 1)=Y(1, 2)
1618      C
1619      C      DO 200 I=1, 6
1620      C      200 Y1(I, 1)=F(I, 1)

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1621      200 CONTINUE
1622      C
1623      RETURN
1624      END
1625      C
1626      C ***** SUBROUTINE RUNGEN *****
1627      C *
1628      C * SUBROUTINE FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS *
1629      C * SOLVING D.E. BY RUNGE-KUTTA METHOD *
1630      C * ( ICON = 5 ) *
1631      C * CALLED BY SUBROUTINE FF5 *
1632      C *****
1633      C
1634      C
1635      SUBROUTINE RUNGEN(N,DT,DDY,DDYT,
1636      * Y,YY,YT,Q,QT,M1,Y2,NZ,AR,XE,XX,XXX,AK1)
1637      C IMPLICIT REAL*8(A-H,O-Z)
1638      DIMENSION Y2(M1,1),Y(M1,2),YY(M1),YT(M1,2),Q(M1,2)
1639      DIMENSION QT(M1,2)
1640      DIMENSION P1(4),P2(4),P3(4),P4(4),P5(4)
1641      DIMENSION Z(10,2),T(10,2),R(10,2)
1642      DATA P1/0.5,1.0,1.0,0.5/
1643      DATA P2/1.0,0.2928932,1.7071068,0.333333/
1644      DATA P3/0.0,0.7071068,-0.7071068,0.0/
1645      DATA P4/1.0,0.5,0.5,0.0/
1646      DATA P5/0.0,0.5,0.5,1.0/
1647      DO 11 I=1,N
1648      DO 10 L=1,2
1649      Q(I,L)=QT(I,L)
1650      Y(I,L)=YT(I,L)
1651      10 CONTINUE
1652      11 CONTINUE
1653      DO 15 JJ=1,4
1654      DDYC=P4(JJ)*DDYT+P5(JJ)*DDY
1655      DO 12 I=1,N
1656      Z(I,1)=Y(I,2)*DT
1657      CALL MATN(Y2,Y,DDYC,Z12,M1,NZ,AR,XE,XX,XXX,AK1)
1658      Z(I,2)=Z12*DT
1659      12 CONTINUE
1660      DO 14 I=1,N
1661      DO 13 L=1,2
1662      T(I,L)=P1(JJ)*Z(I,L)-Q(I,L)
1663      R(I,L)=P2(JJ)*T(I,L)
1664      Y(I,L)=Y(I,L)+R(I,L)
1665      Q(I,L)=3.0*R(I,L)-T(I,L)+P3(JJ)*Z(I,L)
1666      13 CONTINUE
1667      14 CONTINUE
1668      15 CONTINUE
1669      DO 17 I=1,N
1670      CALL MATN(Y2,Y,DDY,Z12,M1,NZ,AR,XE,XX,XXX,AK1)
1671      17 YY(I)=Z12
1672      RETURN
1673      END
1674      C
1675      C ***** SUBROUTINE MATN *****
1676      C *
1677      C * SUBROUTINE FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS *
1678      C * ( ICON = 5 ) *
1679      C * CALLED BY SUBROUTINE RUNGEN *
1680      C *****

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1681 C
1682 C
1683 SUBROUTINE MATN (Y2, Y, DDYG, Z12, J1, NZ, AR, XE, XX, XXX, AK1)
1684 C   IMPLICIT REAL*8 (A-H, O-Z)
1685 DIMENSION Y2 (J1, 1), Y (J1, 2)
1686 C
1687 CALL GOSN (Y2, J1, NZ, XX, AK1, Y, XXX)
1688 Z12=-2.0*Y2 (3, 1) *Y2 (4, 1) *Y (1, 2)
1689 Z12=Z12-Y2 (4, 1) *Y2 (4, 1) *AK1-DDYG
1690 C
1691 RETURN
1692 END
1693 C
1694 C ***** SUBROUTINE GOSN *****
1695 C *
1696 C * SUBROUTINE FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS *
1697 C * ( ICON = 5 ) *
1698 C * CALLED BY SUBROUTINE MATN *
1699 C *****
1700 C
1701 C
1702 SUBROUTINE GOSN (Y2, J1, NZ, XX, AK1, Y, XXX)
1703 C   IMPLICIT REAL*8 (A-H, O-Z)
1704 DIMENSION Y2 (J1, 1), Y (J1, 2)
1705 C
1706 XE=Y2 (5, 1)
1707 AR=Y2 (6, 1)
1708 C
1709 GO TO (100, 200, 300, 400, 500), NZ
1710 C
1711 C
1712 100 AK1=Y (1, 1)
1713 GO TO 1000
1714 C
1715 C
1716 200 AK1=AR*Y (1, 1) + (1.0-AR) *XE
1717 GO TO 1000
1718 C
1719 C
1720 300 AK1=Y (1, 1) + (1.0-AR) * (XE-XX)
1721 GO TO 1000
1722 C
1723 C
1724 400 AK1=AR*Y (1, 1) - (1.0-AR) *XE
1725 GO TO 1000
1726 C
1727 C
1728 500 AK1=Y (1, 1) + (1.0-AR) * (-XX-XE)
1729 C
1730 C
1731 1000 CONTINUE
1732 RETURN
1733 END
1734 C
1735 C ***** SUBROUTINE FF6 *****
1736 C *
1737 C * SUBROUTINE FOR THE PREDICTED STATE VETCOR *
1738 C * OF SINGLE DEGREE OF FREEDOM SYSTEM WITH BOUC-WEN'S *
1739 C * HYSTERETIC MODEL *
1740 C * ( ICON = 6 ) *

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1741 C      *          CALLED BY THE MAIN PROGRAM          *
1742 C      *****
1743 C
1744 C      PURPOSE:
1745 C          TO COMPUTE THE PREDICTED STATE VECTOR FOR SDOF SYSTEM WITH
1746 C          BOUC-WEN'S HYSTERETIC MODEL (ICON.EQ.6)
1747 C
1748 C      USAGE:
1749 C          CALL FF6(F,Y2,Y1,DY,DT,J1,J3,KK,AZ,NM1)
1750 C
1751 C      DESCRIPTION OF PARAMETERS
1752 C      F(J1,1), Y1(J1,1): PREDICTED STATE VECTOR
1753 C          Y2(J1,1): FILTERED STATE VECTOR
1754 C          DY(J3) : INPUT EXCIATION
1755 C          DT : TIME INCREMENT IN DATA IN SEC
1756 C          J1,J3 : DIMENSION OF [F],[Y2] OR [DY] IN CALLING
1757 C          PROGRAM
1758 C          KK : TIME IN DATA PROCESSING
1759 C          AZ : PARAMETER FOR BOUC AND WEN'S MODEL(AZ=1.0)
1760 C          NM1 : START TIME IN DATA PROCESSING
1761 C
1762 C      REMARK:
1763 C
1764 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
1765 C          RUNGXY
1766 C      *****
1767 C
1768 C      SUBROUTINE FF6(F,Y2,Y1,Z,DT,J1,J3,KK,AZ,NM1)
1769 C          IMPLICIT REAL*8(A-H,O-Z)
1770 C          DIMENSION Y1(J1,1),Y2(J1,1),Z(J3),F(J1,1)
1771 C
1772 C
1773 C          AM=1.0
1774 C          AC=2.0*Y2(5,1)*Y2(6,1)
1775 C          AK1=Y2(6,1)*Y2(6,1)
1776 C          BE=Y2(7,1)
1777 C          GA=Y2(8,1)
1778 C          AA=Y2(9,1)
1779 C          CA=Y2(10,1)
1780 C          CV=Y2(11,1)
1781 C          CN=Y2(12,1)
1782 C
1783 C          DO 10 I=5,12
1784 C              F(I,1)=Y2(I,1)
1785 C      10 CONTINUE
1786 C
1787 C          YYD=Y2(1,1)
1788 C          YYV=Y2(2,1)
1789 C          XXD=Y2(3,1)
1790 C          ZZE=Y2(4,1)
1791 C
1792 C          CALL RUNGXY(YYD,YYV,Y1,Z,XXD,AM,AC,AK1,AA,BE,GA,AZ,J3,DT,KK,
1793 C          *          1.0,1.0,CA,CN,CV,ZZE,NM1)
1794 C
1795 C          F(1,1)=YYD
1796 C          F(2,1)=YYV
1797 C          F(3,1)=XXD
1798 C          F(4,1)=ZZE
1799 C
1800 C          DO 100 I=1,12

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1801      Y1(I,1)=F(I,1)
1802      100 CONTINUE
1803      C
1804      RETURN
1805      END
1806      C
1807      C ***** SUBROUTINE RUNGXY *****
1808      C *
1809      C * SUBROUTINE FOR SDOF SYSTEM WITH BOUC-WEN'S MODEL *
1810      C * SOLVING D.E. BY RUNGE-KUTTA METHOD *
1811      C * ( ICON = 1 ) *
1812      C * CALLED BY SUBROUTINE FF6 *
1813      C *****
1814      C
1815      C
1816      SUBROUTINE RUNGXY (YYD, YYV, YYA, Z, XXD, AM, AC, AK1, AAA, BE, GA
1817      * , AZ, N1, DT, KK, GNN, VVV, CA, CN, CV, ZZE, NM1)
1818      C IMPLICIT REAL*8 (A-H, O-Z)
1819      DIMENSION Z (N1)
1820      DIMENSION Y1 (5), Y2 (5), Y3 (5), BK1 (5), BK2 (5), BK3 (5)
1821      DIMENSION R1 (5), R2 (5), R3 (5), Q1 (5), Q2 (5), Q3 (5)
1822      DIMENSION Y4 (5), BK4 (5), R4 (5), Q4 (5)
1823      C
1824      Y1 (1) = YYD
1825      Y2 (1) = YYV
1826      Y3 (1) = XXD
1827      Y4 (1) = ZZE
1828      C
1829      IF (KK.NE.NM1) GO TO 100
1830      AA=AAA
1831      GN=GNN
1832      VV=VVV
1833      Q1 (1) = 0.0
1834      Q2 (1) = 0.0
1835      Q3 (1) = 0.0
1836      Q4 (1) = 0.0
1837      100 CONTINUE
1838      C
1839      BK1 (1) = DT*Y2 (1)
1840      BK2 (1) = -DT* (AM*Z (KK) + AC*Y2 (1) + AK1*Y3 (1)) / AM
1841      YZ2 = ABS (Y2 (1))
1842      YZ3 = ABS (Y3 (1))
1843      C
1844      IF (KK.EQ.NM1) THEN
1845      ZZ1 = 0.0
1846      ZZ2 = 0.0
1847      ELSE
1848      ZZ1 = YZ3** (AZ - 1.0)
1849      ZZ2 = YZ3** AZ
1850      END IF
1851      C
1852      BB1 = DT* (AA*Y2 (1) - VV*BE*YZ2*ZZ1*Y3 (1))
1853      BK3 (1) = (BB1 - VV*DT*GA*Y2 (1)*ZZ2) / GN
1854      BK4 (1) = DT*AK1*Y3 (1)*Y2 (1)
1855      C
1856      R1 (1) = BK1 (1) / 2.0 - Q1 (1)
1857      R2 (1) = BK2 (1) / 2.0 - Q2 (1)
1858      R3 (1) = BK3 (1) / 2.0 - Q3 (1)
1859      R4 (1) = BK4 (1) / 2.0 - Q4 (1)
1860      C

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1861      Y1 (2)=Y1 (1)+R1 (1)
1862      Y2 (2)=Y2 (1)+R2 (1)
1863      Y3 (2)=Y3 (1)+R3 (1)
1864      Y4 (2)=Y4 (1)+R4 (1)
1865      C
1866      Q1 (2)=Q1 (1)+3.0*R1 (1)-BK1 (1)/2.0
1867      Q2 (2)=Q2 (1)+3.0*R2 (1)-BK2 (1)/2.0
1868      Q3 (2)=Q3 (1)+3.0*R3 (1)-BK3 (1)/2.0
1869      Q4 (2)=Q4 (1)+3.0*R4 (1)-BK4 (1)/2.0
1870      C
1871      C
1872      BK1 (2)=DT*Y2 (2)
1873      ZZ=(Z (KK)+Z (KK+1))/2.0
1874      BK2 (2)=-DT*(AM*ZZ+AC*Y2 (2)+AK1*Y3 (2))/AM
1875      YZ2=ABS (Y2 (2))
1876      YZ3=ABS (Y3 (2))
1877      C
1878      IF (KK.EQ.NM1) THEN
1879      ZZ1=0.0
1880      ZZ2=0.0
1881      ELSE
1882      ZZ1=YZ3**(AZ-1.0)
1883      ZZ2=YZ3**AZ
1884      END IF
1885      C
1886      BB1=DT*(AA*Y2 (2)-VV*BE*YZ2*ZZ1*Y3 (2))
1887      BK3 (2)=(BB1-VV*DT*GA*Y2 (2)*ZZ2)/GN
1888      BK4 (2)=DT*Y3 (2)*Y2 (2)*AK1
1889      C
1890      DA1=0.2928932
1891      R1 (2)=DA1*(BK1 (2)-Q1 (2))
1892      R2 (2)=DA1*(BK2 (2)-Q2 (2))
1893      R3 (2)=DA1*(BK3 (2)-Q3 (2))
1894      R4 (2)=DA1*(BK4 (2)-Q4 (2))
1895      C
1896      Y1 (3)=Y1 (2)+R1 (2)
1897      Y2 (3)=Y2 (2)+R2 (2)
1898      Y3 (3)=Y3 (2)+R3 (2)
1899      Y4 (3)=Y4 (2)+R4 (2)
1900      C
1901      Q1 (3)=Q1 (2)+3.0*R1 (2)-DA1*BK1 (2)
1902      Q2 (3)=Q2 (2)+3.0*R2 (2)-DA1*BK2 (2)
1903      Q3 (3)=Q3 (2)+3.0*R3 (2)-DA1*BK3 (2)
1904      Q4 (3)=Q4 (2)+3.0*R4 (2)-DA1*BK4 (2)
1905      C
1906      C
1907      BK1 (3)=DT*Y2 (3)
1908      ZZ=(Z (KK)+Z (KK+1))/2.0
1909      BK2 (3)=-DT*(AM*ZZ+AC*Y2 (3)+AK1*Y3 (3))/AM
1910      YZ2=ABS (Y2 (3))
1911      YZ3=ABS (Y3 (3))
1912      IF (KK.EQ.NM1) THEN
1913      ZZ1=0.0
1914      ZZ2=0.0
1915      ELSE
1916      ZZ1=YZ3**(AZ-1.0)
1917      ZZ2=YZ3**AZ
1918      END IF
1919      C
1920      BB1=DT*(AA*Y2 (3)-VV*BE*YZ2*ZZ1*Y3 (3))

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1921      BK3 (3) = (BB1 - VV * DT * GA * Y2 (3) * ZZ2) / GN
1922      BK4 (3) = DT * Y3 (3) * Y2 (3) * AK1
1923      C
1924      DA1 = 0.17071068E+01
1925      R1 (3) = DA1 * (BK1 (3) - Q1 (3))
1926      R2 (3) = DA1 * (BK2 (3) - Q2 (3))
1927      R3 (3) = DA1 * (BK3 (3) - Q3 (3))
1928      R4 (3) = DA1 * (BK4 (3) - Q4 (3))
1929      C
1930      Y1 (4) = Y1 (3) + R1 (3)
1931      Y2 (4) = Y2 (3) + R2 (3)
1932      Y3 (4) = Y3 (3) + R3 (3)
1933      Y4 (4) = Y4 (3) + R4 (3)
1934      C
1935      Q1 (4) = Q1 (3) + 3.0 * R1 (3) - DA1 * BK1 (3)
1936      Q2 (4) = Q2 (3) + 3.0 * R2 (3) - DA1 * BK2 (3)
1937      Q3 (4) = Q3 (3) + 3.0 * R3 (3) - DA1 * BK3 (3)
1938      Q4 (4) = Q4 (3) + 3.0 * R4 (3) - DA1 * BK4 (3)
1939      C
1940      C
1941      BK1 (4) = DT * Y2 (4)
1942      BK2 (4) = -DT * (AM * Z (KK+1) + AC * Y2 (4) + AK1 * Y3 (4)) / AM
1943      YZ2 = ABS (Y2 (4))
1944      YZ3 = ABS (Y3 (4))
1945      C
1946      ZZ1 = YZ3 ** (AZ - 1.0)
1947      ZZ2 = YZ3 ** AZ
1948      C
1949      BB1 = DT * (AA * Y2 (4) - VV * BE * YZ2 * (ZZ1) * Y3 (4))
1950      BK3 (4) = (BB1 - VV * DT * GA * Y2 (4) * (ZZ2)) / GN
1951      BK4 (4) = DT * Y3 (4) * Y2 (4) * AK1
1952      C
1953      R1 (4) = (BK1 (4) - 2.0 * Q1 (4)) / 6.0
1954      R2 (4) = (BK2 (4) - 2.0 * Q2 (4)) / 6.0
1955      R3 (4) = (BK3 (4) - 2.0 * Q3 (4)) / 6.0
1956      R4 (4) = (BK4 (4) - 2.0 * Q4 (4)) / 6.0
1957      C
1958      Y1 (5) = Y1 (4) + R1 (4)
1959      Y2 (5) = Y2 (4) + R2 (4)
1960      Y3 (5) = Y3 (4) + R3 (4)
1961      Y4 (5) = Y4 (4) + R4 (4)
1962      C
1963      Q1 (5) = Q1 (4) + 3.0 * R1 (4) - BK1 (4) / 2.0
1964      Q2 (5) = Q2 (4) + 3.0 * R2 (4) - BK2 (4) / 2.0
1965      Q3 (5) = Q3 (4) + 3.0 * R3 (4) - BK3 (4) / 2.0
1966      Q4 (5) = Q4 (4) + 3.0 * R4 (4) - BK4 (4) / 2.0
1967      C
1968      YY1 = Y1 (5)
1969      YY2 = Y2 (5)
1970      YY3 = Y3 (5)
1971      YY4 = Y4 (5)
1972      C
1973      YYD = YY1
1974      YYV = YY2
1975      XXD = YY3
1976      ZZE = YY4
1977      C
1978      Q1 (1) = Q1 (5)
1979      Q2 (1) = Q2 (5)
1980      Q3 (1) = Q3 (5)

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1981      Q4(1)=Q4(5)
1982      C
1983      C
1984      AA=AAA-CA*ZZE
1985      GN=GNN+CN*ZZE
1986      VV=VVV+CV*ZZE
1987      C
1988      YYA=- (AM*Z (KK+1)+AC*YV+AK1*XXD) /AM
1989      C
1990      RETURN
1991      END
1992      C
1993      C          *****      SUBROUTINE WW1          *****
1994      C          *
1995      C          * SUBROUTINE FOR THE STATE TRANSITION MATRIX OF LINEAR *
1996      C          * MDOF SYSTEM FORMULATED AS A CONTINUOUS STATE EQUATION *
1997      C          *          ( ICON = 1 )          *
1998      C          *          CALLED BY THE MAIN PROGRAM          *
1999      C          *****
2000      C
2001      C PURPOSE:
2002      C TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM.
2003      C STATE TRANSITION MATRIX IS CONSTRUCTED FROM CONTINUOUS
2004      C STATE EQUATION USING FIRST ORDER APPROXIMATION. (ICON=1)
2005      C
2006      C USAGE:
2007      C CALL WW1 (N,W1,Y2,I1,J1,J3,DT,DY,KK)
2008      C
2009      C DESCRIPTION OF PARAMETERS
2010      C N : NUMBER OF DEGREE OF FREEDOM STRUCTURE
2011      C W1(J1,J1) : STATE TRANSITION MATRIX OF THE BILINEAR
2012      C           HYSYTERETIC SYSTEM
2013      C Y2(J1,1) : FILTERED STATE VECTOR
2014      C I1 : DIMENSION OF EXTENDED STATE VECTOR
2015      C       (I1.LE.30)
2016      C J1,J3 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
2017      C DT : TIME INCREMENT IN SEC
2018      C DY(J3) : OBSERVED INPUT EXCIATION
2019      C KK : TIME IN DATA PROCESSING
2020      C
2021      C REMARK:
2022      C (1) PARAMETER I1 MUST BE LESS THAN 30
2023      C
2024      C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2025      C NONE
2026      C *****
2027      C
2028      C
2029      C SUBROUTINE WW1(N,W1,Y2,I1,J1,J3,DT,DY,KK)
2030      C IMPLICIT REAL*8(A-H,O-Z)
2031      C DIMENSION W1(J1,J1),DY(J3),Y2(J1,1)
2032      C
2033      C
2034      C DO 100 I=1,I1
2035      C DO 100 J=1,I1
2036      C 100 W1(I,J)=0.0
2037      C
2038      C
2039      C DO 200 I=1,N
2040      C II=5*(I-1)

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2041 C
2042 W1(1+II,2+II)=DT
2043 W1(2+II,1+II)=-Y2(4+II,1)*Y2(4+II,1)*DT
2044 W1(2+II,2+II)=-2.0*Y2(3+II,1)*Y2(4+II,1)*DT
2045 W1(2+II,3+II)=-2.0*Y2(4+II,1)*Y2(2+II,1)*DT
2046 A1=Y2(3+II,1)*Y2(2+II,1)
2047 A2=Y2(4+II,1)*Y2(1+II,1)
2048 W1(2+II,4+II)=-2.0*(A1+A2)*DT
2049 W1(2+II,5+II)=-DY(KK)*DT
2050 200 CONTINUE
2051 C
2052 DO 500 I=1, I1
2053 500 W1(I, I)=1.0+W1(I, I)
2054 RETURN
2055 END
2056 C
2057 C ***** SUBROUTINE WW2 *****
2058 C * * * * *
2059 C * SUBROUTINE FOR THE STATE TRANSITION MATRIX OF LINEAR *
2060 C * MDOF SYSTEM FORMULATED AS A DISCRETE STATE EQUATION *
2061 C * BY LINEAR ACCELERATION METHOD *
2062 C * ( ICON = 2 ) *
2063 C * CALLED BY THE MAIN PROGRAM *
2064 C *****
2065 C
2066 C PURPOSE:
2067 C TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM.
2068 C DISCRETE STATE EQUATION IS USED. (ICON.EQ.2)
2069 C
2070 C USAGE:
2071 C CALL WW2(W1, Y2, DY, I1, J1, DT, KK, J3, N, MC)
2072 C
2073 C DESCRIPTION OF PARAMETERS
2074 C W1(J1, J1) : STATE TRANSITION MATRIX OF THE BILINEAR
2075 C HYSTERETIC SYSTEM
2076 C Y2(J1, 1) : FILTERED STATE VECTOR
2077 C DY(J3) : OBSERVED INPUT EXCITATION
2078 C I1 : DIMENSION OF EXTENDED STATE VECTOR
2079 C (I1.LE.30)
2080 C J1, J3 : DIMENSION OF [W1], [Y2] OR [DY] IN CALLING
2081 C PROGRAM
2082 C DT : TIME INCREMENT IN SEC
2083 C KK : TIME IN DATA PROCESSING
2084 C N : NUMBER OF DEGREE OF FREEDOM OF STRUCTURE
2085 C MC(1), MC(2) : PARAMETERS FOR OBSERVATION DATA
2086 C IN (ICON.EQ.2)
2087 C REMARK:
2088 C (1) PARAMETER I1 MUST BE LESS THAN 30
2089 C
2090 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2091 C NONE
2092 C *****
2093 C
2094 C SUBROUTINE WW2(W1, Y2, DY, I1, J1, DT, KK, J3, N, MC)
2095 C IMPLICIT REAL*8 (A-H, O-Z)
2096 C DIMENSION W1(J1, J1), Y2(J1, 1), DY(J3), W(30, 30)
2097 C DIMENSION MC(3)
2098 C DIMENSION C(30)
2099 C
2100 C

