3D-BASIS-M: Nonlinear Dynamic Analysis of Multiple Building Base Isolated Structures

by

P. Tsopelas, S. Nagarajaiah, M.C. Constantinou and A.M. Reinhorn

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3D-BASIS-M:  
Nonlinear Dynamic Analysis of 
Multiple Building Base Isolated Structures

by

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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 2, Secondary and Protective Systems, and more specifically, to protective systems. Protective Systems are devices or systems which, when incorporated into a structure, help to improve the structure’s ability to withstand seismic or other environmental loads. These systems can be passive, such as base isolators or viscoelastic dampers; or active, such as active tendons or active mass dampers; or combined passive-active systems.

Passive protective systems constitute one of the important areas of research. Current research activities, as shown schematically in the figure below, include the following:

1. Compilation and evaluation of available data.
2. Development of comprehensive analytical models.
3. Development of performance criteria and standardized testing procedures.
Over the last few years, a special purpose computer program, named 3D-BASIS, has been developed for the dynamic analysis of base isolated building structures. This program was described in NCEER Reports 89-0019 and 91-0005. In this report, 3D-BASIS is extended to the case of multiple buildings with a common isolation basemat, while retaining other features of 3D-BASIS. The program is called 3D-BASIS-M and its development and verification are presented herein. Also included in this report are the User's Guide (Appendix A), Input-Output printout of a case study considered in the report (Appendix B), and the source code (Appendix C) for easy reference.
ABSTRACT

During the last few years research effort has been devoted to the development of analytical tools for the prediction of the nonlinear seismic response of base isolated structures. Two computer programs emerged out of these research efforts, both capable of analyzing base isolated structures consisting of a single building superstructure.

In cases, however, of long buildings the superstructure may consist of several buildings separated by narrow thermal joints. In these cases, neighboring bearings of adjacent superstructure parts are connected together at their tops to form a large isolation basemat. The isolated structure consists of several buildings on a common basemat with the isolation system below. This situation can not be analyzed with the existing computer programs which are capable of analyzing only a single building superstructure.

One of the aforementioned computer programs is 3D-BASIS which was developed at the State University of New York at Buffalo. An extension of this program which is capable of analyzing multiple building isolated structures has been developed and is described herein. The new program is called 3D-BASIS-M.

This report describes the development and verification of program 3D-BASIS-M. Furthermore, a case study is presented which demonstrates the usefulness of the new computer program.
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SECTION 1

INTRODUCTION

In the last few years, seismic isolation has become an accepted design technique for buildings and bridges (Kelly 1986, Kelly 1988, Buckle et al. 1990). There are two basic types of isolation systems, one typified by elastomeric bearings and the other typified by sliding bearings. Furthermore, combinations of sliding and elastomeric systems and helical steel spring-viscous damper systems have been proposed. Several applications of isolation systems in buildings and bridges have been reported (Kelly 1986, Kelly 1988, Buckle et al. 1990, Makris et al. 1991, Constantinou et al. 1991).

Most isolation systems exhibit strong nonlinear behavior. Furthermore, their force-deflection properties depend on the axial load, bilateral load and rate of loading. Under these conditions, the recently developed requirements for isolated structures (Structural Engineers Association of California 1990) require that dynamic time history analysis be performed for the isolated structure. The analysis should account for the spatial distribution of isolator units, torsion in the structure and the aforementioned force-deflection characteristics of the isolator units.

Existing general purpose nonlinear dynamic analysis programs like DRAIN-2D (Kanaan et al. 1973) and ANSR (Mondkar et al. 1975) can be used in the dynamic analysis of base-isolated structures. These programs are limited to elements exhibiting bilinear hysteretic
behavior and can not accurately model sliding bearings. Furthermore, these programs require detailed modeling which is time consuming and not necessary in the analysis of base isolated structures. Special purpose programs for the analysis of base isolated structures have been developed. Program NPAD (Way et al. 1988) has plasticity based nonlinear elements that can be used to model certain types of elastomeric bearings. Program 3D-BASIS (Nagarajaiah et al. 1989, Nagarajaiah et al. 1991) utilizes viscoplasticity based elements that can model a wide range of isolation devices, including elastomeric and sliding bearings. Both programs represent the superstructure by a condensed, three-degrees-of-freedom per floor model. They are limited to the case of a single building on the top of a rigid basemat with the isolation system below.

A situation in which the aforementioned programs can not be used is that of multiple buildings on a common isolation basemat with the isolation system below. This situation occurs in long buildings which are separated by thermal joints. When isolated, the parts of the building are built on separate isolation basements with the top of neighboring bearings of adjacent parts connected by common steel plates. This results in a complex of several buildings on a common rigid isolation basemat. This type of construction prevents impact of the adjacent parts at the isolation basemat level.

The torsional characteristics of the combined isolation systems of the various parts that form the complex are significantly different.
than those of the individual parts. The distance of corner bearings from the center of resistance of the combined system is much larger than that of individual parts when unconnected. Thus when the combined system is set into torsional motion, the corner bearings may experience inelastic deformations much earlier than when the individual parts are not connected together. Furthermore, the motion experienced by each of the various parts of the combined system is different. This coupled with the possibility of significantly different dynamic characteristics of each of the buildings above the common basemat may result in out-of-phase motion with possible impact of adjacent parts above the basemat.

To evaluate these possible effects it is necessary to analyze the complete system. Analysis of the individual parts as being unconnected from the rest may result in underestimation of the forces and displacements experienced by the system and may give insufficient information for assessing the possibility of impact of adjacent parts. The above considerations motivated the development of an extended version of computer program 3D-BASIS which is capable of analyzing multiple buildings on a common isolation basemat. The program is called 3D-BASIS-M and its development and verification is presented herein. Furthermore, the program is used in the analysis of a multiple building isolated structure and the results demonstrate the significance of the aforementioned effects and the usefulness of the computer program.
SECTION 2

OVERVIEW OF PROGRAM 3D BASIS

Program 3D-BASIS (Nagarajaiah et al. 1989, Nagarajaiah et al. 1991) was developed as a public domain special purpose program for the dynamic analysis of base isolated building structures. The basic features of program 3D-BASIS are:

1. Elastic superstructure,
2. Detailed modeling of the isolation system with spatial distribution of isolation elements,
3. Library of isolation elements which include elastomeric and sliding bearing elements with bidirectional interaction effects and rate loading effects,
4. Time domain solution algorithm for very stiff differential equations, and
5. Bidirectional excitation.

These features are maintained in the extended 3D-BASIS-M program.

2.1 Superstructure Modeling

The superstructure is assumed to be remain elastic at all times. Coupled lateral-torsional response is accounted for by maintaining three degrees of freedom per floor, that is two translational and one rotational degrees of freedom. Two options exists in modeling the superstructure:

a. Shear type representation in which the stiffness matrix of
the superstructure is internally constructed by the program. It is assumed that the centers of mass of all floors lie on a common vertical axis, floors are rigid and walls and columns are inextensible.

b. Full three dimensional representation in which the dynamic characteristics of the superstructure are determined by other computer programs (e.g. ETABS, Wilson et al. 1975) and imported to program 3D-BASIS. In this way, the extensibility of the vertical elements, arbitrary location of centers of mass and floor flexibility may be implicitly accounted for. Still, however, the model for dynamic analysis maintains three degrees of freedom per floor.

In both options, the data needed for dynamic analysis are the mass and the moment of inertia of each floor, frequencies, mode shapes and associated damping ratios for a number of modes. A minimum of three modes of vibration of the superstructure need to be considered.

2.2 Isolation System Modeling

The isolation system is modeled with spatial distribution and explicit nonlinear force-displacement characteristics of individual isolation devices. The isolation devices are considered rigid in the vertical direction and individual devices are assumed to have negligible resistance to torsion.

Program 3D-BASIS has the following elements for modeling the behavior of an isolation system:

1. Linear Elastic element.
2. Linear viscous element.

3. Hysteretic element for elastomeric bearings and steel dampers.


2.2.1 Linear Elastic Element

This element can be used to approximately simulate the behavior of elastomeric bearings along with the viscous element. All linear elastic devices of the isolation system are combined in a single element having the combined properties of the devices. These are the translational stiffnesses, $K_x$ and $K_y$ and the rotational stiffness, $K_r$, with respect to the center of mass of the base. Furthermore, eccentricities $e_x^b$ and $e_y^b$ of the center of resistance of the isolation system to the center of mass of the base need to be specified.

The forces exerted at the center of mass of the base by the linear elastic element are given by the following equations (with reference to figure 2.1)

$$F_x = K_x(u_x^b - e_y^b u_r^b) \quad (2.1)$$

$$F_y = K_y(u_y^b + e_x^b u_r^b) \quad (2.2)$$

$$T = K_r u_r^b + K_y e_x^b u_y^b - K_x e_y^b u_x^b \quad (2.3)$$

2.2.2 Linear Viscous Element

The linear viscous element is used to simulate the combined viscous properties of the isolation devices. All linear viscous devices
are combined in a single viscous element having translational damping coefficients $C_x$ and $C_y$ and rotational damping coefficient $C_r$. Furthermore, eccentricities $e_x^c$ and $e_y^c$ are defined in a manner similar to those of the linear elastic element. The forces exerted by the linear viscous element at the center of mass of the base are given by:

$$F_x = C_x(\ddot{u}_x^b - e_x^c \ddot{u}_r^b)$$  \hspace{1cm} (2.4)

$$F_y = C_y(\ddot{u}_y^b + e_y^c \ddot{u}_r^b)$$  \hspace{1cm} (2.5)

$$T = C_r \ddot{u}_r^b + C_x e_x^c \ddot{u}_y^b - C_y e_y^c \ddot{u}_x^b$$  \hspace{1cm} (2.6)

2.2.3. Biaxial Hysteretic Element for Elastomeric Bearings and Steel Dampers

The forces along the orthogonal directions which are mobilized during motion of elastomeric bearings or steel dampers are described by:

$$F_x = \alpha \frac{F^y}{Y} U_x + (1-\alpha) F^y Z_x, \hspace{1cm} F_y = \alpha \frac{F^y}{Y} U_y + (1-\alpha) F^y Z_y$$  \hspace{1cm} (2.7)

in which, $\alpha$ is the post-yielding to pre-yielding stiffness ratio, $F^y$ is the yield force and $Y$ is the yield displacement. $Z_x$ and $Z_y$ are dimensionless variables governed by the following system of differential equations which was proposed by Park et al. 1986:

$$\begin{bmatrix} \dot{Z}_x \\ \dot{Z}_y \end{bmatrix} = \begin{bmatrix} A & \dot{U}_x \\ A & \dot{U}_y \end{bmatrix} \begin{bmatrix} Z_x^2 (\gamma \text{sgn}(\dot{U}_x Z_x) + \beta) \\ Z_y^2 (\gamma \text{sgn}(\dot{U}_y Z_y) + \beta) \end{bmatrix} \begin{bmatrix} \dot{U}_x \\ \dot{U}_y \end{bmatrix}$$  \hspace{1cm} (2.8)
in which $A$, $\gamma$ and $\beta$ are dimensionless quantities that control the shape of the hysteresis loop. Furthermore, $U_a$, $J_a$, and $U_a$, $J_a$, represent the displacements and velocities that occur at the isolation element.

Constantinou et al. 1990 have shown that when motion commences and displacements exceed the yield displacement, equation 2.8 has the following solution provided that $A/(\beta+\gamma)=1$:

$$Z_x = \cos \theta, \quad Z_y = \sin \theta$$

(2.9)

where $\theta$ is the angle specifying the instantaneous direction of motion

$$\theta = \tan^{-1}(U_y/J_x)$$

(2.10)

Equations 2.7 and 2.9 indicate that the interaction curve of the element is circular. To demonstrate this, consider motion along an angle $\theta$ with respect to the $X$-axis so that $U_x=U \cos \theta$ and $U_y=U \sin \theta$. By substituting equations 2.9 into equations 2.7, it is easily shown that the resultant of mobilized forces is independent of $\theta$ and given by

$$F = (F_x^2 + F_y^2)^{1/2} = \left( (1-\alpha)^2 F_y^2 + \frac{F_y^2}{Y^2} U^2 + 2\alpha(1-\alpha)\frac{F_y^2 U}{Y} \right)^{1/2}$$

(2.11)

Equation 2.11 clearly describes a circle. At the lower limit of inelastic behavior, i.e. $U=0$, equation 2.11 reduces to $F=F'$ which demonstrates that the yield force of the element is equal to $F'$ in all directions. This desirable property is possible only when $A/(\beta+\gamma)=1$ (Constantinou et al. 1990). In particular, $A=1$ and $\beta=0.1$ and $\gamma=0.9$ are suggested.
2.2.4. Biaxial Element for Sliding Bearings

For sliding bearings, the mobilized forces are described by the equations (Constantinou et al. 1990)

\[ F_x = \mu_r NZ_x, \quad F_y = \mu_r NZ_y \]  \hspace{1cm} (2.12)

in which \( N \) is the vertical load carried by the bearing and \( \mu_r \) is the coefficient of sliding friction which depends on the bearing pressure, direction of motion as specified by angle \( \theta \) (equation 2.10) and the instantaneous velocity of sliding \( \dot{U} \)

\[ \dot{U} = (\dot{U}_x^2 + \dot{U}_y^2)^{1/2} \]  \hspace{1cm} (2.13)

The conditions of separation and reattachment and biaxial interaction are accounted for by variables \( Z_x \) and \( Z_y \) in equation 2.8.

The coefficient of sliding friction is modeled by the following equation suggested by Constantinou et al. 1990:

\[ \mu_r = f_{\text{max}} - \Delta f \exp(-a \mid \dot{U} \mid) \]  \hspace{1cm} (2.14)

in which, \( f_{\text{max}} \) is the maximum value of the coefficient of friction and \( \Delta f \) is the difference between the maximum and minimum (at \( \dot{U} = 0 \)) values of the coefficient of friction. Furthermore, \( a \) is a parameter which controls the variation of the coefficient of friction with velocity. Values of parameters \( f_{\text{max}}, \Delta f \) and \( a \) for interfaces used in sliding bearings have been reported in Constantinou et al 1990 and Mokha et al. 1991. In general, parameters \( f_{\text{max}}, \Delta f \) and \( a \) are functions of bearing pressure and angle \( \theta \), though the dependency on \( \theta \) is usually not important.
2.2.5. Uniaxial Model for Elastomeric Bearings, Steel Dampers and Sliding Bearings

The biaxial interaction achieved in the models of equations 2.7 to 2.10 and 2.12 to 2.14 may be neglected by replacing the off-diagonal elements in equation 2.8 by zeroes. This results in two uniaxial independent elements having either sliding or smooth hysteretic behavior in the two orthogonal directions.
FIGURE 2-1 Displacements and Forces at the Center of Mass of a Rigid Diaphragm.
SECTION 3

PROGRAM 3D-BASIS-M

Program 3D-BASIS-M is an extension of program 3D-BASIS for the
dynamic analysis of base isolated structures with multiple building
superstructures on a common isolation system. This section
concentrates on the development of the equations of motion of the
multiple superstructure isolated system and the method of solution.

3.1 Superstructure and Isolation System Configuration

The model used in the analysis of the system (superstructure and
isolation system) has been discussed in Section 2 when program
3D-BASIS was overviewed. The same options available in 3D-BASIS
are adopted in program 3D-BASIS-M. The basic assumptions considered
in modeling the system are:

1. Each floor has three degrees of freedom. These are the X and
   Y translations and rotation about the center of mass of each floor.
   These degrees of freedom are attached to the center of mass of each
   floor.

2. There exists a rigid slab at the level that connects all the
   isolation elements. The three degrees of freedom at the base are
   attached to the center of mass of the base.

3. Since three degrees of freedom per floor are required in the
   three-dimensional representation of the superstructure, the number
   of modes required for modal reduction is always a multiple of three.
   The minimum number of modes required is three.
The degrees of freedom of the floors and base and the configuration of a multiple building isolated structure are illustrated in Figures 3-1 and 3-2. A global reference axis is attached to the center of mass of the base (Figure 3-1). The coordinates of the center of mass of each floor of each superstructure are measured with respect to the reference axis. The center of resistance of each floor is located at distances $e_{xj}$ and $e_{yj}$ (eccentricities) with respect to the center of mass of the floor (Figure 3-2). All degrees of freedom (two translations and one rotation at each floor and base) are attached to the centers of mass as shown in Figures 3-1 and 3-2. Displacements and rotations of each floor are measured with respect to the base, whereas those of the base are measured with respect to the ground as shown in Figure 3-3.

As in program 3D-BASIS, the extended 3D-BASIS-M program has two options for the representation of the superstructure. In the first option, each superstructure is represented by a shear building representation. In this representation, the stiffness characteristics of each story of each superstructure are represented by the story translational stiffnesses, rotational stiffness and eccentricities of the story center of resistance with respect to the center of mass of the floor (see Figure 3-2). Furthermore, and only for the shear type representation, it is assumed that the centers of mass of the all floors of each superstructure lie on a common vertical axis. This common vertical axis is located at distances $X_j$ and $Y_j$ with respect to the global reference axis which
is located at the center of mass of the base (see Figures 3-1 and 3-2). Of course, the shear representation implies that the floors and the base are rigid and all vertical elements are inextensible.

In the second option, all restrictions of the shear type representation other than that of rigid floor and base are relaxed. A complete three dimensional model of each superstructure is developed externally to program 3D-BASIS-M using appropriate computer programs (e.g. ETABS, Wilson et al. 1975). The dynamic characteristics of each superstructure in terms of frequencies and mode shapes are extracted and imported to program 3D BASIS-M.

Modeling of the isolation system in program 3D-BASIS-M is identical to that in program 3D-BASIS. Spatial distribution and biaxial interaction effects are included.

3.2 Analytical Model and Equations of Motion

A multiple building base isolated structure and the coordinates (displacements) used in the basic formulation is shown in Figure 3-3. \( u_i^j \) is the relative displacement vector of the center of mass of floor \( j \) of superstructure \( i \) with respect to the base, \( u_b \) is the relative displacement vector of the center of mass of the base with respect to the ground and \( u_g \) is the ground displacement vector. Each one of the these vectors has translational \( X, Y \) components and rotation about the vertical axis.
The equations of motion of the part of the structure above the base (supertstructures) are:

\[ M_{N_b \times N_b} \dddot{\mathbf{u}}_{N_b \times 1} + C_{N_b \times N_b} \dot{\mathbf{u}}_{N_b \times 1} + K_{N_b \times N_b} \mathbf{u}_{N_b \times 1} = -M_{N_b \times N_b} R_{N_b \times 3} (\dddot{\mathbf{u}}_b + \dddot{\mathbf{u}}_g)_{3 \times 1} \]  

(3.1)

In the above equations \( \mathbf{M}, \mathbf{C} \) and \( \mathbf{K} \) are the combined mass, damping and stiffness matrices of the superstructure buildings, \( \mathbf{u} \) is the combined displacement vector relative to the base and \( \mathbf{R} \) is a transformation matrix which transfers the base (\( \dddot{\mathbf{u}}_b \)) and ground (\( \dddot{\mathbf{u}}_g \)) acceleration vectors from the center of mass of the base to the center of mass of each floor of each superstructure building. The subscripts in equation 3.1 denote the dimension of the matrices. \( N_b \) is the number of degrees of freedom in the part above the base. It is equal to the total number of degrees of freedom minus the three degrees of freedom of the base. In extended form, equations 3.1 are expressed as

\[
\begin{bmatrix}
\mathbf{m}^l & 0 & 0 & 0 & 0 \\
0 & \ddots & 0 & 0 & 0 \\
0 & 0 & \mathbf{m}^l & 0 & 0 \\
0 & 0 & 0 & \ddots & 0 \\
0 & 0 & 0 & 0 & \mathbf{m}^\alpha
\end{bmatrix}
\begin{bmatrix}
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^\alpha
\end{bmatrix}
+ 
\begin{bmatrix}
\mathbf{c}^l & 0 & 0 & 0 & 0 \\
0 & \ddots & 0 & 0 & 0 \\
0 & 0 & \mathbf{c}^l & 0 & 0 \\
0 & 0 & 0 & \ddots & 0 \\
0 & 0 & 0 & 0 & \mathbf{c}^\alpha
\end{bmatrix}
\begin{bmatrix}
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^\alpha
\end{bmatrix}
= 
\begin{bmatrix}
\mathbf{k}^l & 0 & 0 & 0 & 0 \\
0 & \ddots & 0 & 0 & 0 \\
0 & 0 & \mathbf{k}^l & 0 & 0 \\
0 & 0 & 0 & \ddots & 0 \\
0 & 0 & 0 & 0 & \mathbf{k}^\alpha
\end{bmatrix}
\begin{bmatrix}
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^l \\
\dddot{\mathbf{u}}^\alpha
\end{bmatrix}
+ 
\begin{bmatrix}
\mathbf{r}^l \\
\ddots \\
0 & 0 & \mathbf{m}^l & 0 & 0 \\
0 & 0 & 0 & \ddots & 0 \\
0 & 0 & 0 & 0 & \mathbf{m}^\alpha
\end{bmatrix}
\begin{bmatrix}
\dddot{\mathbf{u}}_b + \dddot{\mathbf{u}}_g \\
\ddots \\
\dddot{\mathbf{r}}^l \\
\ddots \\
\dddot{\mathbf{r}}^\alpha
\end{bmatrix}
\]

(3.2)
In equations 3.2, $m^i$, $c^i$, and $k^i$ and the mass, damping and stiffness matrices of superstructure (i). These matrices are of dimensions $3n_f^i$ where $n_f^i$ is the number of floors in superstructure (i). It should be noted that matrices $m^i$ are diagonal and contain the mass and mass moment of inertia of each floor. The range of index (i) varies between one and $n_s$, the number of superstructures. $u^i$ is the displacement vector of superstructure (i) relative to the base. Further, $r^i$ is the transformation matrix which transfers the base and ground acceleration vectors from the center of mass of the base to the center of mass of each floor of superstructure (i):

$$
\mathbf{r}^i = \begin{pmatrix}
R_{n_f^i} \\
.. \\
R_{j_i} \\
.. \\
R_1
\end{pmatrix}
$$

(3.3)

where

$$
\mathbf{R}_j = \begin{pmatrix}
1 & 0 & -y_j \\
0 & 1 & x_j \\
0 & 0 & 1
\end{pmatrix}
$$

(3.4)

in which $x_j$, $y_j$ are the distances to the center of mass of floor (j) of superstructure (i) from the center of mass of the base (see Figure 3-2).
The equilibrium equation of dynamic equilibrium of the base is:
\[
R_b^T M_b R_b \{\ddot{u}_b\} + R_b M_b \{\ddot{f}_b\} + M_b \{\ddot{f}_b\} = 0
\]
(3.5)

in which \(M_b\) is the mass matrix of the base, \(C_b\) is the resultant damping matrix of viscous elements of the isolation system, \(K_b\) is the resultant stiffness matrix of elastic elements of the isolation system at the center of mass of the base and \(f_{\text{ext}}\) is a vector containing the forces mobilized in the nonlinear elements of the isolation system.

Employing modal reduction:
\[
\{u^i\}_{3\eta^i \times 1} = \Phi^i_{\eta^i \times \eta^i} \{Y^i\}_{\eta^i \times 1}
\]
(3.6)

where \(\Phi^i\) is the orthonormal modal matrix relative to the mass matrix of superstructure \((i)\), \(Y^i\) is the modal displacement vector of superstructure \((i)\) relative to the base and \(\eta^i\) is the number of eigenvectors of superstructure \((i)\) retained in the analysis.

Combining equations 3.2 to 3.6, the following equation is derived
\[
\begin{pmatrix}
I & \Phi^i MR \\
R^T M \Phi & R^T M R + M_b
\end{pmatrix}
\begin{pmatrix}
\ddot{Y} \\
\ddot{\bar{u}}_b
\end{pmatrix}
+
\begin{pmatrix}
2\xi \omega & 0 \\
0 & C_b
\end{pmatrix}
\begin{pmatrix}
\dot{Y} \\
\dot{\bar{u}}_b
\end{pmatrix}
+
\begin{pmatrix}
\omega^2 & 0 \\
0 & K_b
\end{pmatrix}
\begin{pmatrix}
Y \\
\bar{u}_b
\end{pmatrix}
+
\begin{pmatrix}
0 \\
\bar{f}_{\text{ext}}
\end{pmatrix}
=
\begin{pmatrix}
\Phi^T M R \\
R^T M R + M_b
\end{pmatrix}
\begin{pmatrix}
\ddot{u}_b
\end{pmatrix}
\]
(3.7)

in which \(M_b\) is the total number of eigenvectors for all superstructures retained in the analysis, and \(\xi\) and \(\omega\) are the
matrices of modal damping and eigenvalues for all eigenvectors of all superstructures, respectively. Furthermore, I denotes an identity matrix and 0 denotes a null matrix.

Equation 3.7 may be written as:

\[
\ddot{M} \ddot{Y}_i + \dot{C} \dot{Y}_i + \dot{K} \dot{Y}_i + f_i = \ddot{F}_i 
\]  

(3.8)

in which subscript \( t \) denotes that the equation is valid at time \( t \). Extending equation 3.8 to time \( t+\Delta t \), where \( \Delta t \) is the time step, we have

\[
\ddot{M} \ddot{Y}_{i+\Delta t} + \dot{C} \dot{Y}_{i+\Delta t} + \dot{K} \dot{Y}_{i+\Delta t} + f_{i+\Delta t} = \ddot{F}_{i+\Delta t} 
\]  

(3.9)

Taking the difference between equations 3.8 and 3.9 gives the incremental equation of equilibrium

\[
\ddot{M} \Delta \ddot{Y}_{i+\Delta t} + \dot{C} \Delta \dot{Y}_{i+\Delta t} + \dot{K} \Delta \dot{Y}_{i+\Delta t} + \Delta f_{i+\Delta t} = \ddot{F}_{i+\Delta t} - \ddot{F}_{i+\Delta t} - \ddot{M} \ddot{Y}_i \dot{C} \dot{Y}_i \dot{K} \ddot{Y}_i \dot{f}_i 
\]  

(3.10)

Accordingly, the response of the multiple building superstructure and base is represented by the modal coordinate vectors \( \ddot{Y}_i \), \( \dot{Y}_i \) and \( Y_i \).

3.3 Method of Solution

The modified Newton-Raphson solution procedure with tangent stiffness representation is widely used in nonlinear dynamic analysis programs and rapidly converges to the correct solution when the nonlinearities of the system are mild. However the method fails to converge when the nonlinearities are severe (Stricklin et al.
1971, Stricklin et al. 1977). Additional studies by Nagarajaiah et al. 1989 reported the failure of this method to converge when nonlinearities stemmed from sliding isolation devices.

The pseudo-force method is used in the present study as originally adopted in the program 3D-BASIS by Nagarajaiah et al. 1989. This method has been used for nonlinear dynamic analysis of shells by Stricklin et al. 1971 and by Darbre and Wolf 1988 for soil structure interaction problems. More details and the advantages of this method in the analysis of base isolated structures have been presented by Nagarajaiah et al. 1989, 1990a, 1990b and 1991. In the pseudo-force method, the incremental nonlinear force vector $\Delta f_{\alpha}$ in equation 3.10 is unknown. It is, thus brought on the right hand side of equation 3.10 and treated as pseudo-force vector.

3.4 Solution Algorithm

The differential equations of motion are integrated in the incremental form of equations 3.10. The solution involves two stages:

(i) Solution of the equations of motion using the unconditionally stable (for both positive and negative tangent stiffness - Cheng 1988) Newmark's constant-average-acceleration method (Newmark 1959).

(ii) Solution of the differential equations governing the nonlinear behavior of the isolation elements using an unconditionally stable
semi-implicit Runge-Kutta method suitable for stiff differential equations (Rosenbrock 1964). The solution algorithm of the pseudo force method with iteration is presented in Table 3-I.

3.4.2 Varying Time Step for Accuracy

The solution algorithm has the option of using a constant time step or variable time step. The time step is reduced from $\Delta t_{\text{slip}}$ (time step at high velocity) to a fraction of its value at low velocities to maintain accuracy in sliding isolated structures. The time step is reduced based on the magnitude of the resultant velocity at the center of mass of the base:

$$\Delta t_{\text{stick}} = \Delta t_{\text{slip}} \left[ 1 - \exp\left( \frac{\dot{u}^2}{\alpha} \right) \right]$$

(3.11)

in which, $\dot{u}$ is the resultant velocity at the center of mass of the base, $\Delta t_{\text{stick}}$ is the reduced time step when the base velocity is low ($\Delta t_{\text{slip}} > \Delta t_{\text{stick}} > \Delta t_{\text{slip}}/n\ell$, $n\ell$ is an integer to introduce the desired reduction) and $\alpha$ is a constant to define the range of velocity over which the reduction takes place. It is important to note that the reduction in the time step is not continuous as indicated by equation 3.11 but rather at discrete intervals of velocity. This procedure is adopted for computational efficiency.
TABLE 3-1  SOLUTION ALGORITHM

A. Initial Conditions:
1. Form stiffness matrix $\hat{K}$, mass matrix $\hat{M}$, and damping matrix $\hat{C}$. Initialize $\hat{u}_0$, $\hat{u}_0$ and $\hat{u}_0$.
2. Select time step $\Delta t$, set parameters $\delta = 0.25$ and $\theta = 0.5$, and calculate the integration constants:
   
   $a_1 = \frac{1}{\delta(\Delta t)^3}$;  $a_2 = \frac{1}{\delta \Delta t}$;  $a_3 = \frac{1}{2 \delta}$;  $a_4 = \frac{\theta}{\delta \Delta t}$;  $a_5 = \frac{\theta}{\delta}$;  $a_6 = \Delta t(\frac{\theta}{2 \delta} - 1)$

3. Form the effective stiffness matrix $K^* = a_1 \hat{M} + a_4 \hat{C} + \hat{K}$
4. Triangularize $K^*$ using Gaussian elimination (only if the time step is different from the previous step).