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```

2101      DO 100 I=1, I1
2102      DO 100 J=1, I1
2103      W(I, J)=0.0
2104      100 W1(I, J)=0.0
2105      C
2106      C
2107      DO 1000 K=1, N
2108      K1=6*(K-1)
2109      C
2110      C
2111      DDT=DT*DT
2112      A4=Y2(4+K1, 1)
2113      A5=Y2(5+K1, 1)
2114      A6=Y2(6+K1, 1)
2115      C
2116      K11=1+K1
2117      K12=3+K1
2118      DO 600 I=K11, K12
2119      600 C(I)=0.0
2120      C
2121      DO 700 I=K11, K12
2122      M1=MC(1)+K1
2123      M2=MC(2)+K1
2124      M=I
2125      IF(I.EQ.M1) M=M2
2126      IF(I.EQ.M2) M=M1
2127      C(M)=Y2(I, 1)
2128      700 CONTINUE
2129      C
2130      A1=C(1+K1)
2131      A2=C(2+K1)
2132      A3=C(3+K1)
2133      C
2134      S=1.0+A4*A5*DT+A5*A5*DDT/6.0
2135      P1=A1*A5*A5+2.0*A2*A4*A5+DT*A2*A5*A5
2136      P2=DT*A3*A4*A5+A3*A5*A5*DDT/3.0+DY(KK+1)*A6
2137      PP=P1+P2
2138      SS=DDT/(6.0*S*S)
2139      W1(1+K1, 1+K1)=1.0-(A5*A5*S)*SS
2140      W1(1+K1, 2+K1)=DT-(2.0*A4*A5+DT*A5*A5)*S*SS
2141      W1(1+K1, 3+K1)=DDT/3.0-(DT*A4*A5+A5*A5*DDT/3.0)*S*SS
2142      W1(1+K1, 4+K1)=-((2.0*A2*A5+DT*A3*A5)*S-(DT*A5*PP))*SS
2143      WAA1=2.0*A1*A5+2.0*A2*A4+2.0*DT*A2*A5
2144      WAA2=DT*A3*A4+2.0*DDT*A3*A5/3.0
2145      W1(1+K1, 5+K1)=-((WAA1+WAA2)*S-(DT*A4+DDT*A5/3.0)*PP)*SS
2146      W1(1+K1, 6+K1)=-DY(KK+1)*S*SS
2147      W1(2+K1, 1+K1)=-3.0/DT*(1.0-W1(1+K1, 1+K1))
2148      W1(2+K1, 2+K1)=1.0-3.0/DT*(DT-W1(1+K1, 2+K1))
2149      W1(2+K1, 3+K1)=DT/2.0-3.0/DT*(DDT/3.0-W1(1+K1, 3+K1))
2150      W1(2+K1, 4+K1)=3.0/DT*W1(1+K1, 4+K1)
2151      W1(2+K1, 5+K1)=3.0/DT*W1(1+K1, 5+K1)
2152      W1(2+K1, 6+K1)=3.0*W1(1+K1, 6+K1)/DT
2153      W1(3+K1, 1+K1)=-6.0/DDT*(1.0-W1(1+K1, 1+K1))
2154      W1(3+K1, 2+K1)=-6.0/DDT*(DT-W1(1+K1, 2+K1))
2155      W1(3+K1, 3+K1)=-6.0/DDT*(DDT/3.0-W1(1+K1, 3+K1))
2156      W1(3+K1, 4+K1)=6.0/DDT*W1(1+K1, 4+K1)
2157      W1(3+K1, 5+K1)=6.0/DDT*W1(1+K1, 5+K1)
2158      W1(3+K1, 6+K1)=6.0*W1(1+K1, 6+K1)/DDT
2159      W1(4+K1, 4+K1)=1.0
2160      W1(5+K1, 5+K1)=1.0

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2161          W1(6+K1,6+K1)=1.0
2162 C
2163 C
2164          K12=6+K1
2165          DO 200 M=K11,K12
2166          DO 200 L=K11,K12
2167 200 W(M,L)=0.0
2168 C
2169          DO 400 I=K11,K12
2170          DO 400 J=K11,K12
2171          M=I
2172          L=J
2173          M1=MC(1)+K1
2174          M2=MC(2)+K1
2175          IF(I.EQ.M1) M=M2
2176          IF(I.EQ.M2) M=M1
2177          IF(J.EQ.M1) L=M2
2178          IF(J.EQ.M2) L=M1
2179          W(M,L)=W1(I,J)
2180 400 CONTINUE
2181 C
2182          DO 500 I=K11,K12
2183          DO 500 J=K11,K12
2184          W1(I,J)=W(I,J)
2185 500 CONTINUE
2186 C
2187 C
2188 1000 CONTINUE
2189 C
2190 C
2191          RETURN
2192          END
2193 C
2194 C ***** SUBROUTINE WW3 *****
2195 C *
2196 C *          SUBROUTINE FOR THE STATE TRANSITION MATRIX *
2197 C * FOR LINEAR MDOF SYSTEM IN FREQUENCY DOMAIN *
2198 C *          ( ICON = 3 ) *
2199 C *          CALLED BY THE MAIN PROGRAM *
2200 C *****
2201 C
2202 C PURPOSE:
2203 C TO COMPUTE STATE TRANSITION MATRIX OF LINEAR MDOF SYSTEM
2204 C IN FREQUENCY DOMAIN(ICON.EQ.3)
2205 C
2206 C USAGE:
2207 C CALL WW3(W1,Y2,I1,J1)
2208 C
2209 C DESCRIPTION OF PARAMETERS
2210 C W1(J1,J1) : STATE TRANSITION MATRIX OF THE FREQUENCY
2211 C TRANSFER FUNCTION
2212 C Y2(J1,1) : FILTERED STATE VECTOR
2213 C I1 : DIMENSION OF EXTENDED STATE VECTOR
2214 C (I1.LE.30)
2215 C J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
2216 C
2217 C REMARK:
2218 C (1) PARAMETER I1 MUST BE LESS THAN 30
2219 C
2220 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED

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2221 C      NONE
2222 C      *****
2223 C
2224 C      SUBROUTINE WW3(W1,Y2,I1,J1)
2225 C      IMPLICIT REAL*8(A-H,O-Z)
2226 C      DIMENSION W1(J1,J1),Y2(J1,1)
2227 C
2228 C      DO 100 I=1,I1
2229 C      DO 100 J=1,I1
2230 C      W1(I,J)=0.0
2231 C      100 CONTINUE
2232 C
2233 C
2234 C      DO 200 I=1,I1
2235 C      W1(I,I)=1.0
2236 C      200 CONTINUE
2237 C
2238 C      RETURN
2239 C      END
2240 C
2241 C      *****      SUBROUTINE WW4      *****
2242 C      *
2243 C      *      SUBROUTINE FOR THE STATE TRANSITION MATRIX      *
2244 C      * FOR SDOF SYSTEM WITH NONPARAMETRIC HYSTERETIC MODEL *
2245 C      *      ( ICON = 4 )      *
2246 C      *      CALLED BY THE MAIN PROGRAM      *
2247 C      *****
2248 C
2249 C      PURPOSE:
2250 C      TO COMPUTE STATE TRANSITION MATRIX OF THE SDOF SYSTEM
2251 C      WITH NONPARAMETRIC (POLYNOMIAL) HYSTERETIC MODEL.
2252 C      STATE TRANSITION MATRIX IS CONSTRUCTED FROM CONTINUOUS
2253 C      STATE EQUATION USING FIRST ORDER APPROXIMATION.
2254 C
2255 C      USAGE:
2256 C      CALL WW4(W1,Y2,I1,J1,DT)
2257 C
2258 C      DESCRIPTION OF PARAMETERS
2259 C      W1(J1,J1) : STATE TRANSITION MATRIX OF THE NONPARAMETRIC
2260 C      MODEL
2261 C      Y2(J1,1)  : FILTERED STATE VECTOR
2262 C      I1       : DIMENSION OF EXTENDED STATE VECTOR
2263 C      (I1.LE.30)
2264 C      J1       : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
2265 C      DT       : TIME INCREMENT IN SEC
2266 C
2267 C      REMARK:
2268 C      (1) PARAMETER I1 MUST BE LESS THAN 30
2269 C
2270 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2271 C      NONE
2272 C      *****
2273 C
2274 C
2275 C      SUBROUTINE WW4(W1,Y2,I1,J1,DT)
2276 C      IMPLICIT REAL*8(A-H,O-Z)
2277 C      DIMENSION W1(J1,J1),Y2(J1,1)
2278 C
2279 C      DO 100 I=1,I1
2280 C      DO 100 J=1,I1

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2281      100 W1 (I, J)=0.0
2282      C
2283          A1=Y2 (1, 1)
2284          A2=Y2 (2, 1)
2285          A3=Y2 (3, 1)
2286          A4=Y2 (4, 1)
2287          A5=Y2 (5, 1)
2288          A6=Y2 (6, 1)
2289      C
2290          W1 (1, 2)=DT
2291      C
2292          W1 (2, 1)=- (3.0*A4*A1*A1+A3) *DT
2293          W1 (2, 2)=- (A5+3.0*A6*A2*A2) *DT
2294          W1 (2, 3)=-A1*DT
2295          W1 (2, 4)=-A1*A1*A1*DT
2296          W1 (2, 5)=-A2*DT
2297          W1 (2, 6)=-A2*A2*A2*DT
2298      C
2299          DO 20 I=1, I1
2300      20 W1 (I, I)=W1 (I, I)+1.0
2301      C
2302      C
2303          RETURN
2304          END
2305
2306      C
2307      C ***** SUBROUTINE WW5 *****
2308      C * * * * *
2309      C *          SUBROUTINE FOR THE STATE TRANSITION MATRIX *
2310      C *          FOR SDOF SYSTEM WITH BILINEAR HYSTERESIS *
2311      C *          ( ICON = 5 ) *
2312      C *          CALLED BY THE MAIN PROGRAM *
2313      C *****
2314      C
2315      C PURPOSE:
2316      C TO COMPUTE STATE TRANSITION MATRIX OF THE SDOF SYSTEM
2317      C WITH BILINEAR HYSTERESIS. STATE TRANSITION MATRIX IS
2318      C CONSTRUCTED FROM CONTINUOUS STATE EQUATION USING FIRST
2319      C ORDER APPROXIMATION.
2320      C
2321      C USAGE:
2322      C CALL WW5 (W1, Y2, DT, I1, J1, XX, NZ, XXX)
2323      C
2324      C DESCRIPTION OF PARAMETERS
2325      C W1 (J1, J1) : STATE TRANSITION MATRIX OF THE BILINEAR
2326      C HYSTERETIC SYSTEM
2327      C Y2 (J1, 1) : FILTERED STATE VECTOR
2328      C DT : TIME INCREMENT IN SEC
2329      C I1 : DIMENSION OF EXTENDED STATE VECTOR
2330      C (I1.LE.30)
2331      C J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
2332      C XX, NZ, XXX : PARAMETERS FOR BILINEAR HYSTERESIS
2333      C
2334      C REMARK:
2335      C (1) PARAMETER I1 MUST BE LESS THAN 30
2336      C
2337      C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2338      C NONE
2339      C *****
2340      C

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2341     SUBROUTINE WW5 (W1, Y2, DT, I1, J1, XX, NZ, XXX)
2342     C      IMPLICIT REAL*8 (A-H, O-Z)
2343     DIMENSION W1 (J1, J1), Y2 (J1, 1)
2344     C
2345     DO 600 I=1, 6
2346     DO 600 J=1, 6
2347     600 W1 (I, J)=0.0
2348     C
2349     DO 700 I=1, 6
2350     700 W1 (I, I)=1.0
2351     C
2352     C
2353     W1 (1, 2)=DT
2354     W1 (2, 2)=1.0-2.0*Y2 (3, 1)*Y2 (4, 1)*DT
2355     W1 (2, 3)=-2.0*Y2 (4, 1)*DT*Y2 (2, 1)
2356     C
2357     C
2358     GO TO (100, 200, 300, 400, 500), NZ
2359     C
2360     100 A1=1.0
2361     A4=Y2 (1, 1)
2362     A5=0.0
2363     A6=0.0
2364     GO TO 1000
2365     C
2366     200 A1=Y2 (6, 1)
2367     A4=Y2 (6, 1)*Y2 (1, 1)+(1.0-Y2 (6, 1))*Y2 (5, 1)
2368     A5=1.0-Y2 (6, 1)
2369     A6=Y2 (1, 1)-Y2 (5, 1)
2370     GO TO 1000
2371     C
2372     300 A1=1.0
2373     A4=(1.0-Y2 (6, 1))*(Y2 (5, 1)-XX)
2374     A4=A4+Y2 (1, 1)
2375     A5=1.0-Y2 (6, 1)
2376     A6=XX-Y2 (5, 1)
2377     GO TO 1000
2378     C
2379     400 A1=Y2 (6, 1)
2380     A4=- (1.0-Y2 (6, 1))*Y2 (5, 1)
2381     A4=A4+Y2 (6, 1)*Y2 (1, 1)
2382     A5=-1.0+Y2 (6, 1)
2383     A6=Y2 (1, 1)+Y2 (5, 1)
2384     GO TO 1000
2385     C
2386     500 A1=1.0
2387     A4=- (1.0-Y2 (6, 1))*(XX+Y2 (5, 1))
2388     A4=Y2 (1, 1)+A4
2389     A5=-1.0+Y2 (6, 1)
2390     A6=XX+Y2 (5, 1)
2391     C
2392     1000 CONTINUE
2393     W1 (2, 1)=-Y2 (4, 1)*Y2 (4, 1)*DT*A1
2394     W1 (2, 4)=-2.0*Y2 (3, 1)*DT*Y2 (2, 1)
2395     W1 (2, 4)=W1 (2, 4)-2.0*Y2 (4, 1)*DT*A4
2396     W1 (2, 5)=-Y2 (4, 1)*Y2 (4, 1)*DT*A5
2397     W1 (2, 6)=-Y2 (4, 1)*Y2 (4, 1)*DT*A6
2398     C
2399     RETURN
2400     END

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2401 C
2402 C
2403 C ***** SUBROUTINE WW6 *****
2404 C *
2405 C * SUBROUTINE FOR THE STATE TRANSITION MATRIX *
2406 C * FOR SDOF SYSTEM WITH BOUC-WEN'S HYSTERESIS MODEL *
2407 C * ( ICON = 6 ) *
2408 C * CALLED BY THE MAIN PROGRAM *
2409 C *****
2410 C
2411 C PURPOSE:
2412 C TO COMPUTE STATE TRANSITION MATRIX OF SDOF SYSTEM WITH
2413 C BOUC-WEN'S HYSTERESIS MODEL. STATE TRANSITION MATRIX
2414 C IS CONSTRUCTED FROM CONTINUOUS STATE EQUATION USING
2415 C FIRST ORDER APPROXIMATION.
2416 C
2417 C USAGE:
2418 C CALL WW6 (W1, Y2, I1, J1, DT, KK, AAZ, NM1)
2419 C
2420 C DESCRIPTION OF PARAMETERS
2421 C W1 (J1, J1) : STATE TRANSITION MATRIX OF BOUC AND WEN'S
2422 C MODEL
2423 C Y2 (J1, 1) : FILTERED STATE VECTOR
2424 C DT : TIME INCREMENT IN SEC
2425 C I1 : DIMENSION OF EXTENDED STATE VECTOR
2426 C (I1.LE.30)
2427 C J1 : DIMENSION OF [W1] OR [Y2] IN CALLING PROGRAM
2428 C DT : TIME INCREMENT IN SEC
2429 C KK : TIME IN DATA PROCESSING
2430 C AAZ : PARAMETER FOR BOUC AND WEN'S MODEL
2431 C NM1 : STARTING TIME IN DATA PROCESSING
2432 C
2433 C REMARK:
2434 C (1) PARAMETER I1 MUST BE LESS THAN 30
2435 C
2436 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2437 C NONE
2438 C *****
2439 C
2440 C
2441 C
2442 C SUBROUTINE WW6 (W1, Y2, I1, J1, DT, KK, AAZ, NM1)
2443 C IMPLICIT REAL*8 (A-H, O-Z)
2444 C DIMENSION W1 (J1, J1), Y2 (J1, 1)
2445 C
2446 C
2447 C DO 100 I=1, I1
2448 C DO 100 J=1, I1
2449 C 100 W1 (I, J)=0.0
2450 C
2451 C
2452 C A1=Y2 (1, 1)
2453 C A2=Y2 (2, 1)
2454 C A3=Y2 (3, 1)
2455 C A4=Y2 (4, 1)
2456 C A5=Y2 (5, 1)
2457 C A6=Y2 (6, 1)
2458 C A7=Y2 (7, 1)
2459 C A8=Y2 (8, 1)
2460 C A9=Y2 (9, 1)

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2461      A10=Y2 (10, 1)
2462      A11=Y2 (11, 1)
2463      A12=Y2 (12, 1)
2464      C
2465      C
2466      W1 (1, 2)=DT
2467      W1 (2, 1)=0.0
2468      W1 (2, 2)=-2.0*A5*A6*DT
2469      W1 (2, 3)=-A6*A6*DT
2470      W1 (2, 4)=0.0
2471      W1 (2, 5)=-2.0*A6*A2*DT
2472      W1 (2, 6)=-2.0*(A5*A2+A3*A6)*DT
2473      C
2474      W1 (3, 1)=0.0
2475      C
2476      C4=(1.0+A12*A4)
2477      C
2478      IF(KK.NE.NM1) GO TO 3000
2479      W1 (3, 2)=0.0
2480      W1 (3, 3)=0.0
2481      GO TO 4000
2482      C
2483      3000 CONTINUE
2484      C
2485      C2=ABS (A2)
2486      C3=ABS (A3)
2487      B1=C3** (AAZ-1.0)
2488      B2=C3**AAZ
2489      B3=C3** (AAZ-2.0)
2490      C
2491      C
2492      D1=A9-A10*A4
2493      D2=1.0+A11*A4
2494      D3=A7*C2*B1*A3/A2+A8*B2
2495      W1 (3, 2)=DT*(D1-D2*D3)/C4
2496      C
2497      D1=(1.0+A11*A4)
2498      D2=(AAZ-1.0)*A7*C2*B3*A3/A3
2499      D3=A7*C2*B1+AAZ*A8*A2*B1/A3
2500      W1 (3, 3)=(-D1*(D2+D3))*DT/C4
2501      C
2502      4000 CONTINUE
2503      C
2504      C
2505      W1 (3, 1)=0.0
2506      C
2507      D1=-A10*A2
2508      D2=-A11*(A7*C2*B1*A3+A8*A2*B2)
2509      D3=(A9-A10*A4)*A2
2510      D4=1.0+A11*A4
2511      D5=A7*C2*B1*A3+A8*A2*B2
2512      D6=((D1+D2)*C4-A12*(D3-D4*D5))/(C4*C4)
2513      W1 (3, 4)=D6*DT
2514      C
2515      W1 (3, 5)=0.0
2516      W1 (3, 6)=0.0
2517      C
2518      D1=- (1.0+A11*A4)*(C2*B1*A3)
2519      W1 (3, 7)=D1*DT/C4
2520      C

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2521      D1=- (1.0+A11*A4) * (A2*B2)
2522      W1 (3, 8)=D1*DT/C4
2523      C
2524      W1 (3, 9)=A2*DT/C4
2525      C
2526      W1 (3, 10)=-A2*A4*DT/C4
2527      C
2528      D1=A7*C2*B1*A3+A8*A2*B2
2529      W1 (3, 11)=-A4*D1*DT/C4
2530      C
2531      D1=(A9-A10*A4) *A2
2532      D2=(1.0+A11*A4) * (A7*C2*B1*A3+A8*A2*B2)
2533      W1 (3, 12)=(-A4*(D1-D2)) *DT/ (C4*C4)
2534      C
2535      W1 (4, 2)=A3*A6*DT*A6
2536      W1 (4, 3)=A2*DT*A6*A6
2537      W1 (4, 6)=2.0*A2*DT*A3*A6
2538      C
2539      C
2540      DO 10 I=1, I1
2541      10 W1 (I, I)=1.0+W1 (I, I)
2542      C
2543      RETURN
2544      END
2545      C
2546      C ***** SUBROUTINE STEP5 *****
2547      C *
2548      C * SUBROUTINE FOR ERROR COVARIANCE MATRIX OF
2549      C * THE PREDICTED STATE
2550      C * CALLED BY THE MAIN PROGRAM
2551      C *****
2552      C
2553      C PURPOSE:
2554      C TO COMPUTE ERROR COVARIANCE MATRIX OF THE PREDICTED
2555      C STATE
2556      C
2557      C USAGE:
2558      C CALL STEP5 (P1, W1, P2, W2, G1, Q, G2, I1, J1)
2559      C
2560      C DESCRIPTION OF PARAMETERS
2561      C P1 (J1, J1): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
2562      C W1 (J1, J1): STATE TRANSITION MATRIX OF THE SYSTEM
2563      C P2 (J1, J1): ERROR COVARIANCE MATRIX OF THE FILTERED STATE
2564      C W2 (J1, J1): TRANSPOSED MATRIX OF [W1]
2565      C G1 (J1, J1): SYSTEM NOISE COEFFICIENT MATRIX
2566      C Q (J1, J1): SYSTEM NOISE COVARIANCE MATRIX
2567      C G2 (J1, J1): TRANSPOSED MATRIX OF [G1]
2568      C I1: DIMENSION OF EXTENDED STATE VECTOR
2569      C (I1.LE.30)
2570      C J2: DIMENSION OF [P1], [W1], [P2], [W2], [G1], [Q]
2571      C OR [G2] IN CALLING PROGRAM
2572      C
2573      C REMARKS
2574      C (1) PARAMETER I1 MUST BE LESS THAN 30
2575      C
2576      C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2577      C TEN MMUT
2578      C *****
2579      C
2580      C SUBROUTINE STEP5 (P1, W1, P2, W2, G1, Q, G2, I1, J1)

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2581 C      IMPLICIT REAL*8(A-H,O-Z)
2582      DIMENSION P1(J1,J1),W1(J1,J1),P2(J1,J1)
2583      DIMENSION W2(J1,J1),G1(J1,J1),Q(J1,J1),G2(J1,J1)
2584      DIMENSION C7(30,30),C8(30,30)
2585      DIMENSION C9(30,30),C10(30,30)
2586      DATA K1/30/
2587 C
2588 C      ----- [W2] <= [W1] -----
2589      CALL TEN(W1,W2,I1,I1,J1,J1,J1,J1)
2590 C      ----- [C7] <= [W1]*[P2] -----
2591      CALL MMUT(W1,P2,C7,I1,I1,I1,J1,J1,J1,K1,K1)
2592 C      ----- [C9] <= [C7]*[W2] -----
2593      CALL MMUT(C7,W2,C9,I1,I1,I1,K1,K1,J1,J1,K1,K1)
2594 C      ----- [G2] <= [G1] TRANSPOSE -----
2595      CALL TEN(G1,G2,I1,I1,J1,J1,J1,J1)
2596 C      ----- [C8] <= [G1]*[Q] -----
2597      CALL MMUT(G1,Q,C8,I1,I1,I1,J1,J1,J1,K1,K1)
2598 C      ----- [C10] <= [C8]*[G2] -----
2599      CALL MMUT(C8,G2,C10,I1,I1,I1,K1,K1,J1,J1,K1,K1)
2600 C
2601 C
2602 C      ----- [P1]<= [C9]+[C10] -----
2603      DO 100 I=1,I1
2604      DO 200 J=1,I1
2605      P1(I,J)=C9(I,J)+C10(I,J)
2606      200 CONTINUE
2607      100 CONTINUE
2608 C
2609 C
2610      RETURN
2611      END
2612 C
2613 C      ***** SUBROUTINE TEN *****
2614 C      *
2615 C      *          SUBROUTINE FOR MATRIX TRANSPOSITION          *
2616 C      *          CALLED BY SUBROUTINES STEP2, STEP3 AND STEP5  *
2617 C      *****
2618 C
2619 C      PURPOSE:
2620 C          TO COMPUTE TRANSPOSED MATRIX
2621 C
2622 C      USAGE:
2623 C          CALL TEN(A1,A2,I1,I2,J1,J2,J3,J4)
2624 C
2625 C      DESCRIPTION OF PARAMETERS
2626 C          A1(J1,J2): MATRIX IN CALLING PROGRAM
2627 C          A2(J3,J4): TRANSPOSED MATRIX OF [A1]
2628 C          I1,I2,J1,J2,J3,J4 : DIMENSION OF [A1] AND [A2] IN CALLING
2629 C          PROGRAM
2630 C
2631 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2632 C          NONE
2633 C      *****
2634 C
2635      SUBROUTINE TEN(A1,A2,I1,I2,J1,J2,J3,J4)
2636 C      IMPLICIT REAL*8(A-H,O-Z)
2637      DIMENSION A1(J1,J2),A2(J3,J4)
2638 C
2639 C          A2(I1,I2) <= A1(I2,I1)
2640 C

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2641      DO 100 II=1, I1
2642      DO 200 IJ=1, I2
2643      A2 (IJ, II)=0.0
2644      200 CONTINUE
2645      100 CONTINUE
2646      C
2647      C
2648      DO 300 II=1, I1
2649      DO 400 IJ=1, I2
2650      A2 (IJ, II)=A1 (II, IJ)
2651      400 CONTINUE
2652      300 CONTINUE
2653      RETURN
2654      END
2655      C
2656      C ***** SUBROUTINE HH1 *****
2657      C * * * * *
2658      C * SUBROUTINE FOR LINEARIZED OBSERVATION VECTOR *
2659      C * EQ. REGARDING AS EACH PARAMETER *
2660      C * CALLED BY THE MAIN PROGRAM *
2661      C *****
2662      C
2663      C PURPOSE:
2664      C TO COMPUTE LINEARIZED OBSERVATION VECTOR BY USING
2665      C PREDICTED STATE VECTOR
2666      C
2667      C USAGE:
2668      C CALL HH1 (H1, I2, DT, J1, J2, KK, ICON, Y1, N)
2669      C
2670      C DESCRIPTION OF PARAMETERS
2671      C H1 (J2, J1): LINEARIZED OBSERVATION VECTOR EQ.
2672      C N: NUMBER OF DEGREE OF FREEDOM STRUCTURE
2673      C KK: TIME IN DATA PROCESSING
2674      C DT: TIME INCREMENT IN SEC
2675      C I2: NUMBER OF RESPONSE OBSERVATIONS
2676      C J1, J2: DIMENSION OF [AHH] OR [Y1] IN CALLING
2677      C PROGRAM
2678      C ICON: PARAMETER FOR STATE VECTOR EQUATION
2679      C AND OBSERVATION VECTOR EQUATION
2680      C
2681      C REMARKS
2682      C
2683      C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2684      C NONE
2685      C *****
2686      C
2687      C SUBROUTINE HH1 (H1, I2, DT, J1, J2, KK, ICON, Y1, N)
2688      C IMPLICIT REAL*8 (A-H, O-Z)
2689      C DIMENSION H1 (J2, J1), Y1 (J1, 1)
2690      C
2691      C
2692      C IQ=1
2693      C DO 100 I=1, N
2694      C IF (ICON.NE.3) THEN
2695      C IF (ICON.EQ.1) IQ=5
2696      C IF (ICON.EQ.2) IQ=6
2697      C II=IQ*(I-1)
2698      C
2699      C DO 200 IIJ=1, I2
2700      C H1 (IIJ, IIJ+II)=1.0

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2701      200 CONTINGE
2702      C
2703      ELSE
2704      C
2705      II=3*(I-1)
2706      A1=Y1 (II+1, 1)
2707      A2=Y1 (II+2, 1)
2708      A3=Y1 (II+3, 1)
2709      OME=FLOAT (KK-1) *DT
2710      C
2711      B1=A2*A2-OME*OME
2712      B2=-A3*B1
2713      B3=2.0*A1*A2*OME
2714      B4=B3*B3
2715      B5=B1*B1+B4
2716      B6=2.0*A3*A1*A2*OME
2717      C
2718      C1=-B2*2.0*B3*2.0*A2*OME/(B5*B5)
2719      H1 (1, II+1)=C1
2720      C
2721      C1=-2.0*A3*A2*B5
2722      C2=2.0*B1*2.0*A2
2723      C3=2.0*B3*2.0*A1*OME
2724      C4=-B2*(C2+C3)
2725      C5=(C1+C4)/(B5*B5)
2726      H1 (1, II+2)=C5
2727      C
2728      C1=-B1/B5
2729      H1 (1, II+3)=C1
2730      C
2731      C
2732      C
2733      C1=2.0*A3*A2*OME*B5
2734      C2=2.0*2.0*A1*A2*OME
2735      C3=C2*2.0*A2*OME
2736      C4=B6*C3
2737      H1 (2, II+1)=(C1-C4)/(B5*B5)
2738      C
2739      C1=2.0*A3*A1*OME*B5
2740      C2=2.0*B1*2.0*A2
2741      C3=2.0*2.0*A1*A2*OME
2742      C4=C3*2.0*A1*OME
2743      C5=(C1-B6*(C2+C4))/(B5*B5)
2744      H1 (2, II+2)=C5
2745      C
2746      C1=2.0*A1*A2*OME
2747      C2=C1/B5
2748      H1 (2, II+3)=C2
2749      C
2750      END IF
2751      100 CONTINUE
2752      C
2753      RETURN
2754      END
2755      C
2756      C ***** SUBROUTINE STEP1 *****
2757      C *
2758      C * SUBROUTINE FOR KALMAN GAIN MATRIX *
2759      C * CALLED BY THE MAIN PROGRAM *
2760      C *****

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2761 C PURPOSE:
2762 C TO COMPUTE THE KALMAN GAIN MATRIX
2763 C
2764 C USAGE:
2765 C CALL STEP1(AK,P1,H1,H2,R,I1,I2,J1,J2)
2766 C
2767 C DESCRIPTION OF PARAMETERS
2768 C AK(J1,J2): KALMAN GAIN MATRIX
2769 C P1(J1,J2): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
2770 C H1(J2,J1): LINEARIZED MATRIX OF THE OBSERVATION EQUATION
2771 C REGARDING EACH PARAMETER
2772 C H2(J1,J2): TRANSPOSED MATRIX OF [H1]
2773 C R(J2,J2): OBSERVATION NOISE COVARIANCE MATRIX
2774 C I1: DIMENSION OF EXTENDED STATE VECTOR
2775 C (I1.LE.30)
2776 C I2: NUMBER OF RESPONSE OBSERVATIONS
2777 C (I2.LE.10)
2778 C J1,J2: DIMENSION OF [AK],[P1],[H1],[H2] OR [R]
2779 C IN CALLING PROGRAM
2780 C
2781 C REMARKS:
2782 C (1) PARAMETER I1 MUST BE LESS THAN 30
2783 C (2) PARAMETER I2 MUST BE LESS THAN 10
2784 C
2785 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2786 C TEN MMUT
2787 C *****
2788 C
2789 C SUBROUTINE STEP1(AK,P1,H1,H2,R,I1,I2,J1,J2)
2790 C IMPLICIT REAL*8(A-H,O-Z)
2791 C DIMENSION AK(J1,J2),P1(J1,J1),H1(J2,J1)
2792 C DIMENSION H2(J1,J2),R(J2,J2)
2793 C DIMENSION C1(30,30),C2(10,10)
2794 C DIMENSION C4(2,2)
2795 C DATA K1/30/
2796 C
2797 C
2798 C ----- [H2]<== [H1] TRANSPOSE -----
2799 C CALL TEN(H1,H2,I2,I1,J2,J1,J1,J2)
2800 C ----- [C1]<== [H1]*[P1] -----
2801 C CALL MMUT(H1,P1,C1,I2,I1,I1,J2,J1,J1,K1,K1)
2802 C ----- [C2]<== [C1]*[H2] -----
2803 C CALL MMUT(C1,H2,C2,I2,I1,I2,K1,K1,J1,J2,J2,J2)
2804 C
2805 C ----- [C2]<== [C2]+[R] -----
2806 C DO 200 I=1,I2
2807 C DO 200 J=1,I2
2808 C C2(I,J)=C2(I,J)+R(I,J)
2809 C 200 CONTINUE
2810 C
2811 C IF(I2.EQ.2) GO TO 400
2812 C IF(I2.EQ.1) GO TO 600
2813 C
2814 C ----- INVERSE MATRIX [C2]<==[C2]-----
2815 C 400 CONTINUE
2816 C A=C2(1,1)*C2(2,2)-C2(2,1)*C2(1,2)
2817 C A=1.0/A
2818 C C4(1,1)=C2(1,1)
2819 C C4(1,2)=C2(1,2)
2820 C C4(2,1)=C2(2,1)

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2821      C4 (2, 2) =C2 (2, 2)
2822      C2 (1, 1) =A*C4 (2, 2)
2823      C2 (1, 2) =-A*C4 (2, 1)
2824      C2 (2, 1) =-A*C4 (1, 2)
2825      C2 (2, 2) =A*C4 (1, 1)
2826      GO TO 500
2827      600 CONTINUE
2828      C2 (1, 1) =1.0/C2 (1, 1)
2829      500 CONTINUE
2830      C
2831      C      ----- [C1] <= [P1] * [H2] -----
2832      CALL MMUT (P1, H2, C1, I1, I1, I2, J1, J1, J1, J2, K1, K1)
2833      C      ----- [AK] <= [C1] * [C2] -----
2834      CALL MMUT (C1, C2, AK, I1, I2, I2, K1, K1, J2, J2, J1, J2)
2835      C
2836      C
2837      RETURN
2838      END
2839      C
2840      C      ***** SUBROUTINE HH2 *****
2841      C      *
2842      C      *      SUBROUTINE FOR OBSREATION VECTOR EQ.      *
2843      C      *      CALLED BY THE MAIN PROGRAM      *
2844      C      *****
2845      C
2846      C      PURPOSE:
2847      C      TO COMPUT ESTIMATED OBSERVATIONS BY USING PREDICTED
2848      C      STATE VECTOR
2849      C
2850      C      USAGE:
2851      C      CALL HH2 (N, AHH, Y1, KK, DT, I2, J1, J2, ICON)
2852      C
2853      C      DESCRIPTION OF PARAMETERS
2854      C      N: NUMBER OF DEGREE OF FREEDOM OF STRUCTURE
2855      C      AHH (J2, 1): ESTIMATED OBSERVATION VECTOR
2856      C      Y1 (J1, 1): PREDICTED STATE VECTOR
2857      C      KK: TIME IN DATA PROCESSING
2858      C      DT: TIME INCREMENT IN SEC
2859      C      I2: NUMBER OF RESPONSE OBSERVATIONS
2860      C      J1, J2: DIMENSION OF [AHH] OR [Y1] IN CALLING
2861      C      PROGRAM
2862      C      ICON: PARAMETER FOR STATE VECTOR EQUATION
2863      C      AND OBSERVATION VECTOR EQUATION
2864      C
2865      C      REMARKS
2866      C
2867      C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2868      C      NONE
2869      C      *****
2870      C
2871      C      SUBROUTINE HH2 (N, AHH, Y1, KK, DT, I2, J1, J2, ICON)
2872      C      IMPLICIT REAL*8 (A-H, O-Z)
2873      C      DIMENSION AHH (J2, 1), Y1 (J1, 1)
2874      C
2875      C      IQ=1
2876      C      DO 100 I=1, I2
2877      C      AHH (I, 1) =0.0
2878      C      100 CONTINUE
2879      C
2880      C      IF (ICON.EQ.3) GO TO 10

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2881      IF (ICON.EQ.1) IQ=5
2882      IF (ICON.EQ.2) IQ=6
2883  C
2884      DO 200 I=1, N
2885      II=IQ*(I-1)
2886      DO 300 J=1, I2
2887      AHH (J, 1)=AHH (J, 1)+Y1 (J+II, 1)
2888  300 CONTINUE
2889  200 CONTINUE
2890      GO TO 20
2891  C
2892  10 CONTINUE
2893      DO 400 I=1, N
2894      II=3*(I-1)
2895      OME=FLOAT (KK-1) *DT
2896  C
2897      A1=Y1 (II+2, 1) *Y1 (II+2, 1) -OME*OME
2898      AA1=A1*A1
2899      A1=2.0*Y1 (II+1, 1) *Y1 (II+2, 1) *OME
2900      AA2=A1*A1
2901      AA=AA1+AA2
2902      AA1=-Y1 (II+3, 1) *(Y1 (II+2, 1) *Y1 (II+2, 1) -OME*OME)
2903      AA2=2.0*Y1 (II+3, 1) *Y1 (II+1, 1) *Y1 (II+2, 1) *OME
2904  C
2905      AHH (1, 1)=AHH (1, 1)+AA1/AA
2906      AHH (2, 1)=AHH (2, 1)+AA2/AA
2907  400 CONTINUE
2908  C
2909  20 CONTINUE
2910  C
2911      RETURN
2912      END
2913  C
2914  C ***** SUBROUTINE STEP2 *****
2915  C *
2916  C * SUBROUTINE FOR THE FILTERED STATE VECTOR *
2917  C * CALLED BY THE MAIN PROGRAM *
2918  C *****
2919  C
2920  C PURPOSE:
2921  C TO COMPUTE THE FILTERED STATE VECTOR
2922  C
2923  C USAGE:
2924  C CALL STEP2 (Y2, Y1, AK, Z, AHH, I1, I2, J1, J2)
2925  C
2926  C DESCRIPTION OF PARAMETERS
2927  C Y2 (J1, 1): FILTERED STATE VECTOR
2928  C Y1 (J1, 1): PREDICTED STATE VECTOR
2929  C AK (J1, 1): KALMAN GAIN MATRIX
2930  C Z (J2, 1): OBSERVATION VECTOR
2931  C AHH (J2, 1): EVALUATED OBSERVATION VECTOR BY USING
2932  C STATE VECTOR
2933  C I1: DIMENSION OF EXTENDED STATE VECTOR
2934  C (I1.LE.30)
2935  C I2: NUMBER OF RESPONSE OBSERVATIONS
2936  C (I2.LE.10)
2937  C J1, J2: DIMENSION OF [AK], [P1], [H1], [H2] OR [R]
2938  C IN CALLING PROGRAM
2939  C
2940  C REMARKS

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2941 C (1) PARAMETER I1 MUST BE LESS THAN 30
2942 C (2) PARAMETER I2 MUST BE LESS THAN 10
2943 C
2944 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
2945 C MMUT
2946 C *****
2947 C
2948 C SUBROUTINE STEP2(Y2,Y1,AK,Z,AHH,I1,I2,J1,J2)
2949 C IMPLICIT REAL*8(A-H,O-Z)
2950 C DIMENSION Y2(J1,1),Y1(J1,1),AK(J1,J2)
2951 C DIMENSION Z(J2,1),AHH(J2,1)
2952 C DIMENSION C3(10,1),C4(30,1),Y6(30,1)
2953 C DATA K1/30/
2954 C
2955 C ----- [C3]<= [Z]-[AHH]-----
2956 C DO 100 I=1,I2
2957 C C3(I,1)=Z(I,1)-AHH(I,1)
2958 C 100 CONTINUE
2959 C
2960 C ----- [C4]<= [AK]*[C3] -----
2961 C CALL MMUT(AK,C3,C4,I1,I2,1,J1,J2,J2,1,K1,1)
2962 C
2963 C ----- [Y6]<= [Y1]+[C4] -----
2964 C DO 200 I=1,I1
2965 C Y6(I,1)=Y1(I,1)+C4(I,1)
2966 C 200 CONTINUE
2967 C 1000 CONTINUE
2968 C
2969 C
2970 C ----- [Y2]<= [Y6] -----
2971 C DO 3000 I=1,I1
2972 C 3000 Y2(I,1)=Y6(I,1)
2973 C
2974 C RETURN
2975 C END
2976 C
2977 C ***** SUBROUTINE STEP3 *****
2978 C * * * * *
2979 C * SUBROUTINE FOR ERROR COVARIANCE MATRIX OF *
2980 C * THE FILTERED STATE *
2981 C * CALLED BY THE MAIN PROGRAM *
2982 C * * * * *
2983 C
2984 C PURPOSE:
2985 C TO COMPUTE ERROR COVARIANCE MATRIX OF THE FILTERED STATE
2986 C
2987 C USAGE:
2988 C CALL STEP3(P2,AK,H1,P1,R,I1,I2,J1,J2)
2989 C
2990 C DESCRIPTION OF PARAMETERS
2991 C P2(J1,J1): ERROR COVARIANCE MATRIX OF THE FILTERED STATE
2992 C AK(J1,J2): KALMAN GAIN MATRIX
2993 C H1(J2,J1): LINEARIZED MATRIX OF THE OBSERVATION EQUATION
2994 C REGARDING EACH PARAMETER
2995 C P1(J1,J2): ERROR COVARIANCE MATRIX OF THE PREDICTED STATE
2996 C R(J2,J2): OBSERVATION NOISE COVARIANCE MATRIX
2997 C I1 : DIMENSION OF EXTENDED STATE VECTOR
2998 C (I1.LE.30)
2999 C I2 : NUMBER OF RESPONSE OBSERVATIONS
3000 C (I2.LE.10)

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3001 C          J1, J2: DIMENSION OF [P2], [AK], [H1], [P1] AND [R]
3002 C
3003 C      REMARKS:
3004 C          (1) PARAMETER I1 MUST BE LESS THAN 30
3005 C          (2) PARAMETER I2 MUST BE LESS THAN 10
3006 C
3007 C      SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
3008 C          TEN, MMUT
3009 C      *****
3010 C
3011 C      SUBROUTINE STEP3(P2, AK, H1, P1, R, I1, I2, J1, J2)
3012 C          IMPLICIT REAL*8(A-H, O-Z)
3013 C          DIMENSION P2(J1, J1), AK(J1, J2), H1(J2, J1), P1(J1, J1)
3014 C          DIMENSION C5(30, 30)
3015 C          DIMENSION C55(30, 30), CP(30, 30), AK11(30, 30)
3016 C          DIMENSION R(J2, J2)
3017 C          DATA K1/30/
3018 C
3019 C
3020 C          ----- [C5]<= [AK]*[H1]-----
3021 C          CALL MMUT(AK, H1, C5, I1, I2, I1, J1, J2, J2, J1, K1, K1)
3022 C
3023 C          ----- [C5]<= -[C5] -----
3024 C          DO 100 I=1, I1
3025 C          DO 100 J=1, I1
3026 C          C5(I, J)=-C5(I, J)
3027 C      100 CONTINUE
3028 C
3029 C          ----- [C5]<= [II]+[C5] ([II];UNIT MATRIX) ----
3030 C          DO 200 I=1, I1
3031 C          C5(I, I)=1.0+C5(I, I)
3032 C      200 CONTINUE
3033 C
3034 C          ----- [C55]<= [C5] TRANSPOSE -----
3035 C          CALL TEN(C5, C55, I1, I1, K1, K1, K1, K1)
3036 C
3037 C          ----- [CP]<= [C5]*[P1] -----
3038 C          CALL MMUT(C5, P1, CP, I1, I1, I1, K1, K1, J1, J1, K1, K1)
3039 C          ----- [C5]<= [CP]*[C55] -----
3040 C          CALL MMUT(CP, C55, C5, I1, I1, I1, K1, K1, K1, K1, K1, K1)
3041 C          ----- [AK11]<= [AK] TRANSPOSE -----
3042 C          CALL TEN(AK, AK11, I1, I2, J1, J2, K1, K1)
3043 C          ----- [C55]<= [AK]*[R] -----
3044 C          CALL MMUT(AK, R, C55, I1, I2, I2, J1, J2, J2, J2, K1, K1)
3045 C          ----- [CP]<= [C55]*[AK11] -----
3046 C          CALL MMUT(C55, AK11, CP, I1, I2, I1, K1, K1, K1, K1, K1, K1)
3047 C
3048 C          ----- [P2]<= [C5]+[CP] -----
3049 C          DO 500 I=1, I1
3050 C          DO 600 J=1, I1
3051 C          P2(I, J)=C5(I, J)+CP(I, J)
3052 C      600 CONTINUE
3053 C      500 CONTINUE
3054 C
3055 C
3056 C          RETURN
3057 C          END
3058 C
3059 C      ***** SUBROUTINE SETN *****
3060 C      *

```

```

3061 C * SUBROUTINE FOR IDENTIFICATION OF BILINEAR HYSTERESIS *
3062 C *          CALLED BY THE MAIN PROGRAM          *
3063 C *****
3064 C
3065 C
3066 C SUBROUTINE SETN(Y3, J1, J3, KK, NZ, XX, XXX)
3067 C   IMPLICIT REAL*8 (A-H, O-Z)
3068 C   DIMENSION Y3 (J1, J3)
3069 C
3070 C   P1=Y3 (1, KK)
3071 C   P2=Y3 (2, KK-1) *Y3 (2, KK)
3072 C
3073 C
3074 C   XE=Y3 (5, KK)
3075 C   GO TO (100, 200, 300, 400, 500) , NZ
3076 C
3077 C
3078 C   100 IF (P1.GE.XE) GO TO 200
3079 C       IF (P1.LE.-XE) GO TO 400
3080 C       NZ=1
3081 C       GO TO 1000
3082 C
3083 C
3084 C   200 IF (NZ.EQ.3) GO TO 220
3085 C       IF (NZ.EQ.1) GO TO 220
3086 C       IF (NZ.EQ.5) GO TO 220
3087 C       IF (P2.LE.0.0) GO TO 300
3088 C   220 NZ=2
3089 C       GO TO 1000
3090 C
3091 C
3092 C   300 IF (NZ.EQ.3) GO TO 310
3093 C       XX=P1
3094 C   310 IF (P1.GE.XX.AND.NZ.EQ.3) GO TO 200
3095 C       XXX=XX-2.0*XE
3096 C       IF (P1.LE.XXX.AND.NZ.EQ.3) GO TO 400
3097 C       NZ=3
3098 C       GO TO 1000
3099 C
3100 C
3101 C   400 IF (NZ.EQ.3) GO TO 420
3102 C       IF (NZ.EQ.1) GO TO 420
3103 C       IF (NZ.EQ.5) GO TO 420
3104 C       IF (P2.LE.0.0) GO TO 500
3105 C   420 NZ=4
3106 C       GO TO 1000
3107 C
3108 C
3109 C   500 IF (NZ.EQ.5) GO TO 510
3110 C       XX=P1
3111 C   510 IF (P1.LE.XX.AND.NZ.EQ.5) GO TO 400
3112 C       XXX=XX+2.0*XE
3113 C       IF (P1.GE.XXX.AND.NZ.EQ.5) GO TO 200
3114 C       NZ=5
3115 C   1000 CONTINUE
3116 C       RETURN
3117 C       END
3118 C
3119 C ***** SUBROUTINE WRITER *****
3120 C *

```

```

3121 C * SUBROUTINE FOR PRINT OUT THE RESULT ON UNIT 6 *
3122 C * CALLED BY THE MAIN PROGRAM *
3123 C *****
3124 C
3125 C PURPOSE:
3126 C TO PRINT OUT THE RESULT UNIT=6
3127 C
3128 C USAGE:
3129 C CALL WRITEB (Y, DY, Y3, K2, I1, J1, J2, J3, NN, Y4)
3130 C
3131 C DESCRIPTION OF PARAMETERS
3132 C Y (J2, J3) : OBSERVATION DATA
3133 C DY (J3) : INPUT EXCITATION
3134 C Y3 (J1, J3) : ESTIMATED STATE VECTOR AT EACH STEP
3135 C FROM NM1 TO NM2
3136 C K2 : NUMBER OF RESPONSE OBSERVATIONS
3137 C I1 : DIMENSION OF EXTENDED STATE VECTOR
3138 C (I1.LE.30)
3139 C J2, J3 : DIMENSION OF [Y], [DY], AND [Y3]
3140 C IN CALLING PROGRAM
3141 C NN : TOTAL NUMBER OF DATA POINT
3142 C Y4 (J1, J3) : ERROR COVARIANCE MATRIX OF THE FILTERED
3143 C STATE AT EACH STEP
3144 C REMARKS
3145 C (1) PARAMETER I1 MUST BE LESS THAN 30
3146 C
3147 C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
3148 C NONE
3149 C *****
3150 C
3151 C SUBROUTINE WRITEB (Y, DY, Y3, K2, I1, J1, J2, J3, NN, Y4)
3152 C IMPLICIT REAL*8 (A-H, O-Z)
3153 C DIMENSION Y (J2, J3), DY (J3), Y3 (J1, J3)
3154 C DIMENSION Y4 (J1, J3)
3155 C DIMENSION Y8 (30)
3156 C DATA K90/30/
3157 C
3158 C WRITE (6, 8000)
3159 C WRITE (6, 710)
3160 C 710 FORMAT (1H ,
3161 C 1 '***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***')
3162 C WRITE (6, 8000)
3163 C
3164 C NOT=5
3165 C NNN=NN-10
3166 C L1=K2/6
3167 C IF (L1.EQ.0) GO TO 100
3168 C DO 20 L2=1, L1
3169 C DO 10 L5=NNN, NN, NOT
3170 C L4=6*(L2-1)+1
3171 C L10=6*L2
3172 C WRITE (6, 503) L5
3173 C 503 FORMAT (1H , 'OBSERVED AT=', I5)
3174 C WRITE (6, 500) (Y (L3, L5), L3=L4, L10)
3175 C 10 CONTINUE
3176 C 20 CONTINUE
3177 C
3178 C K3=K2
3179 C L3=L1*6+1
3180 C GO TO 200

```