B. Iteration at each time step:
1. Assume the pseudo-force $\Delta f_{i+\Delta} = 0$ in iteration $i = 1$.
2. Calculate the effective load vector at time $t + \Delta t$:
   
   $P_{i+\Delta}^* = \Delta P_{i+\Delta} - \Delta f_{i+\Delta} - \hat{M}(a_2 \hat{u}_i + a_3 \hat{\dot{u}}_i) + \hat{C}(a_4 \hat{\ddot{u}}_i + a_5 \hat{\dddot{u}}_i)$

   $\Delta P_{i+\Delta} = \hat{P}_{i+\Delta} - (\hat{M} \hat{\ddot{u}}_i + \hat{C} \hat{\dddot{u}}_i + \hat{K} \hat{\dddot{u}}_i + f_i)$

3. Solve for displacements at time $t + \Delta t$: $K^* \Delta u_{i+\Delta} = P_{i+\Delta}^*$

4. Update the state of motion at time $t + \Delta t$:
   
   $\hat{u}_{i+\Delta} = \hat{u}_i + a_1 \Delta \hat{u}_{i+\Delta} - a_2 \hat{u}_i - a_3 \hat{\dot{u}}_i$;  $\hat{u}_{i+\Delta} = \hat{u}_i + a_4 \Delta \hat{u}_{i+\Delta} - a_5 \hat{u}_i - a_6 \hat{\ddot{u}}_i$;  $\hat{u}_{i+\Delta} = \hat{u}_i + \Delta \hat{u}_{i+\Delta}$

5. Compute the state of motion at each bearing and solve for the nonlinear force at each bearing using semi-implicit Runge-Kutta method.
6. Compute the resultant nonlinear force vector at the center of mass of the base $\Delta f_{i+\Delta}^*$.
7. Compute
   
   $Error = \frac{\|\Delta f_{i+\Delta}^* - \Delta f_{i+\Delta}\|}{Ref.\ Max.\ Moment}$

   Where $\|\|$ is the euclidean norm
8. If $Error \geq$ tolerance, further iteration is needed, iterate starting form step B-1 and use $\Delta f_{i+\Delta}^*$ as the pseudo-force and the state of motion at time $t$, $\hat{u}_i$, $\hat{\dot{u}}_i$, and $\hat{\ddot{u}}_i$.
9. If $Error \leq$ tolerance, no further iteration is needed, update the nonlinear force vector:
   
   $f_{i+\Delta} = f_i + \Delta f_{i+\Delta}^*$

   reset time step if necessary, go to step B-1 if the time step is not reset or go to A-2 if the time step is reset.

3-10
FIGURE 3-1 Multiple Building Isolated Structure.
FIGURE 3-2 Degrees of Freedom and Details of a Typical Floor and Base: (a) Isometric View of Floor $j$ of Superstructure $i$; (b) Plan of Base.
FIGURE 3-3 Displacement Coordinates of Isolated Structure.
SECTION 4

NUMERICAL VERIFICATIONS

Many existing computer programs can be used to model base isolated structures when the isolation system consists of elements exhibiting bilinear behavior. Examples of these programs are DRAIN-2D (Kannan et al. 1975) and ANSR (Mondkar et al. 1975) among others. All these programs are for general purpose nonlinear analysis. They require detailed modeling which is time consuming and not necessary in the analysis of base isolated structures. Furthermore, these programs can not accurately handle special devices used in base isolation such as sliding bearings. Accordingly the tools available to verify the 3D-BASIS-M program are limited.

Extensive verifications of program 3D-BASIS has been carried out by Nagarajaiah et al. 1989, 1990b by comparison to results of DRAIN-2D, ANSR, ANSYS, GTSTRUDL and DNA-3D. Furthermore, 3D-BASIS has been verified by comparison to experimental results and to results of rigorous mathematical solutions.

In this study, verifications of the program 3D-BASIS-M are conducted by comparison to results of DRAIN-2D and ANSR. Simple structural systems are considered which meet the limitations of the previously mentioned programs and also satisfy to the maximum the needs of verifications.
First program DRAIN-2D was used to verify 3D-BASIS-M in unidirectional, uniaxial response assuming linear elastic behavior of the isolation system. Additionally, inelastic analyses were carried out assuming bilinear force displacement relationship of the isolation system. Comparisons of displacement and acceleration time histories are presented.

Further verification tests were undertaken using program ANSR with three dimensional structural systems undergoing coupled lateral and torsional response of the superstructures and having bilinear behavior at the isolation system.

4.1 Comparisons to DRAIN-2D

4.1.1 Superstructure Configuration

The structural system considered consists of two two-story identical superstructures, shown in Figure 4-1, supported by a rigid basemat. The two superstructures have equal floor dimensions \( L = 480 \) in (12192 mm), equal floor weight \( W = 240 \) Kips (1070.2 kN) and equal height between floors \( H = 180 \) in (4572 mm). The base has 960 in \( \times 480 \) in dimensions and weight \( W_b = 480 \) Kips (2140.4 kN).

The mass at the floor levels of the buildings is uniformly distributed so that the centers of mass of both floors of each building lie on the same vertical axis on which the geometric centers of each floor are located. The center of mass of the base coincides with the geometric center of the base (uniform distributed mass). The
stiffness at each level of the two superstructures is 1027.60 Kip/in (180.4 kN/mm) in each lateral direction. No eccentricities between centers of mass and centers of rigidity at each floor of the superstructures are assumed. The fixed base period of each superstructure is 0.25 secs in both principal directions. When a linear elastic isolation system is considered, no damping in the structure is taken into account whereas when the isolation system assumed to be nonlinear, viscous damping in the structure of 2% of critical in each of the superstructure modes is considered.

4.1.2 Isolation System Configuration

The isolation system consists of eight identical bearings placed directly below the eight columns of the two-part superstructure. In the case of elastic behavior of the isolation system, the total horizontal stiffness of the eight bearings is \( K = 36.8 \text{ Kip/in} \) (6.46 kN/mm). This results in a rigid body mode period of 2 secs in both orthogonal directions. Damping in the isolation system is assumed to be 2% of critical in both directions.

In the case of nonlinear behavior of the isolation system, the eight bearings have a combined force-displacement relation which is bilinear with initial stiffness of 239.2 Kip/in (41.99 kN/mm), post-yielding stiffness of 36.8 Kip/in (6.46 kN/mm) and yield strength of 85.09 Kips (379.42 kN). This amounts to 0.059 times
the total weight of the isolated system. The excitation is represented by the first 15 seconds of the 1940 El Centro earthquake (component S00E) applied in the X direction.

Figures 4-2 and 4-3 compare time histories of displacements and structure and base shear as calculated by programs 3D-BASIS-M and DRAIN-2D in the case of the linear isolation system. The calculated responses are identical.

Figures 4-4 and 4-5 compare responses calculated by the two programs in the case of the nonlinear isolation system. Small differences in the base shear and base displacement between the results of the two programs are observed. They are caused by differences in modeling bilinear behavior in the two programs (truly bilinear in DRAIN-2D versus smooth bilinear in 3D-BASIS-M). This difference is illustrated in the hysteresis loop of the isolation system which is shown in Figure 4-6.

4.2 Comparisons to ANSR

4.2.1 Superstructure Configuration

The superstructure consists of three one-story buildings placed on a rigid L-shaped isolated base. Each building has plan dimensions L X L where L= 480 in (12192 mm) and story height H= 180 in (4572 mm). The weight of each building is W= 240 Kips (1070.2 kN) and is represented by four equal concentrated masses at the four corners of the floor. The center of mass coincides with the geometric
center of the floor but the center of rigidity is offsetted from the center of mass by 0.1 L in both directions as a result of nonuniform distribution of stiffness as illustrated in Figure 4-7. The total stiffness in both lateral directions is 272.58 Kip/in (47.58 kN/mm) and the torsional stiffness at the center of mass is 31401193 Kip-in (3547682 kN-m). These properties results in the following fixed base periods of each building: \( T_1=0.335 \text{ sec} \), \( T_2=0.299 \text{ sec} \), \( T_3=0.274 \text{ sec} \). In the analysis with 3D-BASIS-M, viscous damping of 2% of critical was assumed in each vibration mode of each superstructure building. In the ANSR model, an appropriate mass proportional damping coefficient was used to simulate the damping considered in the 3D-BASIS-M model.

4.2.2 Isolation System Configuration

The isolation system is placed below the rigid L-shaped basemat and consists of twelve isolation bearings (four below each building at corners). Dimensions and the configuration of the system are shown in Figures 4-7 and 4-8. The separation (gap) between the three buildings, \( s \), was selected to be 12 in (304.8 mm). Furthermore, the weight of the L-shaped basemat was assumed to be equal to that of the three buildings (3X240=720 Kips or 3203 kN) and is represented by twelve equal concentrated masses each one at the location of each column of the buildings as showed in the Figure 4-7.

Each isolation bearing has bilinear behavior and is modeled by two nonlinear springs placed along directions X and Y as illustrated.
in Figure 4-7. Each of the bearings in building I and III has initial stiffness of 17.8 Kip/in (3.12 kN/mm), post-yielding stiffness of 2.74 Kip/in (0.48 kN/mm) and yield strength of 6.6 Kips (29.36 kN). Each of the bearings in building II has initial stiffness of 10.79 Kip/in (1.89 kN/mm), post-yielding stiffness of 1.66 Kip/in (0.29 kN/mm) and yield strength of 4 Kips (17.79 kN). The uneven distribution of stiffness results in an eccentrically placed center of rigidity (based on the initial bearing stiffnesses) with eccentricities $e_x = 50$ in (1270 mm) and $e_y = 25$ in (635 mm) as shown in Figure 4-8. These eccentricities amount to 5% and 2.5% of the plan dimensions of the complex, respectively.

It should be noted that the combined yield strength of the bearings is 0.048 times the weight of the complex and that the ratio of combined initial stiffness to combined post-yielding stiffness of the bearings is 6.5. These parameters are typical of lead-rubber bearings (Dynamic Isolation Sytems, 1983). Based on a 6 in (152.4 mm) isolation system displacement (which represents the displacement for a ground motion having characteristics of the ATC 0.4g S2 spectrum [SEAOC 1990]), the period of the isolated complex is about 2 secs (based on the effective stiffness at 6 in displacement).

For modeling the complex (isolation system and superstructure) in ANSR, three dimensional truss elements were used. The masses were considered to be concentrated at the nodes as shown in Figure 4-7. The plane rigidity of the floors was modeled using two linear truss
elements with very large area forming an X bracing. Diagonal truss
elements with an appropriate value for area were used in each face
of the buildings to simulate the lateral stiffness. Uniaxial
bilinear elements were used to model the isolators in both 3D-BASIS-M
and ANSR. In ANSR, the bilinear elements exhibited truly bilinear
behavior with sharp transition from initial to post-yielding
stiffness at yield point. In 3D-BASIS-M the transition is smooth.

Bidirectional earthquake excitation was imposed with components
S00E and S90W of the 1940 El Centro motion applied along directions
X and Y, respectively. Computed corner bearing and interstory
displacement histories by the two programs are compared in Figures
4-9 to 4-12. The responses compare well and the observed differences
are attributed to differences in the two models in describing damping
in the system and in representing bilinear behavior.
FIGURE 4-1 Multiple Building Isolated Structure used in Comparison Study to Program DRAIN-2D (1 in = 25.4 mm).
FIGURE 4-2 Displacement Response of Structure with Linear Elastic Isolation System Subjected to 1940 EL-CENTRO S00E Earthquake along the Longitudinal Direction (X); (a) Second Floor Displacement relative to Base; (b) Base Displacement (1 in = 25.4 mm).
FIGURE 4-3 (a) Structural Shear and (b) Base Shear response, of Structure with Linear Elastic Isolation System Subjected to 1940 EL-CENTRO S00E Earthquake along the Longitudinal Direction (X).

4-10
FIGURE 4-4 Displacement response of Structure with Bilinear Isolation System Subjected to 1940 EL-CENTRO S00E Earthquake along the Longitudinal Direction (X); (a) Second Floor Displacement relative to Base; (b) Base Displacement (1 in = 25.4 mm).
FIGURE 4-5 (a) Structural Shear and (b) Base Shear Response, of Structure with Bilinear Isolation System Subjected to 1940 EL-CENTRO S00E Earthquake along the Longitudinal Direction (X).

4-12
FIGURE 4-6 Force-Displacement Loop of Isolation System (1 in = 25.4 mm).
FIGURE 4-7 ANSR Model of Isolated Structure.
FIGURE 4-8 Isolation System Configuration.
FIGURE 4-9 Comparison of Bearing Displacements (Node 36) of Multiple Building Isolated Structure under Bidirectional Excitation (1 in = 25.4 mm).
FIGURE 4-10 Comparison of Interstory Displacements (Node 40 - Node 36) of Multiple Building Isolated Structure under Bidirectional Excitation (1 in = 25.4 mm).
FIGURE 4-11 Comparison of Bearing Displacements (Node 11) of Multiple Building Isolated Structure under Bidirectional Excitation (1 in = 25.4 mm).
FIGURE 4-12 Comparison of Interstory Displacements (Node 15 - Node 11) of Multiple Building Isolated Structure under Bidirectional Excitation (1 in = 25.4 mm).
SECTION 5

A CASE STUDY

The General State Hospital of Mesologgi, Greece is a new facility consisting of five buildings. Four of the buildings are to be seismically isolated and the fifth is to be constructed with a conventional fixed base. The four isolated parts sit on a common large T-shaped base with the isolation system below (Figure 5-1). Above the common base the four buildings are separated by a 0.05 m thermal gap. Two alternative isolation systems were developed for this structure, one of which consisted of lead-rubber bearings.

This study looks into the differences of the response which arise when one part (PART III) of the complex is analyzed as separate building and when is analyzed considering the interaction with the other parts of the complex.

5.1 Description of Facility

The Mesologgi hospital complex consists of four isolated 6-story buildings (parts I to IV) and one non-isolated 4-story building. The layout is shown in Figure 5-1. The four isolated parts form a T-shape in plan with dimensions of approximately 76 m X 57 m. Part III has plan dimensions 10.8 m X 29.7 m. The four isolated buildings are separated by a 0.05 m thermal gap. However, the basemats of the four buildings are connected together at the isolation system level forming a large T-shaped isolation basemat.
The buildings are to be constructed of reinforced concrete. The structural system consists of doubly reinforced slabs supported by reinforced concrete columns and beams. The lateral force resisting system consists of the slabs behaving as rigid diaphragms, concrete shear walls and infill brick shear panels. The total seismic weight of the complex including superstructure (buildings) and basemat is \( W_{\text{tot}} = 174.4 \text{ MN (39100.2 Kips)} \). The seismic weight of part III (superstructure plus basemat) is \( W_{\text{III}} = 37.6 \text{ MN (8438.3 Kips)} \).

The dynamic characteristics of each of the four superstructures of the complex are presented in Table 5-I in terms of the periods of free vibration. These periods, the corresponding mode shapes and damping ratios (assumed to be 5% of critical in each mode) represented input to program 3D-BASIS-M. The periods and mode shapes were calculated in a detailed model of each part using program ETABS (Wilson et al. 1975). In the model, the stiffening effects of brick walls were included so that the calculated fundamental period of each part was consistent with empirical values. Each of the four superstructures could remain elastic for a structural shear force (1st floor shear) of 0.23 times the seismic weight and interstory drift of 0.2% of the story height.

Lead rubber bearings are placed at 153 locations under each column and at the ends of each shear wall. Thirty two of these bearings are placed below part III. Four types of elastomeric bearings are used. Three of these types have cylindrical lead plug in the center.
and one type is without lead core. The properties of each type of bearing are presented in Table 5-II and the location of each bearing is shown in Figure 5-2 with reference to Table 5-III.

Nonlinear dynamic time history analyses of the entire complex and of part III alone were performed using program 3D-BASIS-M. The 1971 San Fernando motion (Record No. 211, component NS), was scaled so that its 5% damped spectrum was compatible with the site specific response spectrum. Figure 5-3 shows the scaled ground acceleration record and a comparison of its spectrum to the site specific response spectrum. The motion was applied in the X direction of the complex. As shown in Figure 5-2, part III is placed at considerable distance from the center of the mass of the entire complex. Its corner columns are at a distance of 34.34 m from the center of mass. For this part, the application of excitation in the X direction represents the worst loading condition. When part III is analyzed alone, its center of mass coincides with its geometric center and the corner columns are at distance of 14.85 m away of the center of mass.

A summary of the response of part III when analyzed as part of the complex and when analyzed alone is presented in Table 5-IV. The table includes the peak floor accelerations at the center of mass of each floor, the peak corner column drift ratio at all stories, the peak structural shear over superstructure weight \( (W_{ii}) \) ratio and the peak corner bearing displacements. Figures 5-4 and 5-5 present time histories of some calculated response quantities.
Bearing displacements in the two analyses are almost the same. However, floor accelerations, interstory drifts and the structural shear of part III are larger in the analysis of the entire complex than in the analysis of part III alone. The underestimation of these response quantities in the analysis of part III alone amounts to about 20% of the values calculated in the analysis of the entire complex. Such deviation is significant and demonstrates the importance of interaction between adjacent buildings supported by a common isolation system.

Next an attempt is presented to explain the observed differences in the response of the part III when analyzed alone and when analyzed as part of the complex. We note that part III has large eccentricities between the center of resistance and the center of mass of each floor. These eccentricities are primarily along the X direction, in which they assume values of more than 10% of the building's long dimension. In the Y direction, eccentricities are almost nonexistent.

When part III is analyzed alone and excitation is applied in the X direction (see Figure 5-6), the isolated part responds primarily in the X direction with insignificant motion in the Y direction. This is due to the almost zero eccentricities in the Y direction. When part III is analyzed as part of the complex and excitation is applied in X direction (see Figure 5-6), the rotation of the T-shaped common basemat introduces a sizeable motion in the Y
direction of part III. This is caused by the significant distance of the center of mass of part III from the center of mass of the common basemat which is 19.64 m (see Figure 5-6). Figure 5-7 shows the distribution with height of acceleration in the Y direction of part III. When part III is analyzed alone, this acceleration is almost zero. When part III is analyzed as part of the complex, this acceleration reaches values of about 15% of the acceleration in X direction (see also results of Table 5-IV). The acceleration that develops in the Y direction when coupled with the sizable eccentricities in that direction results in substantial rotation of the part with accordingly more floor acceleration and interstory drift.
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<td>PART IV</td>
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**TABLE 5-I** Period of Vibration of Parts of Isolated Complex.

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<th>C</th>
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<td>540 X 540</td>
<td>530 X 530</td>
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<td>220</td>
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<td>220</td>
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<td>9.53</td>
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<td>75.83</td>
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<td>YIELD DISPLACEMENT (mm)</td>
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**TABLE 5-II** Properties of Lead Rubber Bearings.
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**TABLE 5-III Location and Type of Isolation Bearings** (with reference to Table 5-II and Figure 5-2).
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**COMPLEX** : Analysis of Entire Complex.

**INDIVIDUAL** : Analysis of Part III Alone

**TABLE 5-IV Maximum Response of Part III of Mesologgi Hospital Complex.**
FIGURE 5-1 Layout of Mesologgi Hospital Complex.
FIGURE 5-3 Acceleration Record of input Motion and Response Spectrum.
FIGURE 5-4 (a) Interstory Drift Ratio History of Corner Column of Part III (above bearing No 67) and (b) Structural Shear History of Part III of Mesologgi Hospital Complex.
FIGURE 5-5 Base Displacement History of Corner Bearing of Part III (bearing No 67) of Mesologgi Hospital Complex.
FIGURE 5-7 Acceleration Response in Y Direction of Part III.
SECTION 6

CONCLUSIONS

A computer program, called 3D-BASIS-M has been developed which is capable of performing dynamic nonlinear analysis of isolated structures consisting of several building superstructures which are connected together at the isolation system level. This situation arises in long buildings which need to be separated by narrow thermal joints.

The developed computer program is an extension of program 3D-BASIS which was developed for the analysis of isolated structures consisting of a single building superstructure. The basic features of program 3D-BASIS-M are:

a. Elastic Superstructure,
b. Spatial distribution of isolation elements,
c. Nonlinear behavior of isolation devices, and
d. Solution algorithm capable of handling severe nonlinearities like those in sliding bearings.

Computer program 3D-BASIS-M was verified by comparison of its results to results obtained by general purpose analysis programs such as DRAIN-2D and ANSR. These computer programs are widely used but are restricted only to elements exhibiting bilinear hysteretic behavior. In contrast, program 3D-BASIS-M is also capable of analyzing systems with sliding elements which exhibit severe nonlinear behavior.
The usefulness of program 3D-BASIS-M has been demonstrated in a case study of an isolated hospital complex consisting of four 6-story buildings on a common isolation basemat with 153 lead-rubber isolation bearings. The seismic response of one of the four buildings of the complex was analyzed
a. As part of the complex and considering the interaction with the adjacent buildings, and
b. As individual building and neglecting the interaction with the adjacent buildings.

A comparison of the computed responses in the two models revealed that the neglect of interaction with adjacent parts could result in substantial underestimation of story shears and interstory drifts of the isolated building.
SECTION 7

REFERENCES


APPENDIX A
3D-BASIS-M PROGRAM USER'S GUIDE

A.1 INPUT FORMAT FOR 3D-BASIS-M

Input file name is 3DBASISM.DAT and the output file is 3DBASISM.OUT. Free format is used to read all input data. Earthquake records are to be given in files WAVEX.DAT and/or WAVEY.DAT. Dynamic arrays are used. Double precision is used in the program for accuracy. Common block size has been set to 100,000 and should be changed if the need arises. All values are to be input unless mentioned otherwise. No blank cards are to be input.

A.2 PROBLEM TITLE

One card
TITLE TITLE up to 80 characters

A.3 UNITS

One card
LENGTH, MASS, RTIME

LENGTH = Basic unit of length
up to 20 characters

MASS = Basic unit of mass
up to 20 characters

RTIME = Basic unit of time
up to 20 characters

A.4 CONTROL PARAMETERS

A.4.1 Control Parameters - Entire structure
One card
ISEV,NB,NP,INP

ISEV = 1 for option 1 - Data for Stiffness of the superstructures to be input.

ISEV = 2 for option 2 - Eigenvalues and eigenvectors of the superstructures (for fixed base condition) to be input.

NB = Number of superstructures on the common base.

NP = Number of bearings.
(If NP<4 then NP set = 4)

INP = Number of bearings at which output is desired.

Notes: 1. For explanation of the option 1 and the option 2 refer to section 3.1.

2. Number of bearings refers to the total number of bearings which could be a combination of linear elastic, viscous, smooth bilinear or sliding bearings.

A.4.2 Control Parameters - Superstructures

NB cards
NF(I),NE(I),I=1,NB

NF(I) = Number of floors of superstructure I excluding base.
(If NF<1 then NF set = 1)
NE(I) = Number of eigenvalues of superstructure I
to be retained in the analysis.
(If NE<3 then NE set = 3)

Notes: 1. Number of eigenvectors to be retained in the analysis should be in groups of three - the minimum being one set of three modes.

A.4.3 Control Parameters - Integration

one card
TSI, TOL, FMNORM, MAXMI, KVSTEP

TSI = Time step of integration.  
Default = TSR (refer to A.4.5)

TOL = Tolerance for the nonlinear force vector computation.  Recommended value -0.001.

FMNORM = Reference moment for convergence.

MAXMI = Maximum number of iterations within a time step.

KVSTEP = Index for time step variation.

KVSTEP = 1 for constant time step.
KVSTEP = 2 for variable time step.
Note: 1. The time step of integration cannot exceed the time step of earthquake record.

2. If MAXMI is exceeded the program is terminated with an error message.

3. Compute an estimate of FMNORM by multiplying the expected base shear by one half the maximum base dimension.

A.4.4 Control Parameters - Newmark's Method

One card
GAM,BET

GAM = Parameter which produces numerical damping within a time step.
(Recommended value = 0.5)

BET = Parameter which controls the variation of acceleration within a time step.
(Recommended value = 0.25)

A.4.5 Control Parameters - Earthquake Input

One card
INDGACC,TSR,LOK,XTH,ULF

INDGACC = 1 for a single earthquake record at an angle of incidence XTH.

INDGACC = 2 for two independent earthquake records along the X and Y axes.

TSR = Time step of earthquake record(s).
LOR = Length of earthquake record(s) (Number of data in earthquake record)

XTH = Angle of incidence of the earthquake with respect to the X axis in anticlockwise direction (for INDGACC=1).

ULF = Load factor.

Notes: 1. Two options are available for the earthquake record input:

a. INDGACC = 1 refers to a single earthquake record input at any angle of incidence XTH. Input only one earthquake record (read through a single file WAVEX.DAT). Refer to D.2 for wave input information.

b. INDGACC = 2 refers to two independent earthquake records input in the X and Y directions, e.g. El Centro N-S along the X direction and El Centros E-W along the Y direction. Input two independent earthquake records in the X and Y directions (read through two files WAVEX.DAT and WAVEY.DAT). Refer to D.2 and D.3 for wave input information.

2. The time step of earthquake record and the length of earthquake record has to be the same in both X and Y directions for INDGACC = 2.

3. Load factor is applied to the earthquake records in both the X and Y directions.
B.1 SUPERSTRUCTURE DATA

Go to B.2 for option 1 – three dimensional shear building representation of superstructure.

Go to B.3 for option 2 – full three dimensional representation of the superstructure. Eigenvalue analysis has to be done prior to the 3D-BASIS-M analysis using computer program ETABS.

Note: 1. The same type of group, B2 or B3, must be given for all superstructures (the same option, either 1 or 2, must be used for all superstructures).

2. The data must be supplied in the following sequence: B2 or B3, B4, B5, B6 and B7 for superstructure No. 1, then repeat for superstructure No. 2, etc. for a total of NB superstructures.

B.2 Shear Stiffness Data for Three Dimensional Shear Building (ISEV = 1)

B.2.1 Shear Stiffness – X Direction (Input only if ISEV = 1)

NF cards
SX(I), I=1,NF  SX(I) = Shear stiffness of story I in the X direction.

Note: 1. Shear stiffness of each story in the X direction starting from the top story to the first story. One card is used for each story.

B.2.2 Shear stiffness in the Y Direction (Input only if ISEV = 1)
NF cards
SY(I),I=1,NF   SY(I) = Shear stiffness of story I in the Y direction.

Note: 1. Shear stiffness of each story in the Y direction starting from the top story to the first story.

B.2.3 Torsional stiffness in the θ Direction
(Input only if ISEV = 1)

NF cards
ST(I),I=1,NF   ST(I) = Torsional stiffness of story I in the θ direction about the center of mass of the floor.

Note: 1. Torsional stiffness of each story in the θ direction starting from the top story to the first story.

B.2.4 Eccentricity Data – X Direction (Input only if ISEV = 1)

NF cards
EX(I),I=1,NF   EX(I) = Eccentricity of center of resistance from the center of mass of the floor I. Default = 0.0001.

B.2.5 Eccentricity Data – Y direction (Input only if ISEV = 1)

NF cards
EY(I),I=1,NF   EY(I) = Eccentricity of center of resistance from the center of mass of the floor I. Default = 0.0001.

Note: 1. The case of zero eccentricity in both the X and Y directions cannot be solved correctly by the eigensolver in the program, hence if both the eccentricities are zero, a default value of 0.0001 is used.
B.3 Eigenvalues and Eigenvectors for Fully Three Dimensional Building
\((ISEV = 2)\)

B.3.1 Eigenvalues (Input only if ISEV = 2)

NE cards
\[ W(I), I=1, NE \quad W(I) = \text{Eigenvalue of } I^{th} \text{ mode.} \]

Note: 1. Input from the first mode to the NE mode.

B.3.2 Eigenvectors (Input only if ISEV =2)

NE cards
\[ E(3*NF,I), I=1, NE \]
\[ E(3*NF,I) = \text{Eigenvector of } I^{th} \text{ mode.} \]

Note: 1. Input from the first mode to the NE mode.

B.4 Superstructure Mass Data

B.4.1 Translational Mass

NF Cards
\[ CMX(I), I=1, NF \quad CMX(I) = \text{Translational mass at floor } I. \]

Note: 1. Input from the top floor to the first floor.

B.4.2 Rotational Mass (Mass Moment of Inertia)

NF Cards
\[ CMT(I), I=1, NF \quad CMT(I) = \text{Mass moment of inertia of floor } I \]
\[ \text{about the center of mass of the floor.} \]

Note: 1. Input from the top floor to the first floor.

B.5 Superstructure Damping Data
NE Cards
DR(I), I=1, NE  DR(I) = Damping ratio corresponding to mode I.

Note:  1. Input from the first mode to the NE mode.

B.6 Distance to the Center of Mass of the Floor

NF cards
XN(I), YN(I), I=1, NF

XN(I) = Distance of the center of mass of the floor I from the center of mass of the base in the X direction.

YN(I) = Distance of the center of mass of the floor I from the center of mass of the base in the Y direction.

(If ISEV = 1 then XN(I) and YN(I) set 0)

Note:  1. Input from the top floor to the first floor.

B.7 Height of the Base and Different Floors

NF+1 cards
H(I), I=1, NF+1  H(I) = Height from the ground to the floor I.

Note:  1. Input from the top floor to the base.
C.1 ISOLATION SYSTEM DATA

C.2 Stiffness Data for Linear Elastic Isolation System

One card
SXE,SYE,STE,EXE,EYE

SXE = Resultant stiffness of linear elastic isolation system in the X direction.

SYE = Resultant stiffness of linear elastic isolation system in the Y direction.

STE = Resultant tortional stiffness of linear elastic isolation system in the \( \theta \) direction about the center of mass of the base.

EXE = Eccentricity of the center of resistance of the linear elastic isolation system in the X direction from the center of mass of the base.

EYE = Eccentricity of the center of resistance of the linear elastic isolation system in the Y direction from the center of mass of the base.

Note: 1. Data for linear elastic elements can also be input individually (refer to C.5.1).
C.3 Mass Data of the Base

One Card
CMXB,CMTB

CMXB = Mass of the base in the translational direction.

CMTB = Mass moment of inertia of the base about the center of mass of the base.

C.4 Global Damping Data

One card
CBX,CBY,CBT,ECX,ECY

CBX = Resultant global damping coefficient in the X direction.

CBY = Resultant global damping coefficient in the Y direction.

CBT = Resultant global damping coefficient in the θ direction about the center of mass of the base.

ECX = Eccentricity of the center of global damping of the isolation system in the X direction from the center of mass of the base.

ECY = Eccentricity of the center of global damping of the isolation system in the Y direction from the center of mass of the base.
Note: 1. Data for viscous elements can also be input individually (refer to C.5.2).

C.5 Isolation Element Data

The isolation element data are input in the following sequence:

1. Coordinates of isolation elements with respect to the center of mass of the base. One card containing the X and Y coordinates of each isolation element is used. The first card in the sequence corresponds to element No. 1, the second to element No. 2, etc. up to element No. NP.