```

3181      100 K3=K2
3182          L3=1
3183      200 CONTINUE
3184          DO 30 L1=NNN,NN,NOT
3185              WRITE (6,503) L1
3186              WRITE (6,500) (Y (L2, L1) , L2=L3, K3)
3187      30 CONTINUE
3188      C
3189      C
3190          NNN=NN-10
3191      C
3192          WRITE (6,8000)
3193          WRITE (6,740)
3194      740 FORMAT (1H ,
3195          1 '***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***')
3196          WRITE (6,8000)
3197          L1=I1/6
3198          IF (L1.EQ.0) GO TO 400
3199          DO 410 L2=1, L1
3200              DO 420 L5=NNN,NN,NOT
3201                  L4=6* (L2-1) +1
3202                  L10=6*L2
3203                  WRITE (6,504) L5
3204      504 FORMAT (1H , 'ESTIMATED AT=' , I5)
3205                  WRITE (6,500) (Y3 (L3, L5) , L3=L4, L10)
3206      420 CONTINUE
3207                  WRITE (6,501)
3208      410 CONTINUE
3209      C          DO 810 L2=1, L1
3210      C          DO 820 L5=NNN,NN,NOT
3211      C          L4=6* (L2-1) +1
3212      C          L10=6*L2
3213      C          WRITE (6,500) (Y4 (L3, L5) , L3=L4, L10)
3214      C      820 CONTINUE
3215      C          WRITE (6,501)
3216      C      810 CONTINUE
3217          IL=I1-L1*6
3218          IF (IL.LE.0 ) GO TO 3000
3219          K3=I1
3220          L3=L1*6+1
3221          GO TO 430
3222      400 K3=I1
3223          L3=1
3224      430 DO 440 L1=NNN,NN,NOT
3225          WRITE (6,504) L1
3226      440 WRITE (6,500) (Y3 (L2, L1) , L2=L3, K3)
3227          WRITE (6,501)
3228      C          C11=0.0
3229      C          DO 840 L1=NNN,NN,NOT
3230      C          DO 4001 J=1, I1
3231      C      4001 C11=Y4 (J, L1) **2+C11
3232      C          C11=SQRT (C11)
3233      C          WRITE (6,500) ( (Y4 (L2, L1) , L2=L3, K3) , C11)
3234      C          C11=0.0
3235      C      840 CONTINUE
3236      3000 CONTINUE
3237      C
3238          AN=NN
3239          A2=K2
3240          K9=2*K2

```

```

3241         K10=3*K2+1
3242         DO 5000 I=1, I1
3243 5000      Y8(I)=0.0
3244         DO 5010 I=1, K2
3245         II=I+K2
3246         DO 5020 J=1, NN
3247         AA=Y(I, J) -Y3(I, J)
3248         AB=AA*AA
3249         AC=Y(I, J) *Y(I, J)
3250         Y8(I)=Y8(I) +AB
3251         Y8(II)=Y8(II) +AC
3252 5020      CONTINUE
3253         Y8(I)=Y8(I) /AN
3254         Y8(II)=Y8(II) /AN
3255 5010      CONTINUE
3256         DO 5030 I=1, K2
3257         II=I+K2
3258 5030      Y8(K9+I)=Y8(I) /Y8(II) *100.0
3259         DO 5040 I=1, K2
3260 5040      Y8(K10)=Y8(K10) +Y8(K9+I)
3261         Y8(K10)=Y8(K10) /A2
3262         AA=0.0
3263         DO 5050 I=1, K2
3264         II=I+K9
3265         A1=Y8(II) -Y8(K10)
3266         A2=A1*A1
3267         AA=AA+A2
3268 5050      CONTINUE
3269         Y8(K10)=SQRT(AA)
3270         WRITE(6, 6000)  Y8(K10)
3271 6000      FORMAT(1H , 'THETA=', E15.8)
3272 C
3273         WRITE(6, 8000)
3274         500 FORMAT(1H , 6(1X, E11.4))
3275         501 FORMAT(1H , 72(' -'))
3276 8000      FORMAT(1H , ' ')
3277         RETURN
3278         END
3279 C
3280 C *****          SUBROUTINE WRITEC          *****
3281 C *
3282 C * SUBROUTINE FOR GENERATING OUTPUT FILES FOR PLOTTING *
3283 C *          UNIT 22 - 30          *
3284 C *          CALLED BY THE MAIN PROGRAM          *
3285 C *****
3286 C
3287 C IF (ICON.LE.3) NO OUTPUT FILES FOR PLOTTING
3288 C
3289 C IF (ICON.GE.4 AND NCON.EQ.1), UNIT 22-30 WILL BE GENERATED.
3290 C     UNIT 22 : ESTIMATED HYSTERESIS DATA
3291 C     UNIT 23-30 : CONVERGENCY PROCESS OF EACH PARAMETER
3292 C                AS FILTERED STATE VECTOR
3293 C
3294 C *****
3295 C
3296 C
3297 C SUBROUTINE WRITEC(ICON, NCON, DT, N, ND, Y3, GG1, J1, J3)
3298 C DIMENSION Y3(J1, J3), GG1(J3), TIME(3000)
3299 C
3300 C     II4=6

```



```

3301      II5=5
3302      II6=ND
3303      IF (ICON.GE.4.AND.NCON.EQ.1) THEN
3304      WRITE (22,1600) II5,II5,II6
3305      WRITE (22,1700) (Y3(1, KK), KK=1, ND)
3306      WRITE (22,1600) II5,II4,II6
3307      WRITE (22,1700) (GG1(KK), KK=1, ND)
3308  C
3309      DO 100 I=1, ND
3310      TIME(I)=FLOAT(I-1)*DT
3311  100 CONTINUE
3312  C
3313      IF (ICON.EQ.4.OR.ICON.EQ.5) THEN
3314      IA=22
3315      DO 20 I=3, 6
3316      IA=IA+1
3317      WRITE (IA,1600) II5,II5,II6
3318      WRITE (IA,1700) (TIME(KK), KK=1, ND)
3319      WRITE (IA,1600) II5,II4,II6
3320      WRITE (IA,1700) (Y3(I, KK), KK=1, ND)
3321      REWIND IA
3322  20 CONTINUE
3323  C
3324      ELSE
3325  C
3326      IA=22
3327      DO 25 I=5,12
3328      IA=IA+1
3329      WRITE (IA,1600) II5,II5,II6
3330      WRITE (IA,1700) (TIME(KK), KK=1, ND)
3331      WRITE (IA,1600) II5,II4,II6
3332      WRITE (IA,1700) (Y3(I, KK), KK=1, ND)
3333      REWIND IA
3334  25 CONTINUE
3335  C
3336      END IF
3337      END IF
3338      1600 FORMAT(3I5)
3339      1700 FORMAT(8(1PE10.3))
3340  C
3341      300 CONTINUE
3342      RETURN
3343      END
3344
3345

```

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 ACCELERATION 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	U _{ij} , dU _{ij} /dt, h _j , w _j , P _{ij} for each mode j=1,...,N
2	6*N	U _{ij} , dU _{ij} /dt, ddU _{ij} /dt ² , h _j , w _i , P _{ij} for each mode j=1,...,N
3	3*N	h _j , w _j , P _{ij} for each mode j=1,...,N
4	6	Z, dZ/dt, a ₁ , a ₂ , a ₃ , a ₄
5	6	Z, dZ/dt, h, w, Z _e , 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 lambda, cv = delta nu, cn = delta eta

I2 : NUMBER OF RESPONSE OBSERVATIONS USED FOR FILTERING
 IF ICON IS 1,4,5 OR 6, I2 IS RECOMMENDED 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 IMAGINARY 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 SUPPLIED; 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; $G_{11}(I)$, $I=1, I_1$

COEFFICIENT MATRIX OF SYSTEM NOISE IS ASSUMED AS DIAGONAL.
DATA FOR DIAGONAL MEMBERS OF SYSTEM NOISE COEFFICIENT MATRIX
MUST BE PROVIDED; $G_{11}(I)$, $I=1, I_1$

9. OBSERVATION NOISE COVARIANCE MATRIX; $Q_{R2}(I)$, $I=1, I_2$

COVARIANCE MATRIX OF OBSERVATIONAL NOISE IS ALSO ASSUMED AS
DIAGONAL. DATA FOR THE DIAGONAL MEMBERS MUST BE SUPPLIED;
 $Q_{R2}(I)$, $I=1, I_2$.

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.IE.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 DISPLACEMENT
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 & IMAGINARY 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. IMAGINARY PARTS OF FREQUENCY RESPONSE FUNCTION
 - 4-A. TITLE CARD (72A)
 - 4-B RESPONSE COMPONENT INDICATOR (I5)
= 2 (IMAGINARY PARTS)
 - 4-C. IMAGINARY 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.)

```
1 ID FOR 2-D,ICON=3;for 1st mode only,H(w) from Displ,W/ 1% NOISE IN VARIANCE
2 3 1 10 10.0
3 1 3 2 1
4 350 0.1023 11 70
5 0.5 10.0 0.5
6 0.1 4.0 1.0
7 0.0 0.0 0.0
8 1.0 1.0 1.0
9 0.1 0.1
```

(b) Step II : For Second Mode Only
(line no.)

```
1 ID FOR 2-D,ICON=3;for 2nd mode only,H(w) from Displ,W/ 1% NOISE IN VARIANCE
2 3 1 10 10.0
3 2 6 2 1
4 350 0.1023 11 170
5 0.0557 6.186 0.766
6 0.5 15.0 0.5
7 0.0 0.0 0.0
8 0.1 4.0 1.0
9 0.0 0.0 0.0
10 0.0 0.0 0.0
11 1.0 1.0 1.0
12 1.0 1.0 1.0
13 0.1 0.1
```

(c) Step III : For First and Second Modes
(line no.)

```
1 ID FOR 2-D,ICON=3;for 1st & 2nd modes,H(w) from Displ,W/ 1% NOISE IN VARIANCE
2 3 1 10 10.0
3 2 6 2 1
4 350 0.1023 11 170
5 0.0557 6.186 0.766
6 0.051 9.313 0.2675
7 0.1 1.0 1.0
8 0.1 1.0 1.0
9 0.0 0.0 0.0
10 0.0 0.0 0.0
11 1.0 1.0 1.0
12 1.0 1.0 1.0
13 0.1 0.1
```

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

(a) Step I : For Linear Parameters Only
(line no.)

```

1      SYS-ID FOR 1-D BILIN. ICON=5, FOR LIN PARA. ONLY; W/ NO NOISE
2      5      1      5      2.0
3      1      6      2      1
4      1000   0.015  1      150
5      0.0 0.0  0.5    5.0 100.0  1.0
6      1.0 1.0  1.0    1.0  1.0  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      1.0 1.0

```

(b) Step II : For Nonlinear Parameters Only
(line no.)

```

1      SYS-ID FOR 1-D BILIN. ICON=5, FOR NONLIN PARA.; W/ NO NOISE
2      5      1      5      2.0
3      1      6      2      1
4      1000   0.015  1      1000
5      0.0 0.0  0.098  3.16 1.0  0.5
6      1.0 1.0  0.0    0.0  1.0  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      1.0 1.0

```

(c) Step III : For Linear and Nonlinear Parameters
(line no.)

```

1      SYS-ID FOR 1-D BILIN. ICON=5, FOR LIN & NONLIN PARA.; W/O NOISE
2      5      1      5      10.0
3      1      6      2      1
4      1000   0.015  1      1000
5      0.0 0.0  0.098  3.16 3.04 0.10
6      1.0 1.0  0.1    1.0  1.0  0.1
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      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.)

```
1 OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
2 3
3 OBSERVED INPUT EXCIATION
4 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 -5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
6 -9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
7 -2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
8 7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
9 1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
10 -1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
11 -2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
12 -3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
13 2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01
14
15
```

Intermediate data have been omitted.

```
16
17
18
19 DISPLACEMENT RESPONSE
20 1
21 0.000e+00-1.628e-01 9.042e-02-2.115e-01-2.270e-01 1.830e-01-1.646e-01-2.909e-01
22 1.493e-01-2.780e-01 3.624e-03-3.870e-01-9.767e-02-3.467e-01-1.837e-01-1.675e-01
23 6.333e-01-1.684e-01 2.845e-01 8.646e-03 2.842e-01-2.156e-01 1.197e-01-4.587e-01
24 -5.936e-02-8.803e-02 3.155e-01 6.353e-02 1.115e-01-1.062e-01-2.329e-01-9.030e-02
25 -1.479e-01-2.788e-02 3.014e-01-1.008e-01 1.459e-01 4.499e-03-2.060e-01 2.577e-01
26 3.319e-02 3.219e-01 1.889e-01 1.605e-01 6.311e-02 1.909e-01 2.167e-01 2.080e-01
27 -2.593e-01-2.696e-01 1.959e-01-1.569e-02-5.816e-01-1.193e-01-6.908e-02-5.862e-02
28 -4.900e-01 3.406e-02-5.230e-01 8.835e-02-6.540e-01-2.507e-01-5.413e-01-1.912e-02
29 -1.769e-01-3.734e-01-4.724e-01-2.523e-01-4.921e-01-5.525e-01-6.128e-02-3.096e-01
30 3.049e-01 8.405e-02-2.604e-02 2.497e-01 4.962e-01 4.402e-01 3.244e-01 6.219e-01
31
32
```

Intermediate data have been omitted.

```
33
34
35 VELOCITY RESPONSE
36 2
37 0.000e+00-1.219e+00 6.917e-01-1.649e+00-1.909e+00 7.656e-01-2.501e+00-3.473e+00
38 6.512e-01-1.914e+00 4.808e-01-2.425e+00-5.886e-01-2.691e+00-9.737e-01-4.618e-02
39 6.372e+00 1.620e-01 3.440e+00 1.304e+00 3.145e+00-1.186e+00 7.581e-01-3.798e+00
40 -5.272e-01-4.466e-01 2.826e+00 1.371e+00 2.158e+00 6.825e-01-3.457e-01 3.984e-01
41 -3.376e-01 5.881e-01 3.351e+00 5.927e-01 2.548e+00 1.234e+00-8.417e-01 2.223e+00
42 1.505e-01 1.994e+00 8.035e-01 4.033e-01-7.477e-01-4.775e-01-7.677e-01-4.782e-01
43 -3.394e+00-3.192e+00 5.937e-01-1.127e+00-6.155e+00-3.484e+00-3.676e+00-3.419e+00
44 -5.777e+00-9.150e-01-4.021e+00 1.829e+00-3.262e+00-1.182e-01-1.942e+00 2.430e+00
45 1.543e+00 5.989e-01 5.669e-01 2.778e+00 1.493e+00 1.285e+00 5.117e+00 3.647e+00
46 8.087e+00 5.670e+00 3.661e+00 3.975e+00 5.129e+00 4.790e+00 3.969e+00 5.746e+00
47
48
```

Intermediate data have been omitted.

```
49
50
51 ACCELERATION RESPONSE
52 3
53 0.000e+00-1.231e+01 6.130e+00-2.461e+01-3.311e+01-3.219e+01-6.494e+01 5.314e+00
54 7.857e+01 1.586e+00 2.018e+01-3.449e+01-4.273e+01-1.940e+01 4.669e+01 4.931e+01
55 6.721e+01-2.024e+01 3.574e+01 5.213e+00 8.122e+00-6.220e+01-1.960e+01-3.501e+01
56 2.536e+01 7.522e+00 5.117e+01 5.508e+01 3.808e+01 1.030e+01-2.273e+01-2.736e+01
57 -1.721e+01 1.774e+01 5.685e+01 1.598e+01 2.035e+01-2.232e+01-4.872e+01-2.826e+00
58 -2.710e+01 1.723e+00 1.636e+00-1.435e+01-4.421e+01-5.711e+01-1.261e+01 5.619e+01
59 -7.946e+00-2.153e+01 3.351e+01-4.901e+01-1.229e+02-7.782e+01-5.487e+01 2.628e+01
60 1.820e+01 5.186e+01 5.833e+01 9.446e+01-3.300e+01 1.394e+01 1.689e+01 4.816e+01
61 3.677e+01 5.525e+01 4.463e+01 5.151e+01 4.579e+01-6.756e+00 6.355e+01 5.222e+01
62 1.259e+01-1.286e+00-9.011e+01-9.377e+01 7.020e+01 2.351e+01 4.775e+01-3.538e+01
63
64
```

The rest of the data has been omitted.

65

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

(line no.)

```

1      2D LIN. H(w); COMPUTED FROM STR. DISPL.,NPT=350,DW=0.1023,W/ 1% NOISE IN VAR.
2      2
3      REAL PART OH H(w)
4      1
5      0.000e+00-3.263e-02-2.490e-02-1.823e-02-5.324e-02-2.462e-02-9.281e-03 3.424e-03
6      8.354e-03-9.255e-03-2.441e-02-2.734e-02-2.570e-02-2.218e-02-1.484e-02-5.533e-02
7      -2.793e-02-2.373e-02-2.791e-02-3.619e-02-2.719e-02-2.509e-02-2.499e-02-2.585e-02
8      -2.682e-02-2.551e-02-1.930e-02-2.012e-02-2.576e-02-2.948e-02-3.091e-02-2.998e-02
9      -2.006e-02-3.662e-02-3.337e-02-3.175e-02-3.090e-02-3.074e-02-3.154e-02-3.505e-02
10     -1.810e-02-3.056e-02-3.527e-02-4.042e-02-4.492e-02-4.427e-02-4.227e-02-4.446e-02
11     -4.922e-02-5.449e-02-5.880e-02-6.137e-02-6.286e-02-6.558e-02-7.240e-02-8.489e-02
12     -1.006e-01-1.100e-01-1.023e-01-8.142e-02-5.883e-02-3.701e-02-3.746e-04 7.618e-02
13     1.015e-01 7.960e-02 6.381e-02 5.617e-02 5.575e-02 7.567e-02 3.253e-02 3.243e-02
14     3.308e-02 3.352e-02 3.395e-02 3.456e-02 3.466e-02 2.955e-02 2.302e-02 1.685e-02
15     1.167e-02 8.474e-03 7.323e-03 7.879e-03 1.085e-02 5.445e-03 4.659e-03 4.966e-03
16     3.559e-03 4.567e-04 1.482e-03 8.255e-03 1.505e-02 2.043e-02 2.421e-02 2.628e-02
17     2.693e-02 2.671e-02 2.618e-02 2.585e-02 2.342e-02 2.166e-02 2.106e-02 2.049e-02
18     1.996e-02 1.936e-02 1.729e-02 1.530e-02 1.550e-02 1.544e-02 1.547e-02 1.595e-02
19     1.661e-02 1.639e-02 1.548e-02 1.466e-02 1.466e-02 1.239e-02 1.211e-02 1.159e-02
20     1.093e-02 1.004e-02 9.612e-03 1.026e-02 1.006e-02 9.531e-03 8.955e-03 8.484e-03
21     8.270e-03 8.306e-03 8.335e-03 8.086e-03 8.596e-03 8.364e-03 7.887e-03 7.376e-03
22     6.866e-03 6.482e-03 6.781e-03 7.397e-03 6.554e-03 5.835e-03 5.556e-03 6.092e-03
23     7.783e-03 6.129e-03 4.784e-03 4.542e-03 4.716e-03 5.041e-03 5.390e-03 5.759e-03
24     6.320e-03 6.256e-03 5.313e-03 4.863e-03 4.731e-03 5.025e-03 6.520e-03 7.073e-03
25     1.419e-03 1.752e-03 2.376e-03 3.091e-03 3.881e-03 4.669e-03 5.288e-03 5.420e-03
26     4.595e-03 3.422e-03 3.179e-03 3.485e-03 3.875e-03 4.199e-03 4.406e-03 4.465e-03
27     4.349e-03 4.140e-03 4.103e-03 3.880e-03 3.471e-03 3.064e-03 2.977e-03 3.293e-03
28     3.520e-03 3.480e-03 3.293e-03 3.077e-03 3.049e-03 3.821e-03 4.798e-03 4.542e-03
29     3.979e-03 3.482e-03 3.082e-03 2.793e-03 2.659e-03 2.738e-03 3.039e-03 3.384e-03

```

Intermediate data have been omitted.

```

34     IMAGINARY PART OF H(w)
35     2
36     0.000e+00 4.940e-03 1.489e-02 9.646e-02-2.441e-02-8.539e-03-8.861e-05 9.159e-04
37     -1.181e-02-2.223e-02-1.234e-02-1.302e-03 6.037e-03 1.150e-02 2.023e-02 4.257e-03
38     8.895e-03 1.300e-02 2.058e-02 2.749e-03 5.892e-04 9.095e-04 1.104e-03 1.748e-03
39     3.644e-03 7.152e-03 6.412e-03-8.652e-04-2.240e-03 3.383e-05 3.395e-03 7.242e-03
40     1.347e-02-2.797e-03 4.025e-03 5.053e-03 4.676e-03 3.423e-03 1.179e-03-4.034e-03
41     3.116e-02 4.823e-03 1.719e-03 1.557e-03 5.168e-03 9.962e-03 9.345e-03 7.122e-03
42     6.903e-03 9.190e-03 1.342e-02 1.817e-02 2.159e-02 2.284e-02 2.335e-02 2.732e-02
43     4.127e-02 6.906e-02 1.023e-01 1.272e-01 1.429e-01 1.587e-01 1.819e-01 1.718e-01
44     9.780e-02 6.139e-02 4.981e-02 4.526e-02 4.314e-02 2.677e-02 1.278e-02 2.069e-02
45     2.044e-02 1.826e-02 1.514e-02 1.166e-02 9.747e-03 8.381e-03 4.828e-03 3.348e-03
46     4.660e-03 7.619e-03 1.080e-02 1.347e-02 1.654e-02 2.416e-02 1.993e-02 1.899e-02
47     1.887e-02 2.185e-02 2.931e-02 3.352e-02 3.329e-02 3.077e-02 2.696e-02 2.268e-02
48     1.868e-02 1.535e-02 1.270e-02 1.017e-02 6.924e-03 7.198e-03 6.754e-03 6.120e-03
49     5.373e-03 4.247e-03 2.525e-03 4.097e-03 4.223e-03 3.581e-03 2.744e-03 2.066e-03
50     2.250e-03 3.040e-03 3.338e-03 3.176e-03 3.517e-03 2.049e-03 1.623e-03 1.206e-03
51     8.538e-04 8.003e-04 1.638e-03 1.533e-03 9.341e-04 6.543e-04 6.613e-04 9.190e-04
52     1.298e-03 1.536e-03 1.465e-03 9.492e-04 2.778e-04 4.382e-04 3.796e-04 3.526e-04
53     4.547e-04 8.036e-04 1.319e-03 4.503e-04-2.351e-04-6.033e-05 4.821e-04 1.182e-03
54     2.045e-04-1.716e-03-9.400e-04-9.826e-05 4.324e-04 6.400e-04 5.593e-04 2.788e-04
55     1.380e-04 8.599e-04 7.250e-04 2.507e-04-1.423e-04-4.542e-04-3.116e-04 5.897e-03
56     3.425e-03 1.704e-03 1.106e-03 8.422e-04 7.278e-04 6.644e-04 4.960e-04 1.359e-05
57     -5.412e-04-1.981e-04 4.639e-04 6.848e-04 6.004e-04 4.034e-04 1.861e-04-1.385e-05
58     -1.521e-04-9.963e-05-7.682e-05-2.281e-04-2.598e-04-4.933e-05 3.513e-04 4.805e-04
59     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.)

1 OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
2 3
3 OBSERVED INPUT EXCIATION
4 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 -5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
6 -9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
7 -2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
8 7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
9 1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
10 -1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
11 -2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
12 -3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
13 2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01
14

Intermediate data have been omitted.

15
16
17
18
19
20 DISPLACEMENT RESPONSE
21 1
22 0.000e+00 5.485e-05 2.736e-04 7.286e-05-1.724e-03-7.723e-03-2.359e-02-4.851e-02
23 -6.976e-02-8.097e-02-8.739e-02-9.226e-02-1.003e-01-1.157e-01-1.313e-01-1.377e-01
24 -1.347e-01-1.300e-01-1.275e-01-1.252e-01-1.239e-01-1.276e-01-1.407e-01-1.609e-01
25 -1.818e-01-1.991e-01-2.140e-01-2.247e-01-2.278e-01-2.257e-01-2.211e-01-2.178e-01
26 -2.181e-01-2.193e-01-2.164e-01-2.066e-01-1.906e-01-1.716e-01-1.546e-01-1.411e-01
27 -1.302e-01-1.219e-01-1.151e-01-1.083e-01-1.041e-01-1.071e-01-1.204e-01-1.367e-01
28 -1.456e-01-1.491e-01-1.501e-01-1.495e-01-1.577e-01-1.815e-01-2.212e-01-2.723e-01
29 -3.227e-01-3.670e-01-4.052e-01-4.313e-01-4.487e-01-4.675e-01-4.875e-01-5.046e-01
30 -5.197e-01-5.315e-01-5.342e-01-5.268e-01-5.094e-01-4.807e-01-4.445e-01-3.958e-01
31 -3.334e-01-2.679e-01-2.025e-01-1.474e-01-1.025e-01-4.709e-02 2.075e-02 1.023e-01
32
33

Intermediate data have been omitted.

34
35
36
37 VELOCITY RESPONSE
38 2
39 0.000e+00 1.097e-02 1.084e-02-5.074e-02-2.074e-01-6.788e-01-1.450e+00-1.678e+00
40 -1.072e+00-5.281e-01-3.418e-01-3.612e-01-7.928e-01-1.150e+00-7.998e-01-5.486e-02
41 3.388e-01 2.359e-01 1.429e-01 1.521e-01-2.268e-02-5.438e-01-1.166e+00-1.442e+00
42 -1.287e+00-1.064e+00-8.948e-01-4.679e-01-7.743e-04 2.594e-01 3.103e-01 9.758e-02
43 -1.046e-01 9.762e-03 4.148e-01 8.825e-01 1.215e+00 1.240e+00 1.014e+00 8.087e-01
44 6.404e-01 4.832e-01 4.530e-01 4.096e-01 1.010e-01-5.619e-01-1.119e+00-8.865e-01
45 -3.621e-01-1.519e-01 5.294e-02-1.333e-01-1.031e+00-2.134e+00-3.135e+00-3.500e+00
46 -3.162e+00-2.792e+00-2.181e+00-1.343e+00-1.139e+00-1.341e+00-1.254e+00-1.061e+00
47 -9.444e-01-5.319e-01 1.624e-01 8.103e-01 1.561e+00 2.168e+00 2.758e+00 3.777e+00
48 4.343e+00 4.431e+00 4.125e+00 3.169e+00 3.200e+00 4.098e+00 5.053e+00 5.578e+00
49

Intermediate data have been omitted.

50
51
52
53
54 ACCELERATION RESPONSE
55 3
56 0.000e+00 1.463e+00-1.480e+00-6.731e+00-1.416e+01-4.869e+01-5.413e+01 2.368e+01
57 5.722e+01 1.524e+01 9.602e+00-1.219e+01-4.536e+01-2.253e+00 4.893e+01 5.039e+01
58 2.095e+00-1.582e+01 3.422e+00-2.193e+00-2.111e+01-4.838e+01-3.453e+01-2.310e+00
59 2.298e+01 6.748e+00 1.580e+01 4.112e+01 2.116e+01 1.353e+01-6.737e+00-2.163e+01
60 -5.330e+00 2.058e+01 3.343e+01 2.892e+01 1.542e+01-1.212e+01-1.803e+01-9.308e+00
61 -1.313e+01-7.824e+00 3.790e+00-9.577e+00-3.157e+01-5.680e+01-1.751e+01 4.855e+01
62 2.136e+01 6.662e+00 2.066e+01-4.548e+01-7.424e+01-7.282e+01-6.063e+01 1.194e+01
63 3.310e+01 1.635e+01 6.505e+01 4.665e+01-1.936e+01-7.582e+00 1.922e+01 6.426e+00
64 9.147e+00 4.585e+01 4.672e+01 3.967e+01 6.039e+01 2.063e+01 5.802e+01 7.777e+01
65 -2.282e+00 1.397e+01-5.469e+01-7.286e+01 7.711e+01 4.258e+01 8.472e+01-1.470e+01
66

The rest of the data has been omitted.

67
68
69

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

(line no.)

```

1      OBSERVED INPUT EXCIATION / OUTPUT RESPONSE
2      3
3      OBSERVED INPUT EXCIATION
4      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      -5.586e+01-1.411e+01-8.526e+00 1.333e+01 4.684e+01 4.116e+00-4.714e+01-4.900e+01
6      -9.800e-01 1.695e+01-2.254e+00 3.332e+00 2.234e+01 4.998e+01 3.665e+01 4.802e+00
7      -2.038e+01-4.116e+00-1.313e+01-3.861e+01-1.891e+01-1.147e+01 8.722e+00 2.372e+01
8      7.546e+00-1.842e+01-3.156e+01-2.744e+01-1.431e+01 1.303e+01 1.891e+01 1.019e+01
9      1.401e+01 8.722e+00-2.940e+00 1.039e+01 3.254e+01 5.821e+01 1.940e+01-4.665e+01
10     -1.970e+01-5.096e+00-1.921e+01 4.704e+01 7.644e+01 7.595e+01 6.478e+01-7.056e+00
11     -2.793e+01-1.098e+01-5.968e+01-4.155e+01 2.450e+01 1.303e+01-1.362e+01-7.840e-01
12     -3.430e+00-4.028e+01-4.155e+01-3.499e+01-5.635e+01-1.725e+01-5.537e+01-7.624e+01
13     2.842e+00-1.411e+01 5.410e+01 7.232e+01-7.811e+01-4.469e+01-8.810e+01 1.019e+01

```

Intermediate data have been omitted.

```

19     DISPLACEMENT RESPONSE
20     1
21     0.000e+00-1.823e-05 9.168e-05-2.173e-04-2.122e-03-8.232e-03-2.421e-02-4.924e-02
22     -7.059e-02-8.189e-02-8.840e-02-9.336e-02-1.015e-01-1.170e-01-1.327e-01-1.392e-01
23     -1.362e-01-1.317e-01-1.293e-01-1.271e-01-1.259e-01-1.297e-01-1.429e-01-1.632e-01
24     -1.843e-01-2.017e-01-2.167e-01-2.275e-01-2.308e-01-2.289e-01-2.244e-01-2.212e-01
25     -2.217e-01-2.231e-01-2.204e-01-2.107e-01-1.950e-01-1.762e-01-1.594e-01-1.462e-01
26     -1.354e-01-1.273e-01-1.208e-01-1.143e-01-1.102e-01-1.134e-01-1.270e-01-1.435e-01
27     -1.526e-01-1.564e-01-1.576e-01-1.572e-01-1.656e-01-1.896e-01-2.296e-01-2.809e-01
28     -3.315e-01-3.761e-01-4.146e-01-4.410e-01-4.588e-01-4.780e-01-4.985e-01-5.161e-01
29     -5.318e-01-5.442e-01-5.477e-01-5.411e-01-5.245e-01-4.967e-01-4.615e-01-4.138e-01
30     -3.525e-01-2.880e-01-2.237e-01-1.698e-01-1.260e-01-7.175e-02-5.070e-03 7.536e-02

```

Intermediate data have been omitted.

```

36     VELOCITY RESPONSE
37     2
38     0.000e+00 3.688e-03 3.614e-03-5.793e-02-2.146e-01-6.864e-01-1.458e+00-1.685e+00
39     -1.078e+00-5.345e-01-3.481e-01-3.678e-01-7.998e-01-1.156e+00-8.058e-01-6.083e-02
40     3.322e-01 2.289e-01 1.361e-01 1.451e-01-2.992e-02-5.515e-01-1.173e+00-1.450e+00
41     -1.294e+00-1.072e+00-9.033e-01-4.766e-01-1.032e-02 2.492e-01 2.992e-01 8.570e-02
42     -1.169e-01-2.704e-03 4.021e-01 8.693e-01 1.201e+00 1.226e+00 9.992e-01 7.941e-01
43     6.256e-01 4.685e-01 4.384e-01 3.949e-01 8.601e-02-5.771e-01-1.134e+00-9.003e-01
44     -3.762e-01-1.661e-01 3.898e-02-1.480e-01-1.046e+00-2.149e+00-3.151e+00-3.516e+00
45     -3.179e+00-2.810e+00-2.201e+00-1.366e+00-1.166e+00-1.371e+00-1.287e+00-1.099e+00
46     -9.865e-01-5.779e-01 1.120e-01 7.556e-01 1.502e+00 2.106e+00 2.693e+00 3.709e+00
47     4.272e+00 4.358e+00 4.050e+00 3.092e+00 3.124e+00 4.021e+00 4.976e+00 5.500e+00

```

Intermediate data have been omitted.

```

53     ACCELERATION RESPONSE
54     3
55     0.000e+00 1.468e+00-1.473e+00-6.723e+00-1.415e+01-4.868e+01-5.412e+01 2.369e+01
56     5.723e+01 1.525e+01 9.605e+00-1.219e+01-4.536e+01-2.256e+00 4.893e+01 5.038e+01
57     2.087e+00-1.583e+01 3.417e+00-2.197e+00-2.111e+01-4.838e+01-3.454e+01-2.325e+00
58     2.296e+01 6.716e+00 1.576e+01 4.108e+01 2.112e+01 1.349e+01-6.777e+00-2.167e+01
59     -5.365e+00 2.055e+01 3.340e+01 2.889e+01 1.540e+01-1.214e+01-1.804e+01-9.316e+00
60     -1.314e+01-7.824e+00 3.792e+00-9.572e+00-3.156e+01-5.679e+01-1.751e+01 4.855e+01
61     2.136e+01 6.663e+00 2.066e+01-4.548e+01-7.423e+01-7.283e+01-6.066e+01 1.188e+01
62     3.300e+01 1.621e+01 6.487e+01 4.644e+01-1.958e+01-7.822e+00 1.896e+01 6.149e+00
63     8.857e+00 4.555e+01 4.642e+01 3.939e+01 6.013e+01 2.039e+01 5.781e+01 7.759e+01
64     -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.)

```

1      SYS-ID FOR 2-DOF, FOR 2ND MODE, ICON=1; W/ 1% NOISE IN VARIANCE
2
3      ANALYSIS CASE : ICON====>    1
4
5      OUTPUT CONTROL : NCON====>    1
6
7      NO. OF GLOBAL ITERATIONS : ITE====>    5
8
9      WEIGHT FOR GLOBAL ITERATION : PITE====>    0.2000e+01
10
11     NO. OF DOF OF SYSTEM : N====>    2
12
13     DIMENSION OF STATE VECTOR : I1====>    10
14
15     NO. OF RESPONSE OBSERVATIONS USED : I2====>    2
16
17     DATA OF OBSERVED RECORDS TO BE USED :
18     NN= 1000    DT= 0.0150    NM1= 1    NM2= 1000
19
20     INITIAL GUESS OF STATE VECTOR : Y2====>
21     0.000e+00  0.000e+00  0.745e-01  0.630e+01  0.959e+00  0.000e+00
22     0.000e+00  0.500e+00  0.150e+02  0.500e+00
23
24     INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11====>
25     0.100e+01  0.100e+01  0.000e+00  0.000e+00  0.000e+00  0.100e+01
26     0.100e+01  0.100e+01  0.100e+01  0.100e+01
27
28     COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1====>
29     0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
30     0.000e+00  0.000e+00  0.000e+00  0.000e+00
31
32     COEFFICIENT MATRIX OF SYSTEM NOISE : G11====>
33     0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
34     0.100e+01  0.100e+01  0.100e+01  0.100e+01
35
36     COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2====>
37     0.100e+01  0.500e+01
38
39     0.00000e+00  0.00000e+00  0.74500e-01  0.63020e+01  0.95900e+00  0.00000e+00
40     0.00000e+00  0.50000e+00  0.15000e+02  0.50000e+00
41     0.10000e+01  0.10000e+01  0.00000e+00  0.00000e+00  0.00000e+00  0.10000e+01
42     0.10000e+01  0.10000e+01  0.10000e+01  0.10000e+01
43
44     ***** NUMBER OF ITERATIONS= 1*****
45
46     INITIAL GUESS OF THE STATE VECTOR =
47     0.00000  0.00000  0.07450  6.30200  0.95900  0.00000
48     0.00000  0.50000  15.00000  0.50000
49
50     ND3= 1    ND5= 1000
51
52     ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
53
54     OBSERVED AT= 990
55     -0.7348e+00 -0.4453e+01
56     OBSERVED AT= 995
57     -0.8556e+00 -0.1075e+00
58     OBSERVED AT= 1000
59     -0.8594e+00 0.2417e+01
60

```


(Appendix II-3-1 Continued)

```
61 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
62
63 ESTIMATED AT= 990
64 -0.9843e+00 -0.5515e+01 0.7450e-01 0.6302e+01 0.9590e+00 -0.9621e-01
65 ESTIMATED AT= 995
66 -0.1146e+01 -0.1017e+00 0.7450e-01 0.6302e+01 0.9590e+00 -0.2912e-01
67 ESTIMATED AT= 1000
68 -0.1031e+01 0.3518e+01 0.7450e-01 0.6302e+01 0.9590e+00 0.4832e-01
69 -----
70 ESTIMATED AT= 990
71 0.2814e+00 0.6699e-01 0.9545e+01 0.3109e+00
72 ESTIMATED AT= 995
73 0.1090e+01 0.6699e-01 0.9545e+01 0.3109e+00
74 ESTIMATED AT= 1000
75 0.1004e+01 0.6692e-01 0.9546e+01 0.3106e+00
76 -----
77 THETA= 0.38190711e+00
78
79
80 ***** NUMBER OF ITERATIONS= 2*****
81
82 INITIAL GUESS OF THE STATE VECTOR =
83 0.00000 0.00000 0.07450 6.30200 0.95900 0.00000
84 0.00000 0.06692 9.54597 0.31061
85
86 ND3= 1 ND5= 1000
87
88 ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
89
90 OBSERVED AT= 990
91 -0.7348e+00 -0.4453e+01
92 OBSERVED AT= 995
93 -0.8556e+00 -0.1075e+00
94 OBSERVED AT= 1000
95 -0.8594e+00 0.2417e+01
96
97 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
98
99 ESTIMATED AT= 990
100 -0.9930e+00 -0.5665e+01 0.7450e-01 0.6302e+01 0.9590e+00 -0.1090e+00
101 ESTIMATED AT= 995
102 -0.1162e+01 -0.1351e+00 0.7450e-01 0.6302e+01 0.9590e+00 -0.4787e-01
103 ESTIMATED AT= 1000
104 -0.1045e+01 0.3611e+01 0.7450e-01 0.6302e+01 0.9590e+00 0.3360e-01
105 -----
106 ESTIMATED AT= 990
107 0.1412e+00 0.6877e-01 0.9530e+01 0.3186e+00
108 ESTIMATED AT= 995
109 0.1076e+01 0.6877e-01 0.9530e+01 0.3186e+00
110 ESTIMATED AT= 1000
111 0.1120e+01 0.6873e-01 0.9530e+01 0.3185e+00
112 -----
113 THETA= 0.24070369e+00
114
115
116 The rest of the data has been omitted.
117
118
```

II-3-2 Linear MDOF Structure : ICON=2 (Step II in Table 4-II)
(line no.)

```

1      SYS-ID FOR 2-DOF, FOR 2ND MODE , ICON=2; W/ 1 % NOISE IN VARIANCE
2
3      ANALYSIS CASE : ICON====>  2
4
5      OUTPUT CONTROL : NCON====>  1
6
7      NO. OF GLOBAL ITERATIONS : ITE ====>  5
8
9      WEIGHT FOR GLOBAL ITERATION : PITE====>  0.1000e+03
10
11     NO. OF DOF OF SYSTEM : N====>  2
12
13     DIMENSION OF STATE VECTOR : I1====>  12
14
15     NO. OF RESPONSE OBSERVATIONS USED : I2====>  1
16
17     CONTROL PARAMETER FOR RESPONSE OBSERVATIONS USED : MC2 ====>  3
18
19     DATA OF OBSERVED RECORDS TO BE USED :
20       NN= 1000    DT=  0.0150    NM1=  1    NM2= 1000
21
22     INITIAL GUESS OF STATE VECTOR : Y2====>
23       0.000e+00  0.000e+00  0.000e+00  0.175e+00  0.661e+01  0.112e+01
24       0.000e+00  0.000e+00  0.000e+00  0.500e+00  0.150e+02  0.500e+00
25
26     INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11====>
27       0.100e+01  0.100e+01  0.500e+01  0.000e+00  0.000e+00  0.000e+00
28       0.100e+01  0.100e+01  0.500e+01  0.100e+01  0.400e+01  0.100e+01
29
30     COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1====>
31       0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
32       0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
33
34     COEFFICIENT MATRIX OF SYSTEM NOISE : G11====>
35       0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
36       0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
37
38     COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2====>
39       0.500e+02
40
41       0.00000e+00 0.00000e+00 0.00000e+00 0.17500e+00 0.66150e+01 0.11210e+01
42       0.00000e+00 0.00000e+00 0.00000e+00 0.50000e+00 0.15000e+02 0.50000e+00
43       0.10000e+01 0.10000e+01 0.50000e+01 0.00000e+00 0.00000e+00 0.00000e+00
44       0.10000e+01 0.10000e+01 0.50000e+01 0.10000e+01 0.40000e+01 0.10000e+01
45
46       ***** NUMBER OF ITERATIONS=  1*****
47
48     INITIAL GUESS OF THE STATE VECTOR =
49       0.00000    0.00000    0.00000    0.17500    6.61500    1.12100
50       0.00000    0.00000    0.00000    0.50000    15.00000    0.50000
51
52     ND3=  1    ND5= 1000
53
54     ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
55
56     OBSERVED AT=  990
57       0.1267e+03
58     OBSERVED AT=  995
59       0.3679e+02
60     OBSERVED AT= 1000
61       0.6559e+02

```

(Appendix II-3-2 Continued)

62
63 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
64
65 ESTIMATED AT= 990
66 0.1238e+03 -0.5463e+00 -0.1108e+01 0.1750e+00 0.6615e+01 0.1121e+01
67 ESTIMATED AT= 995
68 -0.6181e+01 0.4013e+01 -0.9283e+00 0.1750e+00 0.6615e+01 0.1121e+01
69 ESTIMATED AT= 1000
70 0.2790e+02 0.6098e+01 -0.5565e+00 0.1750e+00 0.6615e+01 0.1121e+01
71 -----
72 ESTIMATED AT= 990
73 -0.2606e+02 0.1899e+01 0.3014e+00 0.1288e-01 0.9617e+01 0.2557e-01
74 ESTIMATED AT= 995
75 -0.3213e+02 -0.4439e+00 0.3473e+00 0.1323e-01 0.9615e+01 0.2635e-01
76 ESTIMATED AT= 1000
77 -0.1881e+02 -0.2463e+01 0.2200e+00 0.1360e-01 0.9615e+01 0.2716e-01
78 -----
79 THETA= 0.00000000e+00
80
81
82 ***** NUMBER OF ITERATIONS= 2*****
83
84 INITIAL GUESS OF THE STATE VECTOR =
85 0.00000 0.00000 0.00000 0.17500 6.61500 1.12100
86 0.00000 0.00000 0.00000 0.01360 9.61546 0.02716
87
88 ND3= 1 ND5= 1000
89
90 ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
91
92 OBSERVED AT= 990
93 0.1267e+03
94 OBSERVED AT= 995
95 0.3679e+02
96 OBSERVED AT= 1000
97 0.6559e+02
98
99 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
100
101 ESTIMATED AT= 990
102 0.1338e+03 -0.5463e+00 -0.1108e+01 0.1750e+00 0.6615e+01 0.1121e+01
103 ESTIMATED AT= 995
104 -0.3464e+01 0.4013e+01 -0.9283e+00 0.1750e+00 0.6615e+01 0.1121e+01
105 ESTIMATED AT= 1000
106 0.2840e+02 0.6098e+01 -0.5565e+00 0.1750e+00 0.6615e+01 0.1121e+01
107 -----
108 ESTIMATED AT= 990
109 -0.1608e+02 0.1982e+01 0.2435e+00 0.1759e-01 0.9556e+01 0.7631e-01
110 ESTIMATED AT= 995
111 -0.2941e+02 0.4023e-01 0.3179e+00 0.1783e-01 0.9555e+01 0.7685e-01
112 ESTIMATED AT= 1000
113 -0.1831e+02 -0.1876e+01 0.2353e+00 0.1813e-01 0.9554e+01 0.7751e-01
114 -----
115 THETA= 0.00000000e+00
116
117
118 The rest of the data has been omitted.
119
120

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

(line no.)

```

1      ID FOR 2-D,ICON=3;for NONLIN. para. only,H(w) from Displ,W/ 1% NOISE IN
2
3      ANALYSIS CASE : ICON====>   3
4
5      OUTPUT CONTROL : NCON====>   1
6
7      NO. OF GLOBAL ITERATIONS : ITE ====>   5
8
9      WEIGHT FOR GLOBAL ITERATION : PITE====>   0.1000e+02
10
11     NO. OF DOF OF SYSTEM : N====>   2
12
13     DIMENSION OF STATE VECTOR : I1====>   6
14
15     NO. OF RESPONSE OBSERVATIONS USED : I2====>   2
16
17     DATA OF OBSERVED RECORDS TO BE USED :
18     NN= 350   DT= 0.1023   NM1= 11   NM2= 170
19
20     INITIAL GUESS OF STATE VECTOR : Y2====>
21     0.557e-01  0.619e+01  0.766e+00  0.500e+00  0.150e+02  0.500e+00
22
23     INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11====>
24     0.000e+00  0.000e+00  0.000e+00  0.100e+00  0.400e+01  0.100e+01
25
26     COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1====>
27     0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
28
29     COEFFICIENT MATRIX OF SYSTEM NOISE : G11====>
30     0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
31
32     COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2====>
33     0.100e+00  0.100e+00
34
35     0.55700e-01  0.61860e+01  0.76600e+00  0.50000e+00  0.15000e+02  0.50000e+00
36     0.00000e+00  0.00000e+00  0.00000e+00  0.10000e+00  0.40000e+01  0.10000e+01
37
38     ***** NUMBER OF ITERATIONS= 1*****
39
40     INITIAL GUESS OF THE STATE VECTOR =
41     0.05570   6.18600   0.76600   0.50000   15.00000   0.50000
42
43     ND3= 11   ND5= 170
44
45     ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
46
47     OBSERVED AT= 150
48     0.7073e-02  0.5897e-02
49     OBSERVED AT= 155
50     0.3881e-02  0.7278e-03
51     OBSERVED AT= 160
52     0.3422e-02  -0.1981e-03
53
54     ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
55
56     ESTIMATED AT= 150
57     0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5083e+00
58     ESTIMATED AT= 155
59     0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5081e+00
60     ESTIMATED AT= 160
61     0.5570e-01  0.6186e+01  0.7660e+00  0.5008e+00  0.1499e+02  0.5078e+00
62     -----
63     THETA= 0.24053818e+07
64
65

```

(Appendix II-3-3 Continued)

```
66          ***** NUMBER OF ITERATIONS=  2*****
67
68 INITIAL GUESS OF THE STATE VECTOR =
69      0.05570      6.18600      0.76600      0.50083      14.99316      0.50783
70
71 ND3=  11      ND5=  170
72
73 ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
74
75 OBSERVED AT=  150
76      0.7073e-02  0.5897e-02
77 OBSERVED AT=  155
78      0.3881e-02  0.7278e-03
79 OBSERVED AT=  160
80      0.3422e-02 -0.1981e-03
81
82 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
83
84 ESTIMATED AT=  150
85      0.5570e-01  0.6186e+01  0.7660e+00  0.5122e+00  0.1492e+02  0.5701e+00
86 ESTIMATED AT=  155
87      0.5570e-01  0.6186e+01  0.7660e+00  0.5124e+00  0.1492e+02  0.5688e+00
88 ESTIMATED AT=  160
89      0.5570e-01  0.6186e+01  0.7660e+00  0.5126e+00  0.1492e+02  0.5664e+00
90 -----
91 THETA= 0.29459793e+07
92
93
94          ***** NUMBER OF ITERATIONS=  3*****
95
96 INITIAL GUESS OF THE STATE VECTOR =
97      0.05570      6.18600      0.76600      0.51257      14.91778      0.56638
98
99 ND3=  11      ND5=  170
100
101 ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
102
103 OBSERVED AT=  150
104      0.7073e-02  0.5897e-02
105 OBSERVED AT=  155
106      0.3881e-02  0.7278e-03
107 OBSERVED AT=  160
108      0.3422e-02 -0.1981e-03
109
110 ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
111
112 ESTIMATED AT=  150
113      0.5570e-01  0.6186e+01  0.7660e+00  0.6525e+00  0.1392e+02  0.7811e+00
114 ESTIMATED AT=  155
115      0.5570e-01  0.6186e+01  0.7660e+00  0.6539e+00  0.1392e+02  0.7774e+00
116 ESTIMATED AT=  160
117      0.5570e-01  0.6186e+01  0.7660e+00  0.6545e+00  0.1391e+02  0.7705e+00
118 -----
119 THETA= 0.31820210e+07
120
121
122 The rest of the data has been omitted.
123
```

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

(line no.)

```

1     SYS-ID FOR 1-D BILIN. ICON=5, FOR NONLIN PARA.; W/ NO NOISE
2
3     ANALYSIS CASE : ICON====>   5
4
5     OUTPUT CONTROL : NCON====>   1
6
7     NO. OF GLOBAL ITERATIONS : ITE====>   5
8
9     WEIGHT FOR GLOBAL ITERATION : PITE====>   0.2000e+01
10
11    NO. OF DOF OF SYSTEM : N====>   1
12
13    DIMENSION OF STATE VECTOR : I1====>   6
14
15    NO. OF RESPONSE OBSERVATIONS USED : I2====>   2
16
17    DATA OF OBSERVED RECORDS TO BE USED :
18      NN= 1000   DT= 0.0150   NM1= 1   NM2= 1000
19
20    INITIAL GUESS OF STATE VECTOR : Y2====>
21      0.000e+00  0.000e+00  0.980e-01  0.316e+01  0.100e+01  0.500e+00
22
23    INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11====>
24      0.100e+01  0.100e+01  0.000e+00  0.000e+00  0.100e+01  0.100e+01
25
26    COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1====>
27      0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
28
29    COEFFICIENT MATRIX OF SYSTEM NOISE : G11====>
30      0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
31
32    COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2====>
33      0.100e+01  0.100e+01
34
35      0.00000e+00  0.00000e+00  0.98000e-01  0.31600e+01  0.10000e+01  0.50000e+00
36      0.10000e+01  0.10000e+01  0.00000e+00  0.00000e+00  0.10000e+01  0.10000e+01
37
38      ***** NUMBER OF ITERATIONS= 1*****
39
40    INITIAL GUESS OF THE STATE VECTOR =
41      0.00000   0.00000   0.09800   3.16000   1.00000   0.50000
42
43    ND3= 1   ND5= 1000
44
45    ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
46
47    OBSERVED AT= 990
48      0.8194e+00 -0.4046e+01
49    OBSERVED AT= 995
50      0.5885e+00 -0.3076e+01
51    OBSERVED AT= 1000
52      0.3485e+00 -0.2889e+01
53
54    ***ESTIMATED RESPONSES AND PARAMETERS AS FILTERED STATE***
55
56    ESTIMATED AT= 990
57      0.1336e+01 -0.4257e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1417e+00
58    ESTIMATED AT= 995
59      0.1087e+01 -0.3343e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1416e+00
60    ESTIMATED AT= 1000
61      0.8251e+00 -0.3192e+01  0.9800e-01  0.3160e+01  0.3114e+01  0.1415e+00
62    -----
63    THETA= 0.13464621e+01
64

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(Appendix II-3-4 Continued)

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```
***** 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.)