2. The second set of data for the isolation elements consists of two cards for isolation element. The first card identifies the type of element and the second specifies its mechanical properties. Two cards are used for isolation element No. 1, then another two for element No. 2, etc. up to No. NP. The first of the two cards for each element always contains two integer numbers. These numbers are stored in array INELEM(NP,2) which has NP rows and two columns. The card containing these two numbers will be identified in the sequel as INELEM(K,I,J)

where K refers to the isolation element number (1 to NP), I is the first number and J is the second number. I denotes whether the element is uniaxial (unidirectional) or biaxial (bidirectional). J denotes the type of element:

I = 1 for uniaxial element in the X direction

I = 2 for uniaxial element in the Y direction

I = 3 for biaxial element
\[ J = 1 \text{ for linear elastic element} \]

\[ J = 2 \text{ for viscous element} \]

\[ J = 3 \text{ for hysteretic element for elastomeric bearings/steel dampers} \]

\[ J = 4 \text{ for hysteretic element for sliding bearings} \]

**Note:** 1. Uniaxial element refers to the element in which biaxial interaction between the forces in the X and Y directions is neglected rendering the interaction surface to be square, instead of the circular interaction surface for the biaxial case.

### C.5.1 Linear Elastic Element

One card

\[ \text{INELEM}(K,1:2) \text{ INELEM}(K,1) \text{ can be either 1,2 or 3} \]

\[ \text{INELEM}(K,2) = 1 \]

(Refer to C.5 for further details).

One card

\[ \text{PS}(K,1), \text{PS}(K,2) \]

\[ \text{PS}(K,1) = \text{Shear stiffness in the X direction for biaxial element or uniaxial element in the X direction} \]

(leave blank if the uniaxial element is in the Y direction only.

\[ \text{PS}(K,2) = \text{Shear stiffness in the Y direction for biaxial element or uniaxial} \]
element in the Y direction
(leave blank if the uniaxial element
is in the X direction only.

Note: 1. Biaxial element means elastic stiffness in both X and Y
directions (no interaction between forces in X and Y
direction).

C.5.2 Viscous Element

One card
INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 2
(Refer to C.5 for further details).

One card
PC(K,1),PC(K,2)

PC(K,1) = Damping coefficient in the X
direction for biaxial element or uniaxial
element in the X direction
(leave blank if the uniaxial element
is in the Y direction only.

PC(K,2) = Damping coefficient in the Y
direction for biaxial element or uniaxial
element in the Y direction
(leave blank if the uniaxial element
is in the X direction only.

Note: 1. Biaxial element means elastic stiffness in both X and Y
directions (no interaction between forces in X and Y
direction).
C.5.3 Hysteretic Element for Elastomeric Bearings/Steel Dampers

One card
INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 3
(Refer to C.5 for further details).

One card
ALP(K,I), YF(K,I), YD(K,I), I=1,2

ALP(K,1) = Post-to-preyielding stiffness ratio;
YF(K,1) = Yield force;
YD(K,1) = Yield displacement;
in the X direction
for biaxial element or uniaxial
element in the X direction
(leave blank if the uniaxial element
is in the Y direction only.

ALP(K,2) = Post-to-preyielding stiffness ratio;
YF(K,2) = Yield force;
YD(K,2) = Yield displacement;
in the Y direction
for biaxial element or uniaxial
element in the Y direction
(leave blank if the uniaxial element
is in the X direction only.
C.5.4 Hysteretic Element for Sliding Bearings

One card
INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 4
(Refer to C.5 for further details).

One card
(FMAX(K,I), DF(K,I), PA(K,I), YD(K,I), I=1,2), FN(K)

FMAX(K,1) = Maximum coefficient
of sliding friction;
DF(K,1) = Difference between
the maximum and minimum
coefficient of sliding friction;
PA(K,1) = Constant which controls the
transition of coefficient of sliding
friction from maximum to minimum value;
YD(K,1) = Yield displacement;
in the X direction
for biaxial element or uniaxial
element in the X direction
(leave blank if the uniaxial element
is in the Y direction only.

FMAX(K,2) = Maximum coefficient
of sliding friction;
DF(K,2) = Difference between
the maximum and minimum
coefficient of sliding friction;
PA(K,2) = Constant which controls the
transition of coefficient of sliding
friction from maximum to minimum value;
YD(K,2) = Yield displacement;
in the Y direction
for biaxial element or uniaxial
element in the Y direction
(leave blank if the uniaxial element
is in the X direction only.

FN(K) = Initial normal force at the
sliding interface.

C.6 Coordinates of Bearings

NP Cards
XP(NP),YP(NP),I=1,NP

XP(I) = X Coordinate of isolation
element I from the center of mass
of the base.

YP(I) = Y Coordinate of isolation
element I from the center of mass
of the base.
D.1 EARTHQUAKE DATA

D.2 Unidirectional Earthquake Record

File: WAVEX.DAT

LOR cards
X(I), I=1, LOR X(I) = Unidirectional acceleration component.

Note: 1. If INDGACC as specified in A.4.4 is 1, then the input will be assumed at an angle XTH specified in A.4.4. If INDGACC as specified in A.4.4 is 2, then X(LOR) is considered to be the X component of the bidirectional earthquake.

D.3 Earthquake Record in the Y Direction for the Bidirectional Earthquake

File: WAVEY.DAT (Input only if INDGACC = 2)

LOR cards
Y(I), I=1, LOR Y(I) = Acceleration component in the Y direction.
E.1 Output Data

E.2 Output Parameters

One card
LTMH,KPD,IPROF

LTMH = 1 for both the time history and peak response output.
LTMH = 0 for only peak response output.

KPD = No. of time steps before the next response quantity is output.

IPROF = 1 for accelerations-displacements profiles output.
IPROF = 0 for no accelerations-displacements profiles output.

E.3 Isolator output

INP cards
IP(I),I=1,INP

IP(I) = Bearing number of bearings I at which the force and displacement response is desired.

E.4 Interstory drift output

The following set of cards must be imported as many times as the number of superstructures NB.
One card
ICOR(I), I=1,NB

ICOR(I) = Number of column lines of
superstructure I at which the interstory drift
is desired.

ICOR(I) cards
CORDX(K),CORDY(K), K=1,ICOR(I)

CORDX(K) = X coordinate of the column line
at which the interstory drift is desired.

CORDY(K) = Y coordinate of the column line
at which the interstory drift is desired.

Note: 1. Maximum number of columns at which drift output may be
requested is limited to six for each superstructure (maximum
value for ICOR(I) is six)
2. The coordinates of the column lines are with respect to
the reference axis at the center of mass of the base.
APPENDIX B

3D-BASIS-M INPUT/OUTPUT EXAMPLE

Input and output (for option LTMH=0 -only peak response output) for the case study of section 5 are presented.

Input file was file 3DBASISM.DAT. Furthermore, file WAVEX.DAT contained the ground acceleration record. Output file was 3DBASISM.OUT.
| MESSCOLOGI HOSPITAL 153 LEAD RUBBER ISOLATORS |
| meters | tons*sec^2/sec/meters | sec |
| 2.4 | 153 | 16 |
| 6.6 |
| 6.6 |
| 6.6 |
| 6.6 |
| 0.005 10 1 200 1 |
| 0.6 0.25 |
| 0.1 0.9 |
| 1 0.025 1000 0 9.81 |
| 193.59 |
| 340.812 |
| 574.62 |
| 2255.21 |
| 2733.61 |
| 5011.075 |
| 0.0059400 -0.1169470 0.0030560 0.00052590 -0.0900270 0.00021540 |
| 0.0344570 -0.0616990 0.0012660 0.00033550 -0.0358980 0.00034420 |
| 0.0220280 -0.0133070 -0.0002110 0.0008180 -0.0503770 -0.0005910 |
| -0.1020630 -0.0045800 0.0036720 -0.0832190 -0.025260 0.0029060 |
| -0.0597160 -0.0005760 0.0020700 -0.0483690 0.0008070 0.0012510 |
| -0.0284400 0.0015950 0.0005060 -0.0134670 0.0006270 0.0002090 |
| 0.0209000 0.0118200 0.0163630 0.0184390 0.0140890 0.0132730 |
| 0.0150020 0.0151130 0.0098600 0.00107110 0.0152290 0.0051400 |
| 0.0077300 0.0127030 0.0027690 0.0003760 0.0058720 0.0016620 |
| -0.0269810 0.0053310 -0.0001310 -0.00025530 -0.00021180 |
| 0.0364950 0.0023900 0.0011050 -0.0953630 0.0018520 |
| 0.0102320 -0.0555710 -0.0003560 0.00054310 -0.0275380 -0.0002530 |
| 0.0378400 0.0102410 -0.0013280 0.0228490 -0.0015030 0.0003040 |
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| -0.0759720 -0.0041250 0.0010390 -0.0428490 -0.00022080 0.0004800 |
| 0.0080520 -0.0006750 0.0130530 0.0053480 0.0133640 0.0010460 |
| -0.0024000 0.0135210 -0.0096130 -0.0095550 -0.0050210 -0.0136230 |
| -0.0112180 -0.0327510 -0.0088540 -0.0073750 -0.0204980 -0.0047870 |
| 33.737 | 33.737 | 33.737 | 33.123 | 39.652 | 34.594 |
| 1476.889 | 1476.889 | 1476.889 | 1476.889 | 1625.117 | 1735.886 | 1514.442 |
| 0.05 0.05 0.05 0.05 0.05 0.05 |
| 39.09 2.31 |
| 39.09 2.31 |
| 39.09 2.31 |
| 39.09 2.31 |
| 39.09 2.31 |
| 21.3 18.1 14.9 11.7 7.9 4.7 1 |
| 219.35 |
| 569.81 |
| 1447.225 |
| 4358.06 |
| 8789.97 |
| 10307.88 |
| 0.0022470 -0.0786390 0.0023540 0.0017130 -0.0618930 0.0019890 |
| 0.0010660 -0.0450550 0.0015400 0.0007120 -0.0297010 0.0010310 |
| 0.0003850 -0.0139630 0.0005870 0.0000420 -0.0047610 0.0002050 |
| 0.0013700 0.0349520 0.0065920 0.0010590 0.0249580 0.0051310 |

**CONTROL PARAMETERS - STRUCTURE**

**CONTROL PARAMETERS - INTEGRATION**

**DATA FOR NEWMARK'S METHOD**

**DATA IN HYSTERETIC MODEL (ALWAYS THE SAME)**

**CONTROL PARAMETERS - E'QUAKE INPUT**

**EIGENVALUES (\( \omega^2 \) in rad/sec)**

**1st MODE**

**MODE SHAPES STARTING FROM 1st AND ENTERED IN ROW FORMAT**

**DATA FOR SUPERSTRUCTURE**

**NO. 1 (OPTION 2)**

**MASSES**

**MASS MOMENT OF INERTIA**

**DAMPING RATIOS**

**ECCENTRICITIES**

**HEIGHTS**
### DATA FOR SUPERSTRUCTURE

#### No. 2 (OPTION 2)

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| 102.4 | 1.66 |
| 10.24 | 1.66 |
| 10.24 | 1.66 |
| 9.99 | 1.61 |
| 9.99 | 1.61 |
| 9.99 | 2.14 |

#### DATA FOR SUPERSTRUCTURE

#### No. 3 (OPTION 2)

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**TYPE AND MECHANICAL PROPERTIES OF ISOLATION ELEMENTS**
OUTPUT PARAMETERS
ISOLATOR OUTPUT

SUPERSTRUCTURE No.1

SUPERSTRUCTURE No.2

INTERSTORY DRIFT OUT'PUT

2 COLUMN LINES
COORDINATES OF 2 COLUMN LINES
PROGRAM 3D-BASIS-M....... A GENERAL PROGRAM FOR THE NONLINEAR
DYNAMIC ANALYSIS OF THREE DIMENSIONAL BASE ISOLATED
MULTIPLE BUILDING STRUCTURES

DEVELOPED BY...P. C. TSOPelas, S. NAGARAJAIAH,
M. C. CONSTANTINOU AND A. M. REINHORN
DEPARTMENT OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

VAX VERSION, APRIL 1991

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
STATE UNIVERSITY OF NEW YORK, BUFFALO

MESSEOLOGI HOSPITAL 153 LEAD RUBBER ISOLATORS

UNITS
LENGTH : meters tons*s
MASS : ec*sec/meters s
TIME : ec

*************INPUT DATA*************

************* CONTROL PARAMETERS *************

NO. OF BUILDINGS = 4
NO. OF ISOLATORS = 153
INDEX FOR SUPERSTRUCTURE STIFFNESS DATA = 2
INDEX = 1 FOR 3D SHEAR BUILDING REPRES.
INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED...= 16

TIME STEP OF INTEGRATION (NEWMARK).......= 0.00500
INDEX FOR TYPE OF TIME STEP..............= 1

INDEX = 1 FOR CONSTANT TIME STEP
INDEX = 2 FOR VARIABLE TIME STEP

GAMA FOR NEWMARKS METHOD..................= 0.50000
BETA FOR NEWMARKS METHOD..................= 0.25000
TOLERANCE FOR FORCE COMPUTATION..........= 10.00000
REFERENCE MOMENT OF CONVERGENCE.........= 1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S. ...= 200
BETA FOR WENS MODEL......................= 0.10000
GAMA FOR WENS MODEL.......................= 0.90000

INDEX FOR GROUND MOTION INPUT............= 1

INDEX = 1 FOR UNIDIRECTIONAL INPUT
INDEX = 2 FOR BIDIRECTIONAL INPUT

TIME STEP OF RECORD.......................= 0.02500
LENGTH OF RECORD..........................= 1000
LOAD FACTOR................................= 9.81000
ANGLE OF EARTHQUAKE INCIDENCE............= 0.00000

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......STIFFNESS DATA........

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4  14.900
3  11.700
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SUPERSTRUCTURE : 2

....STIFFNESS DATA....

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SUPERSTRUCTURE : 3

......STIFFNESS DATA.......

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STIFFNESS DATA

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STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. = 0.00000
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ECCENT. IN Y DIR. FROM CEN. OF MASS.......= 0.00000
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TIME HISTORY OPTION .........................= 0
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INDEX = 1 FOR TIME HISTORY OUTPUT

NO. OF TIME STEPS AT WHICH TIME HISTORY OUTPUT IS DESIRED .......................= 5
ACCELERATION-DISPLACEMENTS PROFILES OPTION..= 1
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***************FORCE PROFILES***************

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**FORCE AT C.M. OF ENTIRE BASE**

**MAX OVERTURNING MOMENT Y DIRECTION**

**MAX STRUCTURAL SHEAR Y DIRECTION**
SUPR/STURE  TIME  OVERTURNING MOMENT  TIME  MAX STRUCTURAL SHEAR
1  9.135  1002.1089  9.130  61.2199

FLOOR  INERTIA  FORCES  INERTIA  FORCES
6  21.9919  21.8895  11.6598
5  17.1035  16.9263  7.4672
4  11.8541  11.6598  2.6573
3  7.5518  7.4672  0.6198
2  2.4149  2.6573  -4.0976  FORCE AT C.M. OF ENTIRE BASE
1  0.2606  0.6198
BASE  -4.9300  -4.0976

SUPR/STURE  TIME  OVERTURNING MOMENT  TIME  MAX STRUCTURAL SHEAR
2  11.625  -664.7666  11.020  42.3123

FLOOR  INERTIA  FORCES  INERTIA  FORCES
6  14.6984  11.3954  11.3954
5  -14.3086  11.9918
4  -8.6881  8.9234
3  -3.4055  6.0344
2  2.4655  2.8588
1  4.9944  1.1085
BASE  33.9000  -1.4948  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME  OVERTURNING MOMENT  TIME  MAX STRUCTURAL SHEAR
3  12.600  933.9941  12.605  63.5190

FLOOR  INERTIA  FORCES  INERTIA  FORCES
5  19.4589  19.3882
4  11.3364  11.3584
3  9.6147  9.6775
2  5.3969  5.5112
1  3.1645  3.2889
BASE  3.8913  3.0973  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME  OVERTURNING MOMENT  TIME  MAX STRUCTURAL SHEAR
4  9.310  1242.3959  9.310  84.2086

FLOOR  INERTIA  FORCES  INERTIA  FORCES
6  22.5868  22.5868
5  18.8328  18.8328
4  16.8195  16.8195
3  15.4860  15.4860
2  7.3633  7.3633
1  3.1202  3.1202
BASE  8.2407  8.2407  FORCE AT C.M. OF ENTIRE BASE
MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
(WITH RESPECT TO THE BASE)

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MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE

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<th>TIME</th>
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### Maximum Interstory Drift Ratios for Each Superstructure

**Superstructure: 1**

**Coordinates of Column Lines with Respect to Mass Center of Base**

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**Column Lines**

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<th>Y Dir Time</th>
<th>Y Dir Time</th>
<th>X Dir Time</th>
<th>Y Dir Time</th>
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**Superstructure: 2**

**Coordinates of Column Lines with Respect to Mass Center of Base**

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**Column Lines**

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<th>Time</th>
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<th>Time</th>
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<th>Time</th>
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<th>Y Direct</th>
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### MAX. ACCELERATIONS AT CENTER OF MASS OF BASE

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5  14.310   -2.675E+03  11.630  -2.912E+02  11.140  -4.291E+03
4  14.310   -4.208E+03  11.625  -3.770E+02  11.135  -5.893E+03
3  14.315   -5.804E+03  11.625  -4.110E+02  11.135  -6.965E+03
2  14.320   -7.425E+03  11.025  0.4142E+02  11.130  -7.468E+03
1  14.325   -8.832E+03  11.020  0.4231E+02  11.125  -7.654E+03

SUPERSTRUCTURE :  3
LEVEL TIME FORCE X TIME FORCE Y TIME Z MOMENT
6  14.430   -9.191E+02  12.600  0.1438E+02  14.625  -2.020E+03
5  14.420   -2.218E+03  12.600  0.3384E+02  14.625  -4.516E+03
4  14.395   -3.318E+03  12.600  0.4517E+02  14.625  -6.117E+03
3  14.390   -4.541E+03  12.600  0.5479E+02  14.630  -7.400E+03
2  14.385   -5.641E+03  12.605  0.6023E+02  14.630  -8.007E+03
1  14.380   -6.635E+03  12.605  0.6352E+02  14.635  -8.229E+03

SUPERSTRUCTURE :  4
LEVEL TIME FORCE X TIME FORCE Y TIME Z MOMENT
6  14.435   -1.283E+03  11.055  -2.384E+02  10.665  0.1413E+03
5  14.430   -2.401E+03  11.055  -4.245E+02  10.665  0.2610E+03
4  14.425   -3.585E+03  9.305  0.5828E+02  10.665  0.3780E+03
3  14.405   -5.071E+03  9.305  0.7376E+02  10.670  0.5144E+03
2  14.395   -6.422E+03  9.310  0.8109E+02  10.670  0.5871E+03
1  14.385   -7.793E+03  9.310  0.8421E+02  10.670  0.6221E+03

PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX BASE DISPLACEMENTS

MAXIMUM BASE DISPLACEMENT IN X DIRECTION
TIME : 14.375

SUPERSTRUCTURE :  1
LEVEL DISP ACCEL DISP ACCEL
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5  0.0061  -1.8832  -0.0008  0.0736
4  0.0051  -1.9090  -0.0006  0.0857
3  0.0038  -1.9360  -0.0004  0.0901
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**MAXIMUM BASE DISPLACEMENT IN Y DIRECTION**

**TIME : 12.155**

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### Profiles of Total Acceleration and Displacement at Time of Max Acceleration in Each Building

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**Max Acceleration:**

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**Max Acceleration in X Direction**

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**MAX ACCELERATION IN Y DIRECTION**

**TIME : 9.340**

**SUPERSTRUCTURE : 2**

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**MAX ACCELERATION IN X DIRECTION**

**TIME : 14.310**

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### Max Acceleration in Y Direction

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TIME : 14.325

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MAX STRUC SHEAR IN Y DIRECTION
TIME : 11.020

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SUPERSTRUCTURE : 3

MAX STRUC SHEAR IN X DIRECTION
TIME : 14.380

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TIME : 12.605

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**MAX STRUC SHEAR IN X DIRECTION**

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**MAX STRUC SHEAR IN Y DIRECTION**

**TIME:** 9.310

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### PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX BASE SHEARS

#### MAXIMUM BASE SHEAR IN X DIRECTION

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**Superstructure: 4**

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**Maximum Base Shear in Y Direction**

**Time:** 11.635

**Superstructure: 1**

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**SUPERSTRUCTURE : 3**

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**SUPERSTRUCTURE : 4**

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PROGRAM MULTIPLE3DBASIS

******************************************************************************

PROGRAM 3D-BASIS-M..... A GENERAL PROGRAM FOR THE NONLINEAR
DYNAMIC ANALYSIS OF THREE DIMENSIONAL BASE ISOLATED
MULTIPLE BUILDING STRUCTURES

DEVELOPED BY......P. C. TSOPELAS, S. NAGARAJAIAH,
M. C. CONSTANTINOU AND A. M. REINHORN
DEPARTMENT OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO
VAX VERSION, APRIL 1991

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH, BUFFALO
STATE UNIVERSITY OF NEW YORK, BUFFALO

******************************************************************************

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******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)

CHARACTER *80 BBASE
CHARACTER *20 LENGTH,MASS,RTIME
CHARACTER *4 ILS(10)

COMMON /STEP /TSI,TSR
COMMON /GENBASE /ISET,LOR
COMMON /PRINT /TMH,TPDF,KPD,KPF,INP
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MX
COMMON /GENERAL1/A(100000)
COMMON /GENERAL2/IA(100000)

OPEN (UNIT=5,FILE='3DBASISM.DAT',STATUS='UNKNOWN')
OPEN (UNIT=7,FILE='3DBASISM.OUT',STATUS='NEW')
OPEN (UNIT=8,STATUS='SCRATCH',FORM='UNFORMATTED')
OPEN (UNIT=9,STATUS='SCRATCH',FORM='UNFORMATTED')
OPEN (UNIT=10,STATUS='SCRATCH',FORM='UNFORMATTED')
OPEN (UNIT=13,STATUS='SCRATCH',FORM='UNFORMATTED')
OPEN (UNIT=14,STATUS='SCRATCH',FORM='UNFORMATTED')
OPEN (UNIT=16,FILE='WAVEY.DAT',STATUS='UNKNOWN')
OPEN (UNIT=17,STATUS='SCRATCH',FORM='UNFORMATTED')
REWIND 5
REWIND 7
REWIND 8
REWIND 9
REWIND 10
C-3

0073 REWIND 13
0074 REWIND 14
0075 REWIND 15
0076 REWIND 16
0077 REWIND 17
0078 C
0079 C
0080 MA = 100000
0081 MA1 = 10000
0082 C
0083 C
0084 READ(5,1000) BBASE
0085 READ(5,('(3A20)')) LENGTH,MASS,RTIME
0086 READ(5,*) ISEV,NB,INP,INP
0087 C
0088 WRITE(7,3000)
0089 WRITE(7,)(((/6X,A80//))') BBASE
0090 WRITE(7,2001) LENGTH,MASS,RTIME
0091 C
0092 K1=1
0093 K2=K1+NB
0094 K3=K2+NB
0095 C
0096 CALL READ1 ( IA(1) , IA(K2) )
0097 L 1=1
0098 L 2=L 1 + MNE
0100 L 3=L 2 + NFE
0101 L 4=L 3 + MNF
0102 L 5=L 4 + MNF
0103 L 6=L 5 + (MNF+NB)
0104 L 7=L 6 + NP*2
0105 L 8=L 7 + NP*2
0106 L 9=L 8 + NP*2
0107 L10=L 9 + NP*2
0108 L11=L10 + NP*2
0109 L12=L11 + NP*2
0110 L13=L12 + NP*2
0111 L14=L13 + NP*2
0112 L15=L14 + NP
0113 L16=L15 + NP
0114 L17=L16 + NP
0115 L18=L17 + NB*6
0116 L19=L18 + NB*6
0117 L20=L19 + LGR
0118 C
0119 L21=L20 + LDR
0120 C
0121 L22=L21 + (MNE+3)*(MNE+3)
0122 L23=L22 + (3*MNF+3)*(3*MNF+3)
0123 I 24=I 23 + (MNF+3)*(MNF+3)
0124 L25=L24 + MXF
0125 L26=L25 + MXF
0126 L27=L26 + MXF
0127 L28=L27 + 3*MXF
0128 L29=L28 + (3*MXF)*(3*MXF)
0129 L30=L29 + 3*MXF
0130 L31=L30 + (3*MXF)*(3*MXF)
0131 L32=L31 + MXF
0132 L33=L32 + MXF
0133 L34=L33 + MXF
0134 L35=L34 + MXF
0135 L36=L35 + MXF
0136 C
0137 C
0138 K 1=1
0139 K 4=K 3 + NP*2
0140 K 5=K 4 + INP
0141 K 6=K 5 + NB
0142 C
0143 C
0144 C
CALL CHECK(K 6, MA1, 1)
C
C-----INITIALIZE CM, C MATRICES-----
C
N1=(3*MNF+3)*(3*MNF+3)
DD 80 J=1,N1
A(L22+J)=0.0
80 CONTINUE
N1=(MNE+3)*(MNE+3)
DD 90 J=N1
A(L23+J)=0.0
90 CONTINUE
WRITE (7,500)
N1=0
N2=0
DD 100 I=1,NB
NF1=IA(I)
NE1=IA(K2-1+I)
CALL READ2
ANL3,A( L 4),A( L 5)
+ ,A( L 6),A( L 7),A( L 8),A( L 9),A( L 10)
+ ,A( L 11),A( L 12),A( L 13),A( L 14),A( L 15)
+ ,A( L 16),A( L 17),A( L 18),A( L 19),A( L 20)
+ ,A( L 24),A( L 25)
+ ,A( L 26),A( L 27),A( L 28),A( L 29)
+ ,A( L 31),A( L 32),A( L 33),A( L 34),A( L 35)
+ ,IA(K 3),IA(K 4),IA(K 5)
+ ,NF1,NE1,1
IF(I$EVE.EQ.1)THEN
L37=L36+(MXF)*(MXF)
L38=L37+(MXF)*(MXF)
L39=L38+(MXF)*(MXF)
L40=L39+(MXF)*(MXF)
L41=L40+(MXF)*(MXF)
CALL STIFF1
+ (A(L30)
+ ,A(L31),A(L32),A(L33),A(L34),A(L35)
+ ,A(L36),A(L37),A(L38),A(L39),A(L40)
+ ,NF1,1)
L32=L31+(3*MXF)*(3*MXF)
CALL MASSA
+ (A(L22),A(L24),A(L26)
+ ,A(L26)
+ ,A(L31)
+ ,NF1,1)
CALL JACOBI(A(L30),A(L31),A(L28),A(L27),3*NF1,7,30,3*MXF)
ELSE IF(I$EVE.EQ.2)THEN
CALL MASSB
+ (A(L22),A(L24),A(L25)
+ ,A(L26)
+ ,NF1,1)
END IF
STORE EIGEN-VECTORS - VALUES IN ONE DIMENS ARRAY
N1=N1+NE1
N2=N2+3*NF1*NE1
CALL STORE (A(L1), A(L2), A(L27), A(L28), NE1, N1, NF1, N2)
CALL DAMP
+(A(L7), A(L15), A(L16)
* A(L23), A(L27), A(L29)
+ IA(K3)
+ NE1.I)

100 CONTINUE
C
IF(LTMH.EQ.1) THEN
DO 150 I=1, NB
ISK=50+I
ISK=1000+I
WRITE(ISK(I), ’(I4)’) ISK
OPEN(UNIT=ISK, FILE=ISK(I), STATUS=’NEW’)
ENDIF
WRITE(ISK, 1001) I
CONTINUE
150 CONTINUE
C
END
C
L25=L24+(MNE+3)*(MNE+3)
L26=L25+(MNE+3)*(MNE+3)
L27=L26+(3*MNF+3)*3
L28=L27+(3*MNF+3)*(MNE+3)
L29=L28+(MNE+3)
L30=L29+(MNE+3)
L31=L30+(MNE+3)
L32=L31+(MNE+3)
L33=L32+(MNE+3)*2
L34=L33+(MNE+3)
L35=L34+(MNE+3)
L36=L35+(MNE+3)
L37=L36+(MNE+3)
L38=L37+(MNE+3)
L39=L38+(MNE+3)
L40=L39+(3*MNF+3)
L41=L40+NP
L42=L41+NP
L43=L42+NP
L44=L43+NP
L45=L44+NP
L46=L45+NP
L47=L46+NP
L48=L47+NP
L49=L48+NP
L50=L49+NP
L51=L60+NP
L52=L51+NP
L53=L52+NP
L54=L53+(MNE+3)*(3*MNF+3)
L55=L54+(3*MNF+3)*1
L56=L55+(MNE+3)*(3*MNF+3)
L57=L56+(MNE+3)*3
L58=L57+(3*MNF+3)
L59=L58+(3*MNF+3)
L60=L59+(3*MNF+3)
L61=L60+(3*MNF+3)
L62=L61+MNF*3
L63=L62+MNF*3
L64=L63+NB*3
L65=L64+NB*3
L66=L65+NB*3
L67=L66+2*NB*2
L68=L67+2*(3*MNF+3)*5
L69=L68+2*(3*MNF+3)*5
L70=L69+2*NB*2

C-5
L71=L70 + NB*3*2
L72=L71 + NB*3*2
L73=L72 + NB*3*2
L74=L73 + NB*3*2
L75=L74 + (NB*MXF*6)*6
L76=L75 + INP
L77=L76 + INP
L78=L77 + INP
L79=L78 + INP
L80=L79 + INP
L81=L80 + INP
L82=L81 + NB*2
L83=L82 + NB*2
L84=L83 + MNF+NB
L85=L84 + MNF+NB
L86=L85 + NB
L87=L86 + NB

CALL CHECK(L87,MA,2)