```

1     SYS-ID FOR 1-D BOUC-WEN HYSTERE. ICON=6, FOR NONLIN PARA. ONLY; W/O NOIS
2
3     ANALYSIS CASE : ICON====>   6
4
5     OUTPUT CONTROL : NCON====>   1
6
7     NO. OF GLOBAL ITERATIONS : ITE====>   5
8
9     WEIGHT FOR GLOBAL ITERATION : PITE====>   0.2000e+01
10
11    NO. OF DOF OF SYSTEM : N====>   1
12
13    DIMENSION OF STATE VECTOR : I1====>  12
14
15    NO. OF RESPONSE OBSERVATIONS USED : I2====>   2
16
17    DATA OF OBSERVED RECORDS TO BE USED :
18      NN= 1000   DT=  0.0150   NM1=  1   NM2= 1000
19
20    INITIAL GUESS OF STATE VECTOR : Y2====>
21      0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.105e+00  0.318e+01
22      0.000e+00  0.000e+00  0.100e+01  0.000e+00  0.000e+00  0.000e+00
23
24    INITIAL VALUE OF ERROR COVARIANCE MATRIX (DIAGONAL) : P11====>
25      0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.000e+00  0.000e+00
26      0.100e+01  0.100e+01  0.000e+00  0.000e+00  0.000e+00  0.000e+00
27
28    COVARIANCE MATRIX OF SYSTEM NOISE (DIAGONAL) : QR1====>
29      0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
30      0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00  0.000e+00
31
32    COEFFICIENT MATRIX OF SYSTEM NOISE : G11====>
33      0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
34      0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01  0.100e+01
35
36    COVARIANCE MATRIX OF OBSERVATION NOISE(DIAGONAL) : QR2====>
37      0.100e+01  0.100e+01
38
39      0.00000e+00  0.00000e+00  0.00000e+00  0.00000e+00  0.10500e+00  0.31770e+01
40      0.00000e+00  0.00000e+00  0.10000e+01  0.00000e+00  0.00000e+00  0.00000e+00
41      0.10000e+01  0.10000e+01  0.10000e+01  0.10000e+01  0.00000e+00  0.00000e+00
42      0.10000e+01  0.10000e+01  0.00000e+00  0.00000e+00  0.00000e+00  0.00000e+00
43
44      ***** NUMBER OF ITERATIONS=  1*****
45
46    INITIAL GUESS OF THE STATE VECTOR =
47      0.00000  0.00000  0.00000  0.00000  0.10500  3.17700
48      0.00000  0.00000  1.00000  0.00000  0.00000  0.00000
49
50    ND3=  1   ND5= 1000
51
52    ***OBSERVED RESPONSE DATA USED (REFER TO I2 & MC2)***
53
54    OBSERVED AT=  990
55      -0.1717e+00 -0.2122e+01
56    OBSERVED AT=  995
57      -0.2463e+00 -0.8555e+00
58    OBSERVED AT= 1000
59      -0.3128e+00 -0.5041e+00
  
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(Appendix II-3-5 Continued)