CALL SOLUTION

+( A(L 1),A(L 2),A(L 3),A(L 4),A(L 5)
+ A(L 6),A(L 7),A(L 8),A(L 9),A(L10)
+ A(L11),A(L12),A(L13),A(L14),A(L15)
+ A(L16),A(L17),A(L18),A(L19),A(L20)
+ A(L21),A(L22),A(L23),A(L24),A(L25)
+ A(L26),A(L27),A(L28),A(L29),A(L30)
+ A(L31),A(L32),A(L33),A(L34),A(L35)
+ A(L36),A(L37),A(L38),A(L39),A(L40)
+ A(L41),A(L42),A(L43),A(L44),A(L45)
+ A(L46),A(L47),A(L48),A(L49),A(L50)
+ A(L51),A(L52),A(L53),A(L54),A(L55)
+ A(L56),A(L57),A(L58),A(L59),A(L60)
+ A(L61),A(L62),A(L63),A(L64),A(L65)
+ A(L66),A(L67),A(L68),A(L69),A(L70)
+ A(L71),A(L72),A(L73),A(L74),A(L75)
+ A(L76),A(L77),A(L78),A(L79),A(L80)
+ A(L81),A(L82),A(L83),A(L84),A(L85)
+ A(L86)
+ ,IA( 1),IA(K 2),IA(K 3),IA(K 4),IA(K 5))

CLOSE (UNIT=5)
CLOSE (UNIT=7)
CLOSE (UNIT=8,STATUS=’DELETE’)
CLOSE (UNIT=9,STATUS=’DELETE’)
CLOSE (UNIT=10,STATUS=’DELETE’)
CLOSE (UNIT=14,STATUS=’DELETE’)
CLOSE (UNIT=15)
CLOSE (UNIT=16)

STOP

500 FORMAT(////6X,’*************** SUPERSTRUCTURE DATA **************’)
1000 FORMAT (A80)
1001 FORMAT (////6X,’SUPERSTRUCTURE : ’,I2,///
+ 2X,’TIME’ ,1X,’LEVEL’ ,3X,’ACCEL X’ ,3X,’ACCEL Y’,
+ 3X,’DISPL X’ ,3X,’DISPL Y’ ,3X,’ROTATION’) 2001 FORMAT (////6X,’UNITS’/
+ 6X,’LENGTH’ : ’,1X,A20/
+ 6X,’MASS’ : ’,1X,A20/
+ 6X,’TIME’ : ’,1X,A20/
3000 FORMAT (////6X,’********************************************
+ ’/’/6X,’********************************************’/6X,
+ ’/’/6X,
+ ’/’/6X)
C************************************************************** CHECK **********

SUBROUTINE CHECK(I,MAXA,M)

C***************************************************************
C SUBROUTINE FOR CHECKING THE USAGE OF MASTER ARRAY.
C DEVELOPED BY.-------------------------SATISH NAGARAJAIAH......OCT 1990
C MODIFIED BY.--------------------------PANAGIOTIS TSOPELAS....APR 1991

IMPLICIT REAL*B(A-H,O-Z)

IF(I.LT.MAXA)THEN
   IF (M.EQ.1) WRITE(*,110)I
   IF (M.EQ.2) WRITE(*,100)I
   ELSE
      IF (M.EQ.1) WRITE(*,210)MAXA
      IF (M.EQ.2) WRITE(*,200)MAXA
   END IF
   RETURN
110  FORMAT (/6X,'POINTER WITHIN MASTER ARRAY " IA "',
   + 2X,'MAX STORAGE',I10)
100  FORMAT (/6X,'POINTER WITHIN MASTER ARRAY " A "',
   + 2X,'MAX STORAGE',I10)
210  FORMAT (/6X,'POINTER OUT OF BOUNDS OF MASTER ARRAY " IA ",
   + 12X,'MAX STORAGE REQUIRED',I10)
200  FORMAT (/6X,'POINTER OUT OF BOUNDS OF MASTER ARRAY " A ",
   + 12X,'MAX STORAGE REQUIRED',I10)

C************************************************************** STORE **********

SUBROUTINE STORE (W1,E1,W,E,M1,M2,N1,N2)

IMPLICIT REAL*B(A-H,O-Z)
COMMON /MAIN/ NB,NP,MNF,MNE,NFE,MXF
DIMENSION W1(MNE),E1(NFE)
DIMENSION W(3*MXF),E(3*MXF,3*MXF)

C DD 110 J=1,M1
DD 120 K=1,M1
W1(N1-M1+J)=W(J)
CONTINUE

C-7
C*******************************************************************************
  subroutine read2
*******************************************************************************
C*******************************************************************************
  C Subroutine to read the input data.
  C Developed by: Satish Nagarajaiah, Oct 1990
  C Modified by: Panagioutis Tsopelas, Apr 1991
C*******************************************************************************
C*******************************************************************************
         !!!!!!!!!!!!! BE AWARE !!!!!!!!!!!!!
C*******************************************************************************
C*******************************************************************************
                 DO NOT USE 'I' AS INDEX IN THIS SUBROUTINE
C*******************************************************************************
C*******************************************************************************
 implicit real*(a-h,o-z)
C*******************************************************************************
 common /main /nbl, np, mnl, nfe, mxf
C*******************************************************************************
 common /step /tsi, tsr
C*******************************************************************************
 common /genbase /isev, lnr
C*******************************************************************************
 common /stoff /sx, sy, st, ex, ey
C*******************************************************************************
 common /mass /cmx, cmy, cmyb, cmrb
C*******************************************************************************
 common /damp /cbx, cby, cbs, cex, cey
C*******************************************************************************
 common /int /pnewdr, beta, gam, tol
C*******************************************************************************
 common /load /xth, idat, time, ptrs, ulf, indgacc
C*******************************************************************************
 common /print /ltmh, iprof, kpd, kpf, inp
C*******************************************************************************
 common /direc /drin(3), drin(4)
C*******************************************************************************
 character*1 drin
C*******************************************************************************
 character*2 drin1
C*******************************************************************************
 dimension alp(np,2), yf(np,2), yd(np,2), dfm(np,2)
C*******************************************************************************
 +, df(np,2), fa(np,2), fn(np), xp(np), yp(np)
C*******************************************************************************
 +, sx(mxf), sy(mxf), st(mxf), ex(mxf), ey(mxf)
C*******************************************************************************
 +, w(3*mxf), e(3*mxf), inel(np,2)
C*******************************************************************************
 +, cmx(mxf), cmy(mxf), cmrb(mxf), xn(mnl), y(mnl), h(mfn+nbl)
C*******************************************************************************
 +, dr(3*mxf), pc(np,2), ps(np,2), x(lor), y(lor), ip(inp)
C*******************************************************************************
 dimension icor(nbl), cordx(nbl,6), coryd(nbl,6)
C*******************************************************************************
 pi=4.0*datan(1.0)
C*******************************************************************************
 drin(1)= 'X'
C*******************************************************************************
 drin(2)= 'Y'
C*******************************************************************************
 drin(3)= 'R'
C*******************************************************************************
 drin1(1)= 'Dx'
C*******************************************************************************
 drin1(2)= 'Dy'
C*******************************************************************************
 drin1(3)= 'Fx'
C*******************************************************************************
 drin1(4)= 'Fy'
C*******************************************************************************
 do k=1, 3*mxf
C*******************************************************************************
 do j=1, 3*mxf
C*******************************************************************************

C-9
C-------ISEV=1
C--------STIFFNESS DATA FOR 3D SHEAR BUILDING REPRESENTATION
C--------BEGIN WITH THE TOP FLOOR AND END WITH THE FIRST FLOOR
C

WRITE(7,1025) I
WRITE(7,1030)

IF (ISEV.EQ.1) THEN

WRITE(7,1031)
READ(5,*) (SX(NF+1-J),J=1,NF)
WRITE(5,*) (SY(NF+1-J),J=1,NF)

C--------STIFFNESS AT THE CENTER OF MASS

READ(5,*) (ST(NF+1-J),J=1,NF)
READ(5,*) (EX(NF+1-J),J=1,NF)
READ(5,*) (EY(NF+1-J),J=1,NF)
DO 3 J=1,NF

3 CONTINUE

DO 40 J=1,NF
WRITE(7,2031) NF+1-J,SX(NF+1-J),SY(NF+1-J),ST(NF+1-J),
  EX(NF+1-J),EY(NF+1-J)
40 CONTINUE

C-------ISEV=2
C--------EIGENVALUES AND EIGENVECTORS FOR FULL THREE DIMENSIONAL BUILDING

ELSE IF (ISEV.EQ.2) THEN

READ(5,*) (W(J),J=1,NE)
WRITE(7,1032)
WRITE(7,1033) (J,W(J),2*PI/DSQR(W(J)),J=1,NE)
READ(5,*) ((E(K,J),K=1,3*NF),J=1,NE)
DO 15 L=1,NE,6
IH=LI+5
IF (IH.GT.NE) IH=NE
WRITE(7,2033) (J,J=L,IH)
DO 152 N=1,NF
LN=NF+1-N
NN=3*(N-1)
DO 152 J=1,3
WRITE(7,2034) LN,DRIN(J),(E(NN+J,K),K=L,IH)
152 CONTINUE
END IF

C-------MASES AT SUPERSTRUCTURES LEVELS
C--------BEGIN WITH THE TOP FLOOR AND END WITH THE FIRST FLOOR

READ(5,*) (CMX(NF+1-J),J=1,NF)
DO 8 J=1,NF
CMY(NF+1-J)=CMX(NF+1-J)
8 CONTINUE

C--------MASS AT THE CENTER OF MASS

READ(5,*) (CMR(NF+1-J),J=1,NF)
IF (I.EQ.1) N1=0
IF (I.EQ.1) N2=0
C-------MODAL DAMPING RATIOS FOR THE SUPERSTRUCTURE
C---------LOCATION OF THE CENTER OF MASS OF THE FLOOR WITH RESPECT TO
C---------THE CENTER OF MASS OF THE BASE IN X AND Y DIRECTION
READ(5,*) (DR(J), J=1,NE)

WRITE(7,1050)
DO 170 J=1,NF
170 WRITE(7,2050) NF+1-J,CMX(NF+1-J),CMR(NF+1-J),
+ XN(NF+1-J),YN(NF+1-J)

WRITE(7,1080)
DO 180 J=1,NE
180 WRITE(7,2080) J,DR(J)

C-------HEIGHT TO FLOORS FROM THE GROUND
READ(5,*) (H(N2+1-J), J=1,NF+1)

WRITE(7,1060)
DO 175 J=1,NF+1
175 WRITE(7,2060) NF+1-J,H(N2+1-J)

IF(I.EQ.NB) THEN

C-------STIFFNESS DATA OF LINEAR ELASTIC ISOLATION SYSTEM
READ(5,*) SXE,SYE,STE,EXE,EYE
WRITE (7,600)
WRITE(7,1040)
WRITE(7,2040) SXE,SYE,STE,EXE,EYE

C-------MASS DATA OF BASE
READ(5,*)CMXB,CMRB
CMYB=CMXB
WRITE(7,1070)
WRITE(7,2070) CMXB,CMRB

C-------GLOBAL DAMPING COEFFICIENTS AT THE BASE
READ(5,*) CBX,CBY,CBT,ECX,ECY
WRITE(7,1071)
WRITE(7,2071) CBX,CBY,CBT,ECX,ECY

C-------COORDINATES OF ISOLATORS
READ(5,*) (XP(J),YP(J), J=1,NP)
WRITE(7,1020)
DO 140 J=1,NP
140 WRITE(7,2020) J,XP(J),YP(J)

C-------DATA FOR ISOLATION ELEMENTS
DD 20 K=1,NP
READ(5,*) (INELEM(K,J), J=1,2)
IF(INELEM(K,2).EQ.2)GO TO 10
IF(INELEM(K,2).EQ.3)GO TO 11
IF(INELEM(K,2).EQ.4)GO TO 12

C------DATA FOR LINEAR ELASTIC ELEMENTS

IF(INELEM(K,1).EQ.1)THEN
READ(5,*) PS(K,1)
PS(K,2)=0.0
ELSE IF(INELEM(K,1).EQ.2)THEN
READ(5,*) PS(K,2)
PS(K,1)=0.0
ELSE IF(INELEM(K,1).EQ.3)THEN
READ(5,*) (PS(K,J),J=1,2)
END IF
GO TO 20

C------DATA FOR VISCOUS ELEMENTS

10 IF(INELEM(K,1).EQ.1)THEN
READ(5,*) PC(K,1)
PC(K,2)=0.0
ELSE IF(INELEM(K,1).EQ.2)THEN
READ(5,*) PC(K,2)
PC(K,1)=0.0
ELSE IF(INELEM(K,1).EQ.3)THEN
READ(5,*) (PC(K,J),J=1,2)
END IF
GO TO 20

C------DATA FOR ELASTOMERIC BEARINGS

11 IF(INELEM(K,1).EQ.1)THEN
READ(5,*)ALP(K,1),YF(K,1),YD(K,1)
ALP(K,2)=0.0
YF(K,2)=0.0
YD(K,2)=0.0
ELSE IF(INELEM(K,1).EQ.2)THEN
READ(5,*)ALP(K,2),YF(K,2),YD(K,2)
ALP(K,1)=0.0
YF(K,1)=0.0
YD(K,1)=0.0
ELSE IF(INELEM(K,1).EQ.3)THEN
READ(5,*) (ALP(K,J),J=1,2), (YF(K,J),J=1,2), (YD(K,J),J=1,2)
END IF
GO TO 20

C------DATA FOR SLIDING BEARINGS

12 IF(INELEM(K,1).EQ.1)THEN
READ(5,*)FMAX(K,1),DF(K,1),PA(K,1),YD(K,1),FN(K)
FMAX(K,2)=0.0
DF(K,2)=0.0
PA(K,2)=0.0
YD(K,2)=0.0
ELSE IF(INELEM(K,1).EQ.2)THEN
READ(5,*)FMAX(K,2),DF(K,2),PA(K,2),YD(K,2),FN(K)
FMAX(K,1)=0.0
DF(K,1)=0.0
PA(K,1)=0.0
YD(K,1)=0.0

C-12
ELSE IF(INELEM(K,1).EQ.3) THEN
   READ(B,*),(FMAX(K,J),J=1,2),(DF(K,J),J=1,2),
   + (PA(K,J),J=1,2),(YD(K,J),J=1,2),FN(K)
   END IF

20   CONTINUE

DO 50 K=1,NP
   DO 40 J=1,2
      IF(YD(K,J).EQ.0.0) THEN
         YD(K,J)=0.000001
      END IF
   END DO
50    CONTINUE
40    CONTINUE
50    CONTINUE

K=0
DO 300 IK=1,NP
   IF(INELEM(IK,2).NE.1) GO TO 300
   IF(K.EQ.0) THEN
      WRITE(7,3500)
   END IF
   WRITE(7,3501) IK,(PS(IK,J),J=1,2)
200   K=1
300   CONTINUE

K=0
DO 301 IK=1,NP
   IF(INELEM(IK,2).NE.2) GO TO 301
   IF(K.EQ.0) THEN
      WRITE(7,3600)
   END IF
   WRITE(7,3601) IK,(PC(IK,J),J=1,2)
302   K=1
301   CONTINUE

K=0
DO 110 IK=1,NP
   IF(INELEM(IK,2).NE.3) GO TO 110
   IF(K.EQ.0) THEN
      WRITE(7,1000)
   END IF
   WRITE(7,2000) IK,(ALP(IK,J),J=1,2),(YF(IK,J),J=1,2),
   + (YD(IK,J),J=1,2)
303   K=1
322   CONTINUE
110   CONTINUE