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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

```

1          PROGRAM SRESP
2  C
3  C*****
4  C          PROGRAM SRESP
5  C*****
6  C          A COMPUTER PROGRAM FOR SIMULATING RESPONSE OBSERVATION
7  C          RECORDS WHICH WILL BE USED FOR SYSTEM IDENTIFICATION.
8  C*****
9  C          THIS PROGRAM IS ORIGINALLY CODED BY DR.O.MARUYAMA
10 C          UNDER THE GUIDANCE OF PROF. M. HOSHIYA
11 C          DEPARTMENT OF CIVIL ENGINEERING
12 C          MUSASHI INSTITUTE OF TECHNOLOGY
13 C          1-28-1, TAMAZUTSUMI SETAGAYA-KU,
14 C          TOKYO 158, JAPAN
15 C -----
16 C          LATER REVISED BY DR.O.MARUYAMA
17 C          UNDER THE SUPERVISION OF PROF. M.SHINOZUKA
18 C          DEPARTMENT OF CIVIL ENGINEERING AND OPERATIONS RESEARCH
19 C          SCHOOL OF ENGINEERING/APPLIED SCIENCE
20 C          PRINCETON UNIVERSITY PRINCETON, N.J. 08544, U.S.A.
21 C
22 C          THIS IS VERSION **** SRESP *****
23 C          (04, JANUARY 1989)
24 C*****
25 C
26 C * PURPOSE:
27 C * TO GENERATE SIMULATED RESPONSE OBSERVATION RECORDS
28 C * FOR A LINEAR MULTI-DEGREE OF FREEDOM SYSTEM OR A NONLINEAR
29 C * SINGLE DEGREE OF FREEDOM SYSTEM UNDER EARTHQUAKE EXCITATION.
30 C * INPUT GROUND ACCELERATION RECORD AND SIMULATED RESPONSE
31 C * OBSERVATION RECORDS OF RELATIVE DISPLACEMENT, VELOCITY AND
32 C * ACCELERATION WILL BE STORED IN DATA FILE (UNIT=7) FOR
33 C * PARAMETER IDENTIFICATION BY USING PROGRAM EXKAL2.
34 C
35 C*****
36 C
37 C INPUT DATA FILES
38 C
39 C GENERAL INPUT DATA : UNIT=2
40 C
41 C INPUT GROUND ACCELERATION : UNIT=7
42 C INPUT DATA MUST FURNISHED AS
43 C 1. TITLE CARD OF INPUT EXCITATION
44 C 2. GROUND ACCELERATION DATA CARDS WITH A FORMAT OF 8(1PE10.3)
45 C
46 C OUTPUT DATA FILES
47 C
48 C GENERAL OUTPUT : UNIT=6
49 C
50 C FOR SYSTEM IDENTIFICATION : UNIT=8
51 C
52 C FOR PLOTTING EXCITATION/RESPONSE RECORDS : UNIT=31-35
53 C
54 C SYSTEM SUBROUTINES REQUIRED
55 C
56 C GGUBS AND GGNML FROM IMLS : FOR RANDOM NUMBER GENERATION
57 C
58 C*****
59 C DISRIPTION OF INPUT DATA IN UNIT 2
60 C *** FREE FORMAT ***

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61 C*****
62 C
63 C 1. HEADING CARD
64 C
65 C 2. MASTER CONTROL CARD ; ICOM, NCOM, KCOM
66 C
67 C ICOM: ANALYSIS CASE
68 C ICOM=1 : LINEAR MULTI-DEGREE OF FREEDOM SYSTEM
69 C ICOM=2 : SINGLE-DEGREE OF FREEDOM SYSTEM WITH BILINEAR SPRING
70 C (NON-HYSTERETIC)
71 C ICOM=3 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BILINEAR HYSTERESIS
72 C ICOM=4 : SINGEL-DEGREE OF FREEDOM SYSTEM WITH BOUC AND WEN'S
73 C HYSTERETIC MODEL
74 C
75 C NCOM: OUTPUT CONTROL
76 C NCOM=1 : GENERATING OUTPUT DATA FILE (UNIT=8) FOR SYSTEM
77 C IDENTIFICATION BY USING PROGRAM EXKAL2.
78 C UNIT 8 INCLUDES INPUT EXCITATION AND RELATIVE DISPLACEMENT,
79 C VELOCITY AND ACCELERATION OF STRUCTURE TO GROUND MOTION.
80 C
81 C NCOM=2 : GENERATING OUTPUT DATA FILES (UNIT= 31-34) FOR PLOTTING
82 C EXCITATION/RESPONSE OBSERVATIONS.
83 C UNIT=31 : INPUT EXCIATION
84 C UNIT=32 : RELATIVE DISPLACEMENT OF STRUCTURE
85 C UNIT=33 : RELATIVE VELOCITY OF STRUCTURE
86 C UNIT=34 : RELATIVE ACCELERATION OF STRUCTURE
87 C
88 C NCOM=3 : GENERATING OUTPUT DATA FILE (UNIT= 35) FOR PLOTTING
89 C HYSTERETIC BEHAVOIR
90 C
91 C KCOM: NOISE CONTROL
92 C KCOM=1 : NOISE IMPOSED RESPONSE OBSERVATIONS
93 C OTHERWISE : NOISE FREE
94 C
95 C -----
96 C
97 C 3. CONTROL CARD : N, NN, DT, XN
98 C
99 C N : NUMBER OF MODES USED FOR IDENTIFICATION OF LINEAR MDOF SYSTEM
100 C OR NUMBER OF MOF (=1) FOR NONLINEAR SDOF SYSTEM
101 C NN : TOTAL NUMBER OF DATA POINTS IN INPUT EXCITATION RECORD
102 C AS WELL AS OUTPUT RESPONSE RECORDS TO BE GENERATED
103 C DT : TIME INCREMENT IN DATA (SEC)
104 C XN : SCALE FACTOR FOR INPUT EXCIATION IN UNIT=7
105 C
106 C -----
107 C
108 C 4. LINEAR PARAMETER CARDS : BETAI (I), OME (I), PAL (I), I=1, N
109 C ( N-CARDS MUST BE SUPPLIED FOR MDOF SYSTEM ANALYZED USING N-MODES.)
110 C BETAI (I) : MODAL DAMPING RATIO FOR I-TH MODE
111 C OMEI (I) : NATURAL CIRCULAR FREQUENCY FOR I-TH MODE (RAD/SEC)
112 C PAL (I) :
113 C IF ICOM=1, PARTICIPATION FACTOR FOR I-TH MODE AT THE NODE
114 C WHERE RESPONSE OBSERVATION IS MADE,
115 C OTHERWISE, MAY BE OMITTED.
116 C
117 C -----
118 C
119 C 5. NONLINEAR PARAMETER CARD : REQUIRED ONLY FOR ICOM= 2, 3 OR 4
120 C

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121 C      IF ICOM =2 OR 3 (BILINEAR SPRING, NON-HYSTERETIC OR HYSTERESIS);
122 C          U1 : YIELDING DISPLACEMENT
123 C          AA2 : RATIO OF POST-YIELDING STIFFNESS TO
124 C              PRE-YIELDING STIFFNESS
125 C
126 C      IF ICOM =4 (BOUC-WEN'S HYSTERESIS, SECTION 3-4);
127 C          BE, GA, CA, CV, CN: PARAMETERS FOR BOUC-WEN'S MODEL
128 C
129 C          NOTE :
130 C              BE=BETA; GA=GAMMA; CA=DELTA A; CV= DELTA NU; CN=DELTA ETA.
131 C              PARAMETER A0 AND N HAVE BEEN FIXED AS A0=1.0 AND N=1.
132 C
133 C -----
134 C
135 C      6. OBSERVATION NOISE DATA CARD : REQUIRED ONLY FOR KCOM =1
136 C
137 C          Y1 : LOWER RANGE OF GAUSSIAN WHITE NOISE IN HZ
138 C          Y2 : UPPER RANGE OF GAUSSIAN WHITE NOISE IN HZ
139 C          PA : NOISE RATIO TO STRUCTURAL RESPONSE IN VARIANCE
140 C
141 C *****
142 C
143 C
144 C          DIMENSION YA(3000), YV(3000), YD(3000), F(3000), Z(3000)
145 C          DIMENSION XD(3000), FF(3000), YA1(3000), YV1(3000)
146 C          DIMENSION YD1(3000), BETAL(20), OME1(20), PA1(20)
147 C          DATA N1/3000/
148 C
149 C          --- NUMERICAL VALUE OF THE PARAMETERS OF THE MODEL -----
150 C              FROM UNIT=2
151 C          CALL READA(AM, AC, AK1, AK2, U1, DT, N, NN, ICOM, AA, BE, GA, AZ, XN, NCOM
152 C          *          , GN, VV, CA, CN, CV, OME, Y1, Y2, PA, BETAL, OME1, PA1, KCOM)
153 C
154 C          DO 500 I=1, N1
155 C              YA(I)=0.0
156 C              YV(I)=0.0
157 C              YD(I)=0.0
158 C              YA1(I)=0.0
159 C              YV1(I)=0.0
160 C              YD1(I)=0.0
161 C              F(I) =0.0
162 C              FF(I)=0.0
163 C              XD(I)=0.0
164 C              Z(I) =0.0
165 C          500 CONTINUE
166 C
167 C          ---- READ INPUT EXCITATION ----
168 C              FROM UNIT=7
169 C          CALL READB(Z, NN, N1, XN)
170 C -----
171 C          IF(ICOM.EQ.1) GO TO 10
172 C          IF(ICOM.EQ.2) GO TO 20
173 C          IF(ICOM.EQ.3) GO TO 30
174 C          IF(ICOM.EQ.4) GO TO 40
175 C
176 C      10 CONTINUE
177 C          --- RESTORING FORCE CHARACTERISTIC ==> LINEAR ---
178 C
179 C          DO 200 I=1, N
180 C              AC=2.0*BETAL(I)*OME1(I)

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```

181      AK1=OME1(I)*OME1(I)
182      PPA=PA1(I)
183      CALL LINE(AM,AC,AK1,PPA,YA1,YV1,YD1,Z,NN,DT,N1,F)
184  C
185      DO 300 II=1,NN
186      YA(II)=YA(II)+YA1(II)
187      YV(II)=YV(II)+YV1(II)
188      YD(II)=YD(II)+YD1(II)
189      300 CONTINUE
190      200 CONTINUE
191      GO TO 50
192  C
193      20 CONTINUE
194  C      --- RESTORING FORCE CHARACTERISTIC ==> NONLINEAR SPRING ---
195  C      (NO HYSTERESIS)
196      CALL NOSP(AM,AC,AK1,AK2,U1,YA,YV,YD,Z,NN,DT,N1,F)
197      GO TO 50
198  C
199      30 CONTINUE
200  C      --- RESTORING FORCE CHARACTERISTIC ==> BILINEAR HYSTERESIS ---
201  C
202      CALL BILI(AM,AC,AK1,AK2,U1,DT,YA,YV,YD,Z,NN,N1,F)
203      GO TO 50
204  C
205      40 CONTINUE
206  C      --- RESTORING FORCE CHARACTERISTIC ==> BOUC-WEN'S HYSTERESIS ---
207  C
208      CALL VERS(YD,YV,YA,Z,XD,AM,AC,AK1,AA,BE,GA,AZ,N1,DT,KN,NN,F
209      *      ,GN,VV,CA,CN,CV)
210  C
211      50 CONTINUE
212  C
213      DO 51 I=1,NN
214      FF(I)=F(I)/(OME*OME)
215      51 CONTINUE
216  C
217      IF(KCOM.EQ.1) THEN
218      CALL NOISE1(Y1,Y2,PA,YD,YV,YA,N1,NN,DT,KCOM)
219  C
220      DD1=OME*OME
221      DO 11 I=1,NN
222      FF(I)=- (AM*Z(I)+AM*YA(I)+AC*YV(I))/DD1
223      11 CONTINUE
224      END IF
225  C
226      CALL WRITEB(Z,YD,YV,YA,FF,N1,NN,DT,NCOM)
227  C
228      STOP
229      END
230  C
231  C      ***** SUBROUTINE READA *****
232  C      *
233  C      *   SUBROUTINE FOR READING GENERAL INPUT DATA FROM UNIT 2   *
234  C      *   CALLED BY THE MAIN PROGRAM                               *
235  C      *****
236  C
237      SUBROUTINE READA(AM,AC,AK1,AK2,U1,DT,N,NN,ICOM,AA,BE,GA,AZ,XN,NCOM
238      *      ,GN,VV,CA,CN,CV,OME,Y1,Y2,PA,BETA1,OME1,PA1,KCOM)
239  C
240      CHARACTER*72 TEXT

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```

241     DIMENSION BETA1 (20) , OME1 (20) , PA1 (20)
242   C
243     READ (2, 1200) TEXT
244     WRITE (6, 1201) TEXT
245     1200 FORMAT (72A)
246     1201 FORMAT (2X, 72A)
247   C
248     READ (2, *) ICOM, NCOM, KCOM
249     WRITE (6, 1202) ICOM, NCOM, KCOM
250     1202 FORMAT (/2X, ' ICOM, NCOM, KCOM = ', 5X, 3I5/)
251   C
252     READ (2, *) N, NN, DT, XN
253     WRITE (6, 1203) N, NN, DT, XN
254     1203 FORMAT (/2X, ' N, NN, DT, XN = ', 5X, 2I5, 2E11.3/)
255   C
256     DO 100 I=1, N
257     IF (ICOM.EQ.1) READ (2, *) BETA1 (I) , OME1 (I) , PA1 (I)
258     IF (ICOM.NE.1) READ (2, *) BETA1 (I) , OME1 (I)
259     WRITE (6, 1204) BETA1 (I) , OME1 (I) , PA1 (I)
260     1204 FORMAT (/2X, ' LINEAR PARAMETERS; BETA (I) , OME1 (I) , PA1 (I) = ',
261     1      1X, 3E11.3/)
262     100 CONTINUE
263   C
264     IF (ICOM.EQ.2.OR.ICOM.EQ.3) THEN
265     READ (2, *) U1, AA2
266     WRITE (6, 1205) U1, AA2
267     1205 FORMAT (/2X, ' NONLINEAR PARAMETERS; U1, AA2 = ', 1X, 2E11.3/)
268     END IF
269     IF (ICOM.EQ.4) THEN
270     READ (2, *) BE, GA, CA, CV, CN
271     WRITE (6, 1206) BE, GA, CA, CV, CN
272     1206 FORMAT (/2X, ' BOUC-WEN MODEL; BE, GA, CA, CV, CN = ' /5X, 5E11.3/)
273     END IF
274   C
275     IF (KCOM.EQ.1) THEN
276     READ (2, *) Y1 , Y2 , PA
277     WRITE (6, 1207) Y1 , Y2 , PA
278     1207 FORMAT (/2X, ' OBSERVATION NOISE DATA; Y1, Y2, PA = ', 1X, 3E11.3)
279     END IF
280   C
281     AM=1.0
282     AA=1.0
283     GN=1.0
284     VV=1.0
285     AZ=1.0
286   C
287     IF (N.EQ.1) THEN
288     BETA=BETA1 (1)
289     OME=OME1 (1)
290
291     AC=2.0*BETA*OME
292   C
293     AK1=OME*OME
294     AK2=AA2*OME*OME
295     END IF
296   C
297     RETURN
298     END
299   C
300   C ***** SUBROUTINE READB *****

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301 C *
302 C * SUBROUTINE FOR READING INPUT EXCIATION FROM UNIT 7 *
303 C * CALLED BY THE MAIN PROGRAM *
304 C *****
305 C
306 SUBROUTINE READB(Z, NN, N1, XN)
307 CHARACTER*72 TEXT
308 DIMENSION Z(N1), Z1(3000)
309 C
310 C
311 READ(7,101) TEXT
312 WRITE(6,102) TEXT
313 101 FORMAT(72A)
314 102 FORMAT(2X,72A//)
315 C
316 READ(7,100) (Z(KK), KK=1, NN)
317 100 FORMAT(8(1PE10.3))
318 C
319 DO 10 KK=1, NN
320 Z1(KK)=KN*Z(KK)
321 10 CONTINUE
322 C
323 DO 20 KK=1, NN
324 Z(KK)=Z1(KK)
325 20 CONTINUE
326 C
327 RETURN
328 END
329 C
330 C ***** SUBROUTINE LINE *****
331 C *
332 C * SUBROUTINE FOR A LINEAR MULTI-DEGREE OF FREEDOM SYSTEM *
333 C * CALLED BY THE MAIN PROGRAM *
334 C *****
335 C
336 SUBROUTINE LINE(AM, AC, AK, PA, YA, YV, YD, Z, NN, DT, N1, F)
337 DIMENSION YA(N1), YV(N1), YD(N1), Z(N1), F(N1)
338 C
339 DO 5 I=1, NN
340 YA(I)=0.0
341 YV(I)=0.0
342 YD(I)=0.0
343 5 CONTINUE
344 C
345 C
346 DO 10 KK=1, NN
347 C
348 A1=-AM*PA*Z(KK+1)-AK*YD(KK)
349 A2=-YV(KK)*(AC+DT*AK)
350 A3=-YA(KK)*(DT*AC/2.0+(DT*DT)*AK/3.0)
351 A4=AM+DT*AC/2.0+(DT*DT)*AK/6.0
352 C
353 AA1=(A1+A2+A3)/A4
354 YA(KK+1)=AA1
355 C
356 A5=DT/2.0
357 A6=(DT*DT)/3.0
358 A7=(DT*DT)/6.0
359 C
360 YV(KK+1)=YV(KK)+A5*YA(KK)+A5*AA1

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```

361      YD(KK+1)=YD(KK)+DT*YV(KK)+A6*YA(KK)+A7*AA1
362      F(KK)=AK*YD(KK)
363  C
364      10 CONTINUE
365  C
366      RETURN
367      END
368  C
369  C ***** SUBROUTINE NOSP *****
370  C * * * * *
371  C *   SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
372  C *   A NONLINEAR SPRING (NON-HYSTERETIC) *
373  C *   CALLED BY THE MAIN PROGRAM *
374  C *****
375      SUBROUTINE NOSP(AM,AC,AK1,AK2,U1,YA,YV,YD,Z,NN,DT,N1,F)
376      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
377      DIMENSION F(N1)
378  C
379      A1=DT/2.0
380      A2=(DT*DT)/3.0
381      AK3=(AK1-AK2)*U1
382  C
383      DO 10 KK=1,NN
384  C
385          UK=ABS(YD(KK))
386          IF(UK.LE.U1) GO TO 20
387          IF(YD(KK).LT.-U1) GO TO 30
388          IF(YD(KK).GT.U1) GO TO 40
389  C
390      20 CONTINUE
391          A3=AM*Z(KK+1)+AK1*YD(KK)
392          A4=YV(KK)*(AC+DT*AK1)
393          A5=YA(KK)*(A1*AC+A2*AK1)
394          A6=AM+A1*AC+(DT*DT)*AK1/6.0
395          AA1=- (A3+A4+A5)/A6
396          YA(KK+1)=AA1
397  C
398          CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
399          CALL TUNE(YA,YV,YD,Z,DT,N1,KK,U1,1,AM,AC,AK1,AK2)
400          GO TO 50
401  C
402      30 CONTINUE
403          A3=AM*Z(KK+1)+AK2*YD(KK)
404          A4=YV(KK)*(AC+DT*AK2)
405          A5=YA(KK)*(A1*AC+A2*AK2)
406          A6=AM+A1*AC+(DT*DT)*AK2/6.0
407          AA1=- (A3+A4+A5-AK3)/A6
408          YA(KK+1)=AA1
409  C
410          CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
411          CALL TUNE(YA,YV,YD,Z,DT,N1,KK,U1,2,AM,AC,AK1,AK2)
412          GO TO 50
413  C
414      40 CONTINUE
415          A3=AM*Z(KK+1)+AK2*YD(KK)
416          A4=YV(KK)*(AC+DT*AK2)
417          A5=YA(KK)*(A1*AC+A2*AK2)
418          A6=AM+A1*AC+(DT*DT)*AK2/6.0
419          AA1=- (A3+A4+A5+AK3)/A6
420          YA(KK+1)=AA1

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421 C
422 CALL REVD (AA1, YA, YV, YD, DT, N1, KK)
423 CALL TUNE (YA, YV, YD, Z, DT, N1, KK, U1, 2, AM, AC, AK1, AK2)
424 50 CONTINUE
425 C
426 CCL=YD (KK+1)
427 CALL RES1 (CCL, U1, AK1, AK2, F, KK, N1)
428 C
429 10 CONTINUE
430 RETURN
431 END
432 C
433 C ***** SUBROUTINE REVD *****
434 C *
435 C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
436 C * A BILINEAR SPRING (NON-HYSTERETIC) *
437 C * CALLED BY SUBROUTINE NOSP *
438 C *****
439 SUBROUTINE REVD (AA1, YA, YV, YD, DT, N1, KK)
440 DIMENSION YA (N1), YV (N1), YD (N1)
441 C
442 A1=DT/2.0
443 A2=(DT*DT)/3.0
444 A3=(DT*DT)/6.0
445 C
446 YV (KK+1)=YV (KK)+A1*YA (KK)+A1*AA1
447 YD (KK+1)=YD (KK)+DT*YV (KK)+A2*YA (KK)+A3*AA1
448 C
449 RETURN
450 END
451 C
452 C ***** SUBROUTINE TUNE *****
453 C *
454 C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
455 C * A BILINEAR SPRING (NON-HYSTERETIC) *
456 C * CALLED BY SUBROUTINE NOSP *
457 C *****
458 SUBROUTINE TUNE (YA, YV, YD, Z, DT, N1, KK, U1, ICOM, AM, AC, AK1, AK2)
459 DIMENSION YA (N1), YV (N1), YD (N1), Z (N1)
460 C
461 C
462 IF (ICOM.EQ.1) GO TO 10
463 IF (ICOM.EQ.2) GO TO 20
464 C
465 10 CONTINUE
466 X=ABS (YD (KK+1))
467 X1=YD (KK+1)
468 C
469 IF (X.LE.U1) THEN
470 GO TO 100
471 ELSE
472 C
473 IF (X1.GT.0.0) THEN
474 YYD=U1
475 DTT=(YYD-YD (KK))/YV (KK)
476 YYV=YV (KK)+DTT*YA (KK)
477 YYA=- (AC*YYV+AK1*U1+AM*Z (KK))/AM
478 C
479 DTA=DT-DTT
480 B1=DTA/2.0

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481      B2=DTA*DTA/3.0
482      B3=DTA*DTA/6.0
483      C
484      A1=AM*Z (KK+1)+AK2*YYD
485      A2=YYV*(AC+DTA*AK2)
486      A3=YYA*(B1*AC+B2*AK2)
487      A4=(AK1-AK2)*U1
488      A5=AM+B1*AC+B3*AK2
489      YY1=- (A1+A2+A3+A4)/A5
490      YY2=YYV+B1*YYA+B1*YY1
491      YY3=YYD+DTA*YYV+B2*YYA+B3*YY1
492      YA (KK+1)=YY1
493      YV (KK+1)=YY2
494      YD (KK+1)=YY3
495      C
496      ELSE
497      YYD=-U1
498      DTT=(YYD-YD (KK) ) /YV (KK)
499      YYV=YV (KK) +DTT*YA (KK)
500      YYA=- (AC*YYV-AK1*U1+AM*Z (KK) ) /AM
501      C
502      DTA=DT-DTT
503      B1=DTA/2.0
504      B2=DTA*DTA/3.0
505      B3=DTA*DTA/6.0
506      C
507      A1=AM*Z (KK+1)+AK2*YYD
508      A2=YYV*(AC+DTA*AK2)
509      A3=YYA*(B1*AC+B2*AK2)
510      A4=- (AK1-AK2)*U1
511      A5=AM+B1*AC+B3*AK2
512      YY1=- (A1+A2+A3+A4)/A5
513      YY2=YYV+B1*YYA+B1*YY1
514      YY3=YYD+DTA*YYV+B2*YYA+B3*YY1
515      YA (KK+1)=YY1
516      YV (KK+1)=YY2
517      YD (KK+1)=YY3
518      END IF
519      END IF
520      GO TO 100
521      C
522      20 CONTINUE
523      X=ABS (YD (KK+1) )
524      X1=YD (KK+1)
525      C
526      IF (X.GE.U1) THEN
527      GO TO 100
528      ELSE
529      C
530      IF (X1.GT.0.0) THEN
531      YYD=U1
532      ELSE
533      YYD=-U1
534      END IF
535      C
536      DTT=(YYD-YD (KK) ) /YV (KK)
537      YYV=YV (KK) +DTT*YA (KK)
538      YYA=- (AC*YYV+AK2*YYD+ (AK1-AK2) *YYD+AM*Z (KK) ) /AM
539      C
540      DTA=DT-DTT

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541      B1=DTA/2.0
542      B2=(DTA*DTA)/3.0
543      B3=(DTA*DTA)/6.0
544      C
545      A1=AM*Z(KK+1)+AK1*YYD
546      A2=YYV*(AC+DTA*AK1)
547      A3=YVA*(B1*AC+B2*AK1)
548      A4=AM+B1*AC+B3*AK1
549      YY1=-(A1+A2+A3)/A4
550      YY2=YYV+B1*YVA+B1*YY1
551      YY3=YYD+DTA*YYV+B2*YVA+B3*YY1
552      YA(KK+1)=YY1
553      YV(KK+1)=YY2
554      YD(KK+1)=YY3
555      END IF
556      100 CONTINUE
557      RETURN
558      END
559      C
560      C ***** SUBROUTINE BILI *****
561      C *
562      C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
563      C * A BILINEAR HYSTERETIC BEHAVOIR *
564      C * CALLED BY THE MAIN PROGRAM *
565      C *****
566      SUBROUTINE BILI(AM,AC,AK1,AK2,U1,DT,YA,YV,YD,Z,NN,N1,F)
567      DIMENSION YA(N1),YV(N1),YD(N1),Z(N1)
568      DIMENSION F(N1)
569      C
570      C
571      C
572      UAO=U1
573      UBO=-U1
574      BB=0.0
575      C
576      DO 10 KK=1,NN
577      C
578      C
579      C
580      XD=ABS(YD(KK))
581      XD1=YD(KK)
582      XV1=YV(KK)
583      A1=AM*Z(KK+1)
584      A2=AC*(YV(KK)+DT*YA(KK))/2.0
585      A3=YD(KK)+DT*YV(KK)
586      A4=A3+DT*DT*YA(KK)/3.0
587      A5=DT/2.0
588      A6=(DT*DT)/6.0
589      C
590      IF(XD1.GE.UBO.AND.XD1.LE.UAO) GO TO 20
591      IF(XD1.GE.UAO.AND.XV1.GE.0.0) GO TO 30
592      IF(XD1.LE.UBO.AND.XV1.LE.0.0) GO TO 50
593      C
594      20 CONTINUE
595      AA1=(-(A1+A2+AK1*A4)-BB)/(AM+A5*AC+A6*AK1)
596      YA(KK+1)=AA1
597      CALL REVD(AA1,YA,YV,YD,DT,N1,KK)
598      CALL TUNE2(YA,YV,YD,DT,N1,KK,AM,AC,AK1,AK2,
599      *          Z,U1,BB,UAO,UBO,1)
600      GO TO 70

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601 C
602 30 CONTINUE
603 CC=(AK1-AK2)*U1
604 AA1=(-(A1+A2+AK2*A4)-CC)/(AM+A5*AC+A6*AK2)
605 YA(KK+1)=AA1
606 CALL REVD(AA1, YA, YV, YD, DT, N1, KK)
607 CALL TUNE2(YA, YV, YD, DT, N1, KK, AM, AC, AK1, AK2,
608 * Z, U1, BB, UAO, UB0, 2)
609 GO TO 70
610 C
611 50 CONTINUE
612 CC=(AK1-AK2)*U1
613 AA1=(-(A1+A2+AK2*A4)+CC)/(AM+A5*AC+A6*AK2)
614 YA(KK+1)=AA1
615 CALL REVD(AA1, YA, YV, YD, DT, N1, KK)
616 CALL TUNE2(YA, YV, YD, DT, N1, KK, AM, AC, AK1, AK2,
617 * Z, U1, BB, UAO, UB0, 3)
618 GO TO 70
619 C
620 70 CONTINUE
621 C
622 DD1=YD(KK+1)
623 VV1=YV(KK+1)
624 C
625 CALL RES2(DD1, VV1, BB, U1, UAO, UB0, AK1, AK2, F, KK, N1)
626 C
627 10 CONTINUE
628 RETURN
629 END
630 C
631 C ***** SUBROUTINE TUNE2 *****
632 C *
633 C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
634 C * A BILINEAR HYSTERETIC BEHAVOIR *
635 C * CALLED BY SUBROUTINE BILI *
636 C *****
637 C SUBROUTINE TUNE2(YA, YV, YD, DT, N1, KK, AM, AC, AK1, AK2,
638 * Z, U1, BB, UAO, UB0, ICOM)
639 C DIMENSION YA(N1), YV(N1), YD(N1), Z(N1)
640 C
641 C A1=YD(KK+1)
642 C A2=YV(KK+1)
643 C
644 C IF(ICOM.EQ.1) GO TO 10
645 C IF(ICOM.EQ.2) GO TO 20
646 C IF(ICOM.EQ.3) GO TO 30
647 C
648 C 10 CONTINUE
649 C
650 C IF(A1.GE.UB0.AND.A1.LE.UAO) GO TO 100
651 C IF(A1.GE.UAO.AND.A2.GE.0.0) GO TO 50
652 C IF(A1.LE.UB0.AND.A2.LE.0.0) GO TO 60
653 C
654 C 50 CONTINUE
655 C
656 C DTT=(UA0-YD(KK))/YV(KK)
657 C YYD=UA0
658 C YYV=YV(KK)+DTT*YA(KK)
659 C YYA=-(AC*YYV+AK1*YYD+BB+AM*Z(KK))/AM
660 C

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661      DTA=DT-DTT
662      B1=DTA/2.0
663      B2=(DTA*DTA)/3.0
664      B3=DTA*DTA/6.0
665      B4=AM*Z(KK+1)
666      B5=AC*(YYV+B1*YYA)
667      B6=AK2*(YYD+DTA*YYV+B2*YYA)
668      B7=AM+B1*AC+B3*AK2
669      B8=- (AK1-AK2) *U1
670  C
671      AA1=- (B4+B5+B6-B8) /B7
672      AA2=YYV+B1*YYA+B1*AA1
673      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
674      YA(KK+1)=AA1
675      YV(KK+1)=AA2
676      YD(KK+1)=AA3
677  C
678      GO TO 100
679  C
680      60 CONTINUE
681      DTT=(UB0-YD(KK) ) /YV(KK)
682      YYD=UB0
683      YYV=YV(KK) +DTT*YA(KK)
684      YYA=- (AC*YYV+AK1*YYD+BB+AM*Z(KK) ) /AM
685  C
686      DTA=DT-DTT
687      B1=DTA/2.0
688      B2=DTA*DTA/3.0
689      B3=DTA*DTA/6.0
690      B4=AM*Z(KK+1)
691      B5=AC*(YYV+B1*YYA)
692      B6=AK2*(YYD+DTA*YYV+B2*YYA)
693      B7=AM+B1*AC+B3*AK2
694      B8=(AK1-AK2) *U1
695  C
696      AA1=- (B4+B5+B6-B8) /B7
697      AA2=YYV+B1*YYA+B1*AA1
698      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
699      YA(KK+1)=AA1
700      YV(KK+1)=AA2
701      YD(KK+1)=AA3
702      GO TO 100
703  C
704      20 CONTINUE
705      IF(A1.GE.UA0.AND.A2.GE.0.0) GO TO 100
706      IF(A1.GE.UA0.AND.A2.LE.0.0) GO TO 70
707  C
708      70 CONTINUE
709      DTT=-YV(KK) /YA(KK)
710      YYD=YD(KK) +DTT*YV(KK) + (DTT*DTT*YA(KK) ) /2.0
711      YYV=0.0
712      YYA=- (AC*YYV+AK2*YYD+ (AK1-AK2) *U1+AM*Z(KK) ) /AM
713  C
714      UA0=YYD
715      UB0=YYD-2.0*U1
716      BB=- (AK1-AK2) * (UA0-U1)
717  C
718      DTA=DT-DTT
719      B1=DTA/2.0
720      B2=(DTA*DTA) /3.0

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```

721      B3=(DTA*DTA)/6.0
722      B4=AM*Z (KK+1)
723      B5=AC*(YYV+B1*YYA)
724      B6=AK1*(YYD+DTA*YYV+B2*YYA)
725      B7=AM+B1*AC+B3*AK1
726  C
727      AA1=- (B4+B5+B6+BB)/B7
728      AA2=YYV+B1*YYA+B1*AA1
729      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
730      YA (KK+1)=AA1
731      YV (KK+1)=AA2
732      YD (KK+1)=AA3
733  C
734      GO TO 100
735  C
736      30 CONTINUE
737      IF (A1.LE.UB0.AND.A2.LE.0.0) GO TO 100
738      IF (A1.LE.UB0.AND.A2.GE.0.0) GO TO 80
739  C
740      80 CONTINUE
741      DTT=-YV (KK)/YA (KK)
742      YYD=YD (KK)+DTT*YV (KK)+(DTT*DTT*YA (KK))/2.0
743      YYV=0.0
744      YYA=- (AC*YYV+AK2*YYD-(AK1-AK2)*U1+AM*Z (KK))/AM
745  C
746      UA0=YYD+2.0*U1
747      UB0=YYD
748      BB=- (AK1-AK2)*(YYD+U1)
749  C
750      DTA=DT-DTT
751      B1=DTA/2.0
752      B2=DTA*DTA/3.0
753      B3=DTA*DTA/6.0
754      B4=AM*Z (KK+1)
755      B5=AC*(YYV+B1*YYA)
756      B6=AK1*(YYD+DTA*YYV+B2*YYA)
757      B7=AM+B1*AC+B3*AK1
758  C
759      AA1=- (B4+B5+B6+BB)/B7
760      AA2=YYV+B1*YYA+B1*AA1
761      AA3=YYD+DTA*YYV+B2*YYA+B3*AA1
762      YA (KK+1)=AA1
763      YV (KK+1)=AA2
764      YD (KK+1)=AA3
765  C
766      GO TO 100
767  C
768      100 CONTINUE
769      RETURN
770      END
771  C
772  C ***** SUBROUTINE VERS *****
773  C *
774  C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
775  C * A BOUC-WEN'S HYSTERETIC BEHAVOIR *
776  C * CALLED BY THE MAIN PROGRAM *
777  C *****
778  C SUBROUTINE VERS (YD, YV, YA, Z, XD, AM, AC, AK1, AA, BE, GA, AZ, N1, DT, KK, NN, F
779  C * , GN, VV, CA, CN, CV)
780  C DIMENSION YD (N1), YV (N1), YA (N1), Z (N1), XD (N1)

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781     DIMENSION F (N1)
782     C
783     C
784     DO 10 KK=1, NN
785     YYD=YD (KK)
786     YYV=YV (KK)
787     XXD=XD (KK)
788     JJ=KK
789     C
790     CALL RUNGEX (YYD, YYV, YYA, Z, XXD, AM, AC, AK1, AA, BE, GA, AZ, N1, DT, JJ
791     *           , GN, VV, CA, CN, CV)
792     C
793     YD (KK+1) =YYD
794     YV (KK+1) =YYV
795     YA (KK+1) =YYA
796     XD (KK+1) =XXD
797     F (KK+1) =XXD*AK1
798     C
799     10 CONTINUE
800     RETURN
801     END
802     C
803     C ***** SUBROUTINE RUNGEX *****
804     C *
805     C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
806     C * A BOUC-WEN'S HYSTERETIC BEHAVOIR *
807     C * CALLED BY SUBROUTINE VERS *
808     C *****
809     SUBROUTINE RUNGEX (YYD, YYV, YYA, Z, XXD, AM, AC, AK1, AAA, BE, GA
810     *           , AZ, N1, DT, KK, GNN, VVV, CA, CN, CV)
811     DIMENSION Z (N1)
812     DIMENSION Y1 (5), Y2 (5), Y3 (5), BK1 (5), BK2 (5), BK3 (5)
813     DIMENSION R1 (5), R2 (5), R3 (5), Q1 (5), Q2 (5), Q3 (5)
814     DIMENSION Y4 (5), BK4 (5), R4 (5), Q4 (5)
815     C
816     Y1 (1) =YYD
817     Y2 (1) =YYV
818     Y3 (1) =XXD
819     Y4 (1) =ZZE
820     C
821     IF (KK.NE.1) GO TO 100
822     AA=AAA
823     GN=GNN
824     VV=VVV
825     Q1 (1) =0.0
826     Q2 (1) =0.0
827     Q3 (1) =0.0
828     Q4 (1) =0.0
829     100 CONTINUE
830     C
831     BK1 (1) =DT*Y2 (1)
832     BK2 (1) =-DT* (AM*Z (KK) +AC*Y2 (1) +AK1*Y3 (1)) /AM
833     YZ2=ABS (Y2 (1))
834     YZ3=ABS (Y3 (1))
835     C
836     IF (KK.EQ.1) THEN
837     ZZ1=0.0
838     ZZ2=0.0
839     ELSE
840     ZZ1=YZ3** (AZ-1.0)

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841      ZZ2=YZ3**AZ
842      END IF
843      C
844      BB1=DT*(AA*Y2 (1) -VV*BE*YZ2*ZZ1*Y3 (1) )
845      BK3 (1) =(BB1-VV*DT*GA*Y2 (1) *ZZ2) /GN
846      BK4 (1) =DT*AK1*Y3 (1) *Y2 (1)
847      C
848      R1 (1) =BK1 (1) /2.0-Q1 (1)
849      R2 (1) =BK2 (1) /2.0-Q2 (1)
850      R3 (1) =BK3 (1) /2.0-Q3 (1)
851      R4 (1) =BK4 (1) /2.0-Q4 (1)
852      C
853      Y1 (2) =Y1 (1) +R1 (1)
854      Y2 (2) =Y2 (1) +R2 (1)
855      Y3 (2) =Y3 (1) +R3 (1)
856      Y4 (2) =Y4 (1) +R4 (1)
857      C
858      Q1 (2) =Q1 (1) +3.0*R1 (1) -BK1 (1) /2.0
859      Q2 (2) =Q2 (1) +3.0*R2 (1) -BK2 (1) /2.0
860      Q3 (2) =Q3 (1) +3.0*R3 (1) -BK3 (1) /2.0
861      Q4 (2) =Q4 (1) +3.0*R4 (1) -BK4 (1) /2.0
862      C
863      C
864      BK1 (2) =DT*Y2 (2)
865      ZZ= (Z (KK) +Z (KK+1) ) /2.0
866      BK2 (2) =-DT*(AM*ZZ+AC*Y2 (2) +AK1*Y3 (2) ) /AM
867      YZ2=ABS (Y2 (2) )
868      YZ3=ABS (Y3 (2) )
869      C
870      IF (KK.EQ.1) THEN
871      ZZ1=0.0
872      ZZ2=0.0
873      ELSE
874      ZZ1=YZ3** (AZ-1.0)
875      ZZ2=YZ3**AZ
876      END IF
877      C
878      BB1=DT*(AA*Y2 (2) -VV*BE*YZ2*ZZ1*Y3 (2) )
879      BK3 (2) =(BB1-VV*DT*GA*Y2 (2) *ZZ2) /GN
880      BK4 (2) =DT*Y3 (2) *Y2 (2) *AK1
881      C
882      DA1=0.2928932
883      R1 (2) =DA1*(BK1 (2) -Q1 (2) )
884      R2 (2) =DA1*(BK2 (2) -Q2 (2) )
885      R3 (2) =DA1*(BK3 (2) -Q3 (2) )
886      R4 (2) =DA1*(BK4 (2) -Q4 (2) )
887      C
888      Y1 (3) =Y1 (2) +R1 (2)
889      Y2 (3) =Y2 (2) +R2 (2)
890      Y3 (3) =Y3 (2) +R3 (2)
891      Y4 (3) =Y4 (2) +R4 (2)
892      C
893      Q1 (3) =Q1 (2) +3.0*R1 (2) -DA1*BK1 (2)
894      Q2 (3) =Q2 (2) +3.0*R2 (2) -DA1*BK2 (2)
895      Q3 (3) =Q3 (2) +3.0*R3 (2) -DA1*BK3 (2)
896      Q4 (3) =Q4 (2) +3.0*R4 (2) -DA1*BK4 (2)
897      C
898      C
899      BK1 (3) =DT*Y2 (3)
900      ZZ= (Z (KK) +Z (KK+1) ) /2.0

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901      BK2 (3) = -DT * (AM * ZZ + AC * Y2 (3) + AK1 * Y3 (3)) / AM
902      YZ2 = ABS (Y2 (3))
903      YZ3 = ABS (Y3 (3))
904      IF (KK.EQ.1) THEN
905      ZZ1 = 0.0
906      ZZ2 = 0.0
907      ELSE
908      ZZ1 = YZ3 ** (AZ - 1.0)
909      ZZ2 = YZ3 ** AZ
910      END IF
911      C
912      BB1 = DT * (AA * Y2 (3) - VV * BE * YZ2 * ZZ1 * Y3 (3))
913      BK3 (3) = (BB1 - VV * DT * GA * Y2 (3) * ZZ2) / GN
914      BK4 (3) = DT * Y3 (3) * Y2 (3) * AK1
915      C
916      DA1 = 0.17071068E+01
917      R1 (3) = DA1 * (BK1 (3) - Q1 (3))
918      R2 (3) = DA1 * (BK2 (3) - Q2 (3))
919      R3 (3) = DA1 * (BK3 (3) - Q3 (3))
920      R4 (3) = DA1 * (BK4 (3) - Q4 (3))
921      C
922      Y1 (4) = Y1 (3) + R1 (3)
923      Y2 (4) = Y2 (3) + R2 (3)
924      Y3 (4) = Y3 (3) + R3 (3)
925      Y4 (4) = Y4 (3) + R4 (3)
926      C
927      Q1 (4) = Q1 (3) + 3.0 * R1 (3) - DA1 * BK1 (3)
928      Q2 (4) = Q2 (3) + 3.0 * R2 (3) - DA1 * BK2 (3)
929      Q3 (4) = Q3 (3) + 3.0 * R3 (3) - DA1 * BK3 (3)
930      Q4 (4) = Q4 (3) + 3.0 * R4 (3) - DA1 * BK4 (3)
931      C
932      C
933      BK1 (4) = DT * Y2 (4)
934      BK2 (4) = -DT * (AM * Z (KK+1) + AC * Y2 (4) + AK1 * Y3 (4)) / AM
935      YZ2 = ABS (Y2 (4))
936      YZ3 = ABS (Y3 (4))
937      C
938      BB1 = DT * (AA * Y2 (4) - VV * BE * YZ2 * (YZ3 ** (AZ - 1.0)) * Y3 (4))
939      BK3 (4) = (BB1 - VV * DT * GA * Y2 (4) * (YZ3 ** AZ)) / GN
940      BK4 (4) = DT * Y3 (4) * Y2 (4) * AK1
941      C
942      R1 (4) = (BK1 (4) - 2.0 * Q1 (4)) / 6.0
943      R2 (4) = (BK2 (4) - 2.0 * Q2 (4)) / 6.0
944      R3 (4) = (BK3 (4) - 2.0 * Q3 (4)) / 6.0
945      R4 (4) = (BK4 (4) - 2.0 * Q4 (4)) / 6.0
946      C
947      Y1 (5) = Y1 (4) + R1 (4)
948      Y2 (5) = Y2 (4) + R2 (4)
949      Y3 (5) = Y3 (4) + R3 (4)
950      Y4 (5) = Y4 (4) + R4 (4)
951      C
952      Q1 (5) = Q1 (4) + 3.0 * R1 (4) - BK1 (4) / 2.0
953      Q2 (5) = Q2 (4) + 3.0 * R2 (4) - BK2 (4) / 2.0
954      Q3 (5) = Q3 (4) + 3.0 * R3 (4) - BK3 (4) / 2.0
955      Q4 (5) = Q4 (4) + 3.0 * R4 (4) - BK4 (4) / 2.0
956      C
957      YY1 = Y1 (5)
958      YY2 = Y2 (5)
959      YY3 = Y3 (5)
960      YY4 = Y4 (5)

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```

961 C
962 YYD=YY1
963 YYV=YY2
964 XXD=YY3
965 ZZE=YY4
966 C
967 Q1 (1)=Q1 (5)
968 Q2 (1)=Q2 (5)
969 Q3 (1)=Q3 (5)
970 Q4 (1)=Q4 (5)
971 C
972 C
973 AA=AAA-CA*ZZE
974 GN=GNN+CN*ZZE
975 VV=VVV+CV*ZZE
976 C
977 YYA=- (AM*Z (KK+1)+AC*YYV+AK1*XXD)/AM
978 C
979 RETURN
980 END
981 C
982 C ***** SUBROUTINE RES1 *****
983 C *
984 C * SUBROUTINE FOR A SINGLE DEGREE OF FREEDOM SYSTEM WITH *
985 C * A BILINEAR SPRING (NON-HYSTERETIC) *
986 C * CALLED BY SUBROUTINE NOSP *
987 C *****
988 SUBROUTINE RES1 (YY3, U1, AK1, AK2, F, KK, N1)
989 DIMENSION F (N1)
990 C
991 XXI=ABS (YY3)
992 C
993 IF (XXI.LE.U1) GO TO 10
994 IF (YY3.GT.U1) GO TO 20
995 IF (YY3.LT.-U1) GO TO 30
996 C
997 10 CONTINUE
998 AA1=AK1*YY3
999 F (KK+1)=AA1
1000 GO TO 40
1001 C
1002 20 CONTINUE
1003 AA1=AK2*YY3+(AK1-AK2)*U1
1004 F (KK+1)=AA1
1005 GO TO 40
1006 C
1007 30 CONTINUE
1008 AA1=AK2*YY3-(AK1-AK2)*U1
1009 F (KK+1)=AA1
1010 C
1011 40 CONTINUE
1012 C
1013 RETURN
1014 END
1015 C
1016 C ***** SUBROUTINE RES2 *****
1017 C *
1018 C * SUBROUTINE FOR SINGLE DEGREE OF FREEDOM SYSTEM WITH *
1019 C * A BILINEAR HYSTERETIC BEHAVOIR *
1020 C * CALLED BY SUBROUTINE BILI *

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1021 C *****
1022 SUBROUTINE RES2 (DD1, VV1, BB, U1, UAO, UBO, AK1, AK2, F, KK, N1)
1023 DIMENSION F (N1)
1024 C
1025 IF (DD1.GE.UBO.AND.DD1.LE.UAO) GO TO 10
1026 IF (DD1.GT.UAO.AND.VV1.GE.0.0) GO TO 20
1027 IF (DD1.LT.UBO.AND.VV1.LE.0.0) GO TO 30
1028 C
1029 10 CONTINUE
1030 AA1=AK1*DD1+BB
1031 F (KK+1)=AA1
1032 GO TO 40
1033 C
1034 20 CONTINUE
1035 AA1=AK2*DD1+(AK1-AK2)*U1
1036 F (KK+1)=AA1
1037 GO TO 40
1038 C
1039 30 CONTINUE
1040 AA1=AK2*DD1-(AK1-AK2)*U1
1041 F (KK+1)=AA1
1042 GO TO 40
1043 C
1044 40 CONTINUE
1045 RETURN
1046 END
1047 C
1048 C
1049 C ***** SUBROUTINE NOISE1 *****
1050 C *
1051 C * SUBROUTINE FOR GENERATING OBSERVATIONAL NOISE *
1052 C * CALLED BY THE MAIN PROGRAM *
1053 C *****
1054 C
1055 SUBROUTINE NOISE1 (Y1, Y2, PA, YD, YV, YA, N1, NN, DT, KCOM)
1056 DIMENSION YD (N1), YV (N1), YA (N1)
1057 C
1058 CALL AUC (1, NN, DT, YD, YV, YA, 1, N1, PA, Y1, Y2, KCOM)
1059 C
1060 RETURN
1061 END
1062 C
1063 C ***** SUBROUTINE AUC *****
1064 C *
1065 C * SUBROUTINE FOR GENERATING OBSERVATIONAL NOISE *
1066 C * CALLED BY SUBROUTINE NOISE1 *
1067 C *****
1068 C
1069 SUBROUTINE AUC (N, NN, DT, YD, YV, YA, M1, M2, PA, Z1, Z2, KCOM)
1070 DIMENSION Y1 (3, 1, 3000), X1 (3000), YD (M2), YV (M2), YA (M2)
1071 DIMENSION X2 (3000)
1072 C
1073 DO 11 I=1, NN
1074 Y1 (1, 1, I)=YD (I)
1075 Y1 (2, 1, I)=YV (I)
1076 Y1 (3, 1, I)=YA (I)
1077 11 CONTINUE
1078 C
1079 IF (PA.EQ.0.0) GO TO 20
1080 B=0.0

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```

1081      CALL STGU(NN,DT,X1,3000,Z1,Z2)
1082      X1(1)=0.0
1083      C
1084      IF(KCOM.EQ.2) THEN
1085      DO 112 I=1,NN
1086      X2(I)=X1(I)*X1(I)*X1(I)
1087      112 CONTINUE
1088      DO 113 I=1,NN
1089      X1(I)=X2(I)
1090      113 CONTINUE
1091      END IF
1092      C
1093      DO 100 K=1,NN
1094      100 B=B+X1(K)*X1(K)
1095      20 CONTINUE
1096      C
1097      C
1098      DO 200 I=1,N
1099      DO 300 J=1,3
1100      A=0.0
1101      DO 400 K=1,NN
1102      A=A+Y1(J,I,K)*Y1(J,I,K)
1103      400 CONTINUE
1104      C
1105      IF(PA.EQ.0.0) GO TO 40
1106      A1=A*PA/B
1107      A2=SQRT(A1)
1108      DO 500 K=1,NN
1109      500 Y1(J,I,K)=X1(K)*A2+Y1(J,I,K)
1110      C=0.0
1111      DO 600 K=1,NN
1112      600 C=C+Y1(J,I,K)*Y1(J,I,K)
1113      40 CONTINUE
1114      300 CONTINUE
1115      200 CONTINUE
1116      C
1117      DO 12 I=1,NN
1118      YD(I)=Y1(1,1,I)
1119      YV(I)=Y1(2,1,I)
1120      YA(I)=Y1(3,1,I)
1121      12 CONTINUE
1122      C
1123      RETURN
1124      END
1125      C
1126      C ***** SUBROUTINE STGU *****
1127      C *
1128      C * SUBROUTINE FOR GENERATING OBSERVATIONAL NOISE *
1129      C * CALLED BY SUBROUTINE AUC *
1130      C *****
1131      C
1132      SUBROUTINE STGU(NDATA,DELT,X,M2,Y1,Y2)
1133      IMPLICIT REAL*4 (Z)
1134      C
1135      DIMENSION A(5001),X(M2),AA(5001),AA1(5001)
1136      DIMENSION Y(5001),OME(5001),PHI(5001)
1137      DIMENSION Z(5001),ZZ(5001)
1138      C
1139      C
1140      OHL=Y1

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1141      OHH=Y2
1142      NSUM=200
1143      IX=1
1144      OL=OHL*6.283186
1145      OH=OHH*6.283186
1146      OS=OH-OL
1147      DEO=OS/FLOAT(NSUM)
1148      S=0.5/OS
1149  C
1150      SDE=SQRT(4.0*S*DEO)
1151  C
1152      CALL RNDFL(1.D0,5001,Z)
1153      CALL RNDNOR(1.D0,5001,ZZ)
1154  C
1155      DO 55 I=1,5001
1156      A(I)=Z(I)
1157      AA(I)=ZZ(I)
1158 55 CONTINUE
1159  C
1160      DO 60 I=1,NDATA
1161      AA1(I)=AA(I)*SDE
1162 60 CONTINUE
1163  C
1164      DO 10 K=1,NSUM
1165      OME(K)=DEO*(FLOAT(K)-0.5)+OL
1166      PHI(K)=A(K)*6.283186
1167  C
1168 10 CONTINUE
1169  C
1170      DO 20 J=1,NDATA
1171      T=DELT*FLOAT(J-1)
1172      SUM=0.0
1173      DO 50 K=1,NSUM
1174      Y(K)=AA1(K)*SIN(OME(K)*T+PHI(K))
1175 50 SUM=SUM+Y(K)
1176      X(J)=SUM
1177 20 CONTINUE
1178      RETURN
1179      END
1180  C
1181  C ***** SUBROUTINE WRITER *****
1182  C * * * * *
1183  C * SUBROUTINE FOR GENERATING OUTPUT FILES TO BE *
1184  C * USED FOR IDENTIFICATION AND PLOTTING *
1185  C * CALLED BY THE MAIN PROGRAM *
1186  C *****
1187      SUBROUTINE WRITER(Z,YD,YV,YA,F,N1,NN,DT,NCOM)
1188      DIMENSION Z(N1),YD(N1),YV(N1),YA(N1),F(N1)
1189      DIMENSION TIME(3000)
1190  C
1191      III=5
1192      II2=6
1193      IF(NCOM.EQ.1) GO TO 10
1194      IF(NCOM.EQ.2) GO TO 20
1195      IF(NCOM.EQ.3) GO TO 30
1196  C
1197 10 CONTINUE
1198  C
1199      WRITE(8,*) 'OBSERVED INPUT EXCIATION / OUTPUT RESPONSE'
1200      NRSP=3

```

```

1201      WRITE (8,101) NRSP
1202      101 FORMAT (I5)
1203      C
1204      WRITE (8,*) 'OBSERVED INPUT EXCIATION'
1205      WRITE (8,100) (Z (KK) ,KK=1, NN)
1206      C
1207      WRITE (8,*) 'DISPLACEMENT RESPONSE'
1208      JDX=1
1209      WRITE (8,101) JDX
1210      WRITE (8,100) (YD (KK) ,KK=1, NN)
1211      C
1212      WRITE (8,*) 'VELOCITY RESPONSE'
1213      JDX=2
1214      WRITE (8,101) JDX
1215      WRITE (8,100) (YV (KK) ,KK=1, NN)
1216      C
1217      WRITE (8,*) 'ACCELERATION RESPONSE'
1218      JDX=3
1219      WRITE (8,101) JDX
1220      WRITE (8,100) (YA (KK) ,KK=1, NN)
1221      GO TO 40
1222      C
1223      20 CONTINUE
1224      DO 1000 I=1, NN
1225      TIME (I)=DT*FLOAT (I-1)
1226      1000 CONTINUE
1227      C
1228      WRITE (31,150) III, III, NN
1229      WRITE (31,100) (TIME (KK) ,KK=1, NN)
1230      WRITE (31,150) III, II2, NN
1231      WRITE (31,100) (Z (KK) ,KK=1, NN)
1232      REWIND 21
1233      C
1234      WRITE (32,150) III, III, NN
1235      WRITE (32,100) (TIME (KK) ,KK=1, NN)
1236      WRITE (32,150) III, II2, NN
1237      WRITE (32,100) (YD (KK) ,KK=1, NN)
1238      REWIND 22
1239      C
1240      WRITE (33,150) III, III, NN
1241      WRITE (33,100) (TIME (KK) ,KK=1, NN)
1242      WRITE (33,150) III, II2, NN
1243      WRITE (33,100) (YV (KK) ,KK=1, NN)
1244      REWIND 23
1245      C
1246      WRITE (34,150) III, III, NN
1247      WRITE (34,100) (TIME (KK) ,KK=1, NN)
1248      WRITE (34,150) III, II2, NN
1249      WRITE (34,100) (YA (KK) ,KK=1, NN)
1250      REWIND 24
1251      GO TO 40
1252      C
1253      30 CONTINUE
1254      WRITE (35,150) III, III, NN
1255      WRITE (35,100) (YD (KK) ,KK=1, NN)
1256      WRITE (35,150) III, II2, NN
1257      WRITE (35,100) (F (KK) ,KK=1, NN)
1258      GO TO 40
1259      C
1260

```



```

1261      40 CONTINUE
1262      C
1263      100 FORMAT(8(1PE10.3))
1264      150 FORMAT(3I5)
1265      C
1266      RETURN
1267      END
1268      C-----
1269      C          SUBROUTINE RNDNOR
1270      C-----
1271      SUBROUTINE RNDNOR (DSEED, NR, R)
1272      C
1273      REAL          R(NR), X
1274      DOUBLE PRECISION DSEED
1275      INTEGER       NR, IER
1276      C
1277      CALL RNDFL(DSEED, NR, R)
1278      DO 5 I=1, NR
1279          X=R(I)
1280          CALL RNDRI(X, R(I), IER)
1281      5 CONTINUE
1282      RETURN
1283      END
1284      C-----
1285      C          SUBROUTINE RNDFL
1286      C-----
1287      SUBROUTINE RNDFL (DSEED, NR, R)
1288      C
1289      REAL          R(NR)
1290      INTEGER       I, NR
1291      DOUBLE PRECISION D2P31M, D2P31, DSEED
1292      DATA          D2P31M/2147483647.D0/
1293      DATA          D2P31/2147483711.D0/
1294      DO 5 I=1, NR
1295          DSEED = DMOD(16807.D0*DSEED, D2P31M)
1296      5 R(I) = DSEED / D2P31
1297      RETURN
1298      END
1299      C-----
1300      C          SUBROUTINE RNDRI
1301      C-----
1302      SUBROUTINE RNDRI (P, Y, IER)
1303      INTEGER       IER
1304      REAL          P, Y
1305      REAL          EPS, G0, G1, G2, G3, H0, H1, H2, A, W, WI, SN, SD
1306      REAL          SIGMA, SQRT2, X, XINF
1307      DATA          XINF/.3402823E+39/
1308      DATA          SQRT2/1.414214/
1309      DATA          EPS/1.192093E-07/
1310      DATA          G0/.1851159E-3/, G1/-.2028152E-2/
1311      DATA          G2/-.1498384/, G3/.1078639E-1/
1312      DATA          H0/.9952975E-1/, H1/.5211733/
1313      DATA          H2/-.6888301E-1/
1314      IER = 0
1315      IF (P .GT. 0.0 .AND. P .LT. 1.0) GO TO 5
1316      IER = 129
1317      SIGMA = SIGN(1.0, P)
1318      Y = SIGMA * XINF
1319      GO TO 9000
1320      5 IF(P.LE.EPS) GO TO 10

```

```

1321      X = 1.0 -(P + P)
1322      CALL RNDR2 (X,Y,IER)
1323      Y = -SQRT2 * Y
1324      GO TO 9005
1325      10 A = P+P
1326      W = SQRT(-ALOG(A+(A-A*A)))
1327      WI = 1./W
1328      SN = ((G3*WI+G2)*WI+G1)*WI
1329      SD = ((WI+H2)*WI+H1)*WI+H0
1330      Y = W + W*(G0+SN/SD)
1331      Y = -Y*SQRT2
1332      GO TO 9005
1333      9000 CONTINUE
1334      CALL RNDR3 (IER,'RNRD1')
1335      9005 RETURN
1336      END
1337 C-----
1338 C          SUBROUTINE RNDR2
1339 C-----
1340 C
1341      SUBROUTINE RNDR2 (P,Y,IER)
1342      REAL          P,Y
1343      INTEGER       IER
1344      REAL          A,B,X,Z,W,WI,SN,SD,F,Z2,RINFM,A1,A2,A3,B0,B1,
1345      *             B2,B3,C0,C1,C2,C3,D0,D1,D2,E0,E1,E2,E3,F0,F1,
1346      *             F2,G0,G1,G2,G3,H0,H1,H2,SIGMA
1347      DATA         A1/-.5751703/,A2/-1.896513/,A3/-.5496261E-1/
1348      DATA         B0/-.1137730/,B1/-3.293474/,B2/-2.374996/
1349      DATA         B3/-1.187515/
1350      DATA         C0/-.1146666/,C1/-.1314774/,C2/-.2368201/
1351      DATA         C3/.5073975E-1/
1352      DATA         D0/-44.27977/,D1/21.98546/,D2/-7.586103/
1353      DATA         E0/-.5668422E-1/,E1/.3937021/,E2/-.3166501/
1354      DATA         E3/.6208963E-1/
1355      DATA         F0/-6.266786/,F1/4.666263/,F2/-2.962883/
1356      DATA         G0/.1851159E-3/,G1/-.2028152E-2/
1357      DATA         G2/-.1498384/,G3/.1078639E-1/
1358      DATA         H0/.9952975E-1/,H1/.5211733/
1359      DATA         H2/-.6888301E-1/
1360      DATA         RINFM/.3402823E+39/
1361      IER = 0
1362      X = P
1363      SIGMA = SIGN(1.0,X)
1364      IF (.NOT.(X.GT.-1. .AND. X.LT.1.)) GO TO 30
1365      Z = ABS(X)
1366      IF (Z.LE. .85) GO TO 20
1367      A = 1.-Z
1368      B = Z
1369      5 W = SQRT(-ALOG(A+A*B))
1370      IF (W.LT.2.5) GO TO 15
1371      IF (W.LT.4.) GO TO 10
1372      WI = 1./W
1373      SN = ((G3*WI+G2)*WI+G1)*WI
1374      SD = ((WI+H2)*WI+H1)*WI+H0
1375      F = W + W*(G0+SN/SD)
1376      GO TO 25
1377      10 SN = ((E3*W+E2)*W+E1)*W
1378      SD = ((W+F2)*W+F1)*W+F0
1379      F = W + W*(E0+SN/SD)
1380      GO TO 25

```

```

1381      15 SN = ((C3*W+C2)*W+C1)*W
1382      SD = ((W+D2)*W+D1)*W+D0
1383      F = W + W*(C0+SN/SD)
1384      GO TO 25
1385      20 Z2 = Z*Z
1386      F = Z+Z*(B0+A1*Z2/(B1+Z2+A2/(B2+Z2+A3/(B3+Z2))))
1387      25 Y = SIGMA*F
1388      IER = 0
1389      GO TO 9005
1390      30 IER = 129
1391      Y = SIGMA * RINFM
1392      9000 CONTINUE
1393      CALL RNRD3 (IER, 'RNRD2 ')
1394      9005 RETURN
1395      END
1396      C-----
1397      C      SUBROUTINE RNRD3
1398      C-----
1399      C
1400      SUBROUTINE RNRD3 (IER, NAME)
1401      INTEGER          IER
1402      CHARACTER        NAME*(*)
1403      INTEGER          I, IEQDF, IOUNIT, LEVEL, LEVOLD, NIN, NMTB
1404      CHARACTER        IEQ, NAMEQ(6), NAMSET(6), NAMUPK(6)
1405      DATA            NAMSET/'U','E','R','S','E','T'/
1406      DATA            NAMEQ/6*' '/
1407      DATA            LEVEL/4/, IEQDF/0/, IEQ/'='/
1408      CALL RNRD5 (NAME, 6, NAMUPK, NMTB)
1409      CALL RNRD4 (1, NIN, IOUNIT)
1410      IF (IER.GT.999) GO TO 25
1411      IF (IER.LT.-32) GO TO 55
1412      IF (IER.LE.128) GO TO 5
1413      IF (LEVEL.LT.1) GO TO 30
1414      IF (IEQDF.EQ.1) WRITE (IOUNIT, 35) IER, NAMEQ, IEQ, NAMUPK
1415      IF (IEQDF.EQ.0) WRITE (IOUNIT, 35) IER, NAMUPK
1416      GO TO 30
1417      5 IF (IER.LE.64) GO TO 10
1418      IF (LEVEL.LT.2) GO TO 30
1419      IF (IEQDF.EQ.1) WRITE (IOUNIT, 40) IER, NAMEQ, IEQ, NAMUPK
1420      IF (IEQDF.EQ.0) WRITE (IOUNIT, 40) IER, NAMUPK
1421      GO TO 30
1422      10 IF (IER.LE.32) GO TO 15
1423      IF (LEVEL.LT.3) GO TO 30
1424      IF (IEQDF.EQ.1) WRITE (IOUNIT, 45) IER, NAMEQ, IEQ, NAMUPK
1425      IF (IEQDF.EQ.0) WRITE (IOUNIT, 45) IER, NAMUPK
1426      GO TO 30
1427      15 CONTINUE
1428      DO 20 I=1, 6
1429      IF (NAMUPK(I).NE.NAMSET(I)) GO TO 25
1430      20 CONTINUE
1431      LEVOLD = LEVEL
1432      LEVEL = IER
1433      IER = LEVOLD
1434      IF (LEVEL.LT.0) LEVEL = 4
1435      IF (LEVEL.GT.4) LEVEL = 4
1436      GO TO 30
1437      25 CONTINUE
1438      IF (LEVEL.LT.4) GO TO 30
1439      IF (IEQDF.EQ.1) WRITE (IOUNIT, 50) IER, NAMEQ, IEQ, NAMUPK
1440      IF (IEQDF.EQ.0) WRITE (IOUNIT, 50) IER, NAMUPK

```

```

1441      30 IEQDF = 0
1442      RETURN
1443      35 FORMAT (19H *** TERMINAL ERROR,10X,7H( IER = , I3,
1444      1      23H) IN RANDOM GENERATION , 6A1,A1, 6A1)
1445      40 FORMAT (27H *** WARNING WITH FIX ERROR,2X,7H( IER = , I3,
1446      1      23H) IN RANDOM GENERATION , 6A1,A1, 6A1)
1447      45 FORMAT (18H *** WARNING ERROR,11X,7H( IER = , I3,
1448      1      23H) IN RANDOM GENERATION , 6A1,A1, 6A1)
1449      50 FORMAT (20H *** UNDEFINED ERROR,9X,7H( IER = , I5,
1450      1      23H) IN RANDOM GENERATION , 6A1,A1, 6A1)
1451      55 IEQDF = 1
1452      DO 60 I=1, 6
1453      60 NAMEQ(I) = NAMUPK(I)
1454      65 RETURN
1455      END
1456 C-----
1457 C          SUBROUTINE RNDRA
1458 C-----
1459 C
1460      SUBROUTINE RNDRA (IOPT,NIN,NOUT)
1461      INTEGER          IOPT,NIN,NOUT,NIND,NOUTD
1462      DATA            NIND/5/,NOUTD/6/
1463      IF (IOPT.EQ.3) GO TO 10
1464      IF (IOPT.EQ.2) GO TO 5
1465      IF (IOPT.NE.1) GO TO 9005
1466      NIN = NIND
1467      NOUT = NOUTD
1468      GO TO 9005
1469      5 NIND = NIN
1470      GO TO 9005
1471      10 NOUTD = NOUT
1472      9005 RETURN
1473      END
1474 C-----
1475 C          SUBROUTINE RNDRA5
1476 C-----
1477      SUBROUTINE RNDRA5 (PACKED,NCHARS,UNPAKD,NCHMTB)
1478      INTEGER          NC,NCHARS,NCHMTB
1479      CHARACTER        UNPAKD(1),IBLANK
1480      CHARACTER*(1)    PACKED(1)
1481      DATA            IBLANK /' '/
1482      NCHMTB = 0
1483      IF(NCHARS.LE.0) RETURN
1484      NC = MIN0 (129,NCHARS)
1485      DO 5 I=1,NC
1486      UNPAKD(I) = PACKED(I)
1487      5 CONTINUE
1488      150 FORMAT (129A1)
1489      DO 200 N = 1,NC
1490      NN = NC - N + 1
1491      IF (UNPAKD(NN) .NE. IBLANK) GO TO 210
1492      200 CONTINUE
1493      NN = 0
1494      210 NCHMTB = NN
1495      RETURN
1496      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 : SINGLE-DEGREE OF FREEDOM SYSTEM WITH BILINEAR HYSTERESIS
ICOM=4 : SINGLE-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 EXCITATION
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 SDOF 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 EXCITATION 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 $ICOM=1$, PARTICIPATION 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
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(Appendix IV-2 Continued)

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