K=0
DO 120 IK=1,NP
   IF(INELEM(IK,2).NE.4) GO TO 120
   IF(K.EQ.0) THEN
      WRITE(7,1010)
   END IF
   WRITE(7,2010) IK,(FMAX(IK,J),J=1,2),(DF(IK,J),J=1,2),
   + (PA(IK,J),J=1,2),(YD(IK,J),J=1,2),FN(IK)
304   K=1
333   CONTINUE
120   CONTINUE

C--------EARTHQUAKE - ACCELEROMGRAM

READ(15,*),(X(K),K=1,LOR)

C--------EARTHQUAKE - ACCELEROMGRAM IN Y DIRECTION IF
C--------BIDIRECTIONAL EXCITATION IS DESIRED

IF(INDGACC.EQ.2) THEN
   READ(16,*),(Y(K),K=1,LOR)
END IF

C-13
DO 210 K=1,NB
READ(5,*),(ICOR(K))
READ(5,*) (CORDX(K,J),CORDY(K,J),J=1,ICOR(K))
210 CONTINUE
ENDIF
RETURN
600 FORMAT///6X,'*************** ISOLATION SYSTEM DATA **************)
700 FORMAT///6X,'*************** OUTPUT PARAMETERS **************)
100 FORMAT///6X,'ELASTOMERIC/DAMPER FORCE
200 FORMAT///6X,'DISPLACEMENT LOOP PARAMETERS............)
+ 6X,'ISOLATOR'9X,'ALPHA X'2X,'ALPHA Y'3X,'YIELD FORCE X'2X
+ 4V,'YIELD DISPL. X'2X,'YIELD DISPL. Y'2X)
2000 FORMAT///6X,'SLIDING BEARING PARAMETERS............)
300 FORMAT///6X,'ISOLATOR'9X,'FMAX X'2X,'FMAX Y'6X,'DF X'2X
1000 FORMAT///6X,'DF Y'6X,'PA X'6X,'PA Y'2X,'YIELD DISPL. X'2X
+ 2X,'YIELD DISPL. Y'4X,'NORMAL FORCE/>
2010 FORMAT///6X,'ISOLATORS LOCATION INFORMATION............)
1020 FORMAT///6X,'ISOLATOR'5X,'X'5X,'Y')
2020 FORMAT///6X,'ISOLATOR'5X,'X'5X,'Y')
1029 FORMAT///6X,'SUPERSTRUCTURE'2X,'I',2)
1030 FORMAT///6X,'....STIFFNESS DATA...........
1031 FORMAT///6X,'STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING).....)
+ 6X,'LEVEL'11X,'STIFF X'11X,'STIFF Y'11X
+ 11X,'STIFF R'5X,'ECCENT X'5X,'ECCENT Y')
2031 FORMAT///6X,'STIFFNESS FOR LINEAR-ELASTIC',
3025 FORMAT///6X,'STIFFNESS DATA FOR LINEAR-ELASTIC',
3033 FORMAT///6X,'STIFFNESS DATA FOR LINEAR-ELASTIC',
400 FORMAT///6X,'MODE SHAPES/.
+ 6X,'LEVEL'6X,'x(6X,'I',4X))
2034 FORMAT///6X,'MODE SHAPES/.
+ 6X,'LEVEL'11X,'TRANSL. MASS'6X
+ 'ROTATIONAL MASS'8X,'ECCENT X'5X,'ECCENT Y')
1050 FORMAT///6X,'SUPERSTRUCTURE MASS............)
+ 6X,'LEVEL'11X,'TRANSL. MASS'6X
+ 'ROTATIONAL MASS'8X,'ECCENT X'5X,'ECCENT Y')
2050 FORMAT///6X,'HEIGHT'20.5,
1060 FORMAT///6X,'HEIGHT'20.5,
+ 6X,'LEVEL'8X,'HEIGHT')
2060 FORMAT///6X,'MASS AT THE CENTER OF MASS OF THE BASE.....)
+ 6X,'12X,'TRANSL. MASS ',
+ 'ROTATIONAL MASS')
2070 FORMAT///6X,'MASS'3F15.5,}
1071 FORMAT///6X,'GLOBAL ISOLATION DAMPING AT THE CENTER
+OF MASS OF THE BASE.....,
+ 6X,12X,
+ R,
+ ECX,
+ ECY,
2071 FORMAT(/6X,'DAMPING ',5F15.5/)
1080 FORMAT(/6X,'SUPERSTRUCTURE DAMPING.......
+ 6X,'MODE SHAPE','5X,'DAMPING RATIO'/)
2080 FORMAT(6X,16X,F15.6)
1090 FORMAT(/6X,'LOCAL ISOLATOR DAMPING AT EACH
+ INDIVIDUAL BEARING.....
+ /6X,'BEARING',2X,'DAMPING COEFF./
2090 FORMAT(6X,15,3X,F15.5)
1092 FORMAT(/6X,'INITIAL CONDITIONS.........
+ 6X,7X,9X,'DISPLACEMENTS',8X,10X,'VELOCITIES',10X,
+ 5X,'ACCELERATIONS',8X,
+ 6X,'FLOOR',2X,3(6X,'X',5X,6X,'Y',5X,6X,'R',5X))
2092 FORMAT(6X,15,2X,9F12.4)
3000 FORMAT
+(/6X,'TIME HISTORY OPTION
+ 6X,'INDEX = 0 FOR NO TIME HISTORY OUTPUT',
+ 6X,'INDEX = 1 FOR TIME HISTORY OUTPUT',
+ 6X,'NO. OF TIME STEPS AT WHICH TIME HISTORY',
+ 6X,'OUTPUT IS DESIRED
+ 6X,'FORCE-DISPLACEMENT TIME HISTORY DESIRED',
+ 6X,'AT ISOLATORS NUMBERED
+(/6X,5(I4.1X))
3050 FORMAT(/6X,'COORDINATES OF 2 POINTS AT WHICH INTERSTORY DRIFTS
+ ARE DESIRED',/6X,'FLOOR',5X,'X. CORD. PT.1',4X,
+ 'Y. CORD. PT.2',2X,'X. CORD. PT.2',3X,'Y. CORD. PT.2',/)
3100 FORMAT(6X,14,5X,4(F12.6,3X))
3500 FORMAT(/6X,'LINEAR ELASTIC ELEMENT PARAMETERS.......
+ 6X,'ISOLATOR',8X,'STIFFNESS X',8X,'STIFFNESS Y'
3501 FORMAT(6X,15,3X,2F20.5)
3600 FORMAT(/6X,'VISCOUS ELEMENT PARAMETERS............
+ 6X,'ISOLATOR',8X,'DAMP-COEFF X',8X,'DAMP-COEFF Y'
3601 FORMAT(6X,15,3X,2F20.5)
END
C**********************************************************************************
SUBROUTINE STIFF1
 *
+ 5X, SY, ST, EX, EY
+ SGX,SGY,SGT,SGTX, SGY
+ ,NF,1)
C**********************************************************************************
SUBROUTINE FOR ASSEMBLING THE STIFFNESS MATRIX FOR THE
SUPERSTRUCTURE, FOR THE FIRST OPTION - THREE DIMENSIONAL
SHEAR BUILDING.
DEVELOPED BY ................. SATISH NAGARAJAIAH ....OCT 1990
MODIFIED BY .................. PANAGIOTIS TSOPELAS ....APR 1991
C**********************************************************************************
C !!!!!!!!!!!!! BE AWARE !!!!!!!!!!!!!
DO NOT USE ' I ' AS INDEX IN THIS SUBROUTINE
C**********************************************************************************
DO 20 J=1,NF
DO 15 K=1,NF
SGX(J,K)=0.0
SGY(J,K)=0.0
SGT(J,K)=0.0
SGX(J,K)=0.0
S&T(J,K)=0.0
SGXT(J,K)=0.0
SGYT(J,K)=0.0
GO TO 20
15 CONTINUE
20 CONTINUE

FORM NF*NF STIFFNESS MATRIX PARTITIONS

SGX(1,1)=SX(NF)
SGX(1,2)=-SX(NF)
SGY(1,1)=SY(NF)
SGY(1,2)=-SY(NF)
SGT(1,1)=ST(NF)
SGT(1,2)=-ST(NF)
SGXT(1,1)=-SX(NF)*EY(NF)
SGXT(1,2)=SX(NF)*EY(NF)
SGYT(1,1)=SY(NF)*EX(NF)
SGYT(1,2)=-SY(NF)*EX(NF)

DO 35 J=2,NF
JJ=NF+1-J
SGX(J,J)=SX(JJ)+SX(JJ+1)
SGY(J,J)=SY(JJ)+SY(JJ+1)
SGT(J,J)=ST(JJ)+ST(JJ+1)
SGXT(J,J)=SX(JJ)*EY(JJ)
SGYT(J,J)=-SY(JJ)*EX(JJ)
35 CONTINUE

IF (J,JT,NF-1)GO TO 35
SGX(J,J+1)=-SX(JJ)
SGY(J,J+1)=-SY(JJ)
SGT(J,J+1)=-ST(JJ)
SGXT(J,J+1)=SX(JJ)*EY(JJ)
SGYT(J,J+1)=-SY(JJ)*EX(JJ)

DO 50 J=1,3*NF
JJ=NF+1-J
J1=3*(J-1)+1
JJ=J1+2
J2=J1+1
J3=J1+2
S&T(J1,J1)=SGX(J,J)
S&T(J2,J2)=SGY(J,J)
S&T(J3,J3)=SGT(J,J)
S&T(J1,J2)=SGXT(J,J)
S&T(J2,J3)=SGYT(J,J)

IF (J3,GE,3*NF)GO TO 60

DO 60 J=1,3*NF
DO 70 J=1,3*NF
C******************************************************************** MASSA *********

C SUBROUTINE MASSA
C EACH SUPERSTRUCTURE AND THE DIAGONAL MASS MATRIX FOR THE WHOLE
C STRUCTURE, FOR THE FIRST OPTION - THREE DIMENSIONAL SHEAR BUILDING.
C DEVELOPED BY.............................................SATISH NAGARAJUAIH.....OCT 1990
C MODIFIED BY.............................................PANAGIOTIS TSOPELAS.....APR 1991

C********************************************************************

C !!!!!!!!!! BE AWARE !!!!!!!!!!
C DO NOT USE ' I ' AS INDEX IN THIS SUBROUTINE

IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MXF
COMMON /TSEP /TSE,TSR
COMMON /MASS1 /CMXB,CMYB,CMRB
DIMENSION CM(3*MNF+3,3*MNF+3),CMX(MXF),CMY(MXF),CMR(MXF)

DO 20 J=1,3*MXF
DO 20 K=1,3*MXF
TEMP2(J,K)=0.0
20 CONTINUE

DO 30 J=1,NF
JJ=NF+1-J
J1=3*(J-1)+1
J2=J1+1
J3=J1+2
TEMP2(J1,J1)=CMX(JJ)
TEMP2(J2,J2)=CMY(JJ)
TEMP2(J3,J3)=CMR(JJ)
30 CONTINUE

IF(I.EQ.1) N1=0
N1=N1+NF
DO 40 J=1,NF
J1=3*(N1-NF)+3*(J-1)+1
J2=J1+1
J3=J1+2
CM(J1,J1)=CMX(NF+1-J)
CM(J2,J2)=CMY(NF+1-J)
CM(J3,J3)=CMR(NF+1-J)
40 CONTINUE

IF(I.EQ.NB) THEN
CM(3*MNF+1,3*MNF+1)=CMXB
CM(3*MNF+2,3*MNF+2)=CMYB
CM(3*MNF+3,3*MNF+3)=CMRB
ENDIF

RETURN
END
C******************************************************************** MASSB ********
SUBROUTINE MASSB
+ ( CM, CMX, CMY
+ , CMR
+ , NF, I)

C*******************************************************************************
C ROUTINE FOR ASSEMBLING THE DIAGONAL LUMPED MASS MATRIX FOR
C THE WHOLE STRUCTURE, FOR THE SECOND OPTION - FULLY THREE
C DIMENSIONAL BUILDING.
C DEVELOPED BY .......................PANAGIOTIS TSOPelas....APR 1991
C*******************************************************************************
C
C
!!!!!!!!! BE AWARE !!!!!!!!!!
C
C DO NOT USE ' I ' AS INDEX IN THIS SUBROUTINE
C
C*******************************************************************************
IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MXF
COMMON /STEP /TSI,TSR
COMMON /MASS1 /CMXB,CMYB,CMRB
DIMENSION CM(3*MNF+3,3*MNF+3),CMX(MXF),CMY(MXF),CMR(MXF)

C
IF(I.EQ.1) N1=0

N1=N1+NF
DO 40 J=1,NF
J1=3*(N1-NF)+3*(J-1)+1
J2=J1+1
J3=J1+2
CM(J1,J1)=CMX(NF+1-J)
CM(J2,J2)=CMY(NF+1-J)
CM(J3,J3)=CMR(NF+1-J)
40 CONTINUE

IF(I.EQ.NB) THEN
CM(3*MNF+1,3*MNF+1)=CMXB
CM(3*MNF+2,3*MNF+2)=CMYB
CM(3*MNF+3,3*MNF+3)=CMRB
ENDIF

C
RETURN
C
END

C*******************************************************************************
DAMP ********
C*******************************************************************************

SUBROUTINE DAMP
+( PC,XP,YP
+ , C, W, DR
+ , INELEM
+ , NF, I)

C*******************************************************************************
C ROUTINE FOR ASSEMBLING THE MODAL DAMPING MATRIX FOR
C THE WHOLE STRUCTURE AND THE DAMPING AT THE BASE (CONSIDERED TO BE
C EITHER LOCAL DAMPING OF INDIVIDUAL BEARING ASSEMBLED EXPLICITLY
C OR GLOBAL DAMPING OF BASE).
C DEVELOPED BY .......................SATISH NAGARAJAIAH.....OCT 1990
C MODIFIED BY .......................PANAGIOTIS TSOPelas....APR 1991
C*******************************************************************************
C
!!!!!!!!! BE AWARE !!!!!!!!!!
C
C DO NOT USE ' I ' AS INDEX IN THIS SUBROUTINE
C
C*******************************************************************************
IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MXF
COMMON /STEP /TSI,TSR
COMMON /DAMP1 /GBX,GBY,CBT,ECX,ECY

C-18
DIMENSION DR(3*MXF),C(MNE+3,MNE+3),W(3*MXF)
DIMENSION PC(NP,2),XP(NP),YP(NP),INELEM(NP,2)

C

IF(I.EQ.1) N1=0
N1=N1+NE

DO 30 J=1,NE
C(N1-NE+J,N1-NE+J)=2*DR(J)*DSQRT(W(J))
30 CONTINUE

IF(I.EQ.NB) THEN

J1=MNE+1
J2=MNE+2
J3=MNE+3

CXYT=CBX+CBY+CBT

IF(CXYT.EQ.0) GO TO 35

C(J1,J1)=CBX
C(J2,J2)=CBY
C(J3,J3)=CBT
C(J1,J3)=-CBX*ECY
C(J2,J3)=CBY*ECX

35 CONTINUE

SUM1=0.
SUM2=0.\nNUMBEL=0

DO 40 K=1,NP

IF(INELEM(K,2).NE.1) GO TO 40

SUM1=SUM1+PC(K,1)
SUM2=SUM2+PC(K,2)
NUMBEL=NUMBEL+1

40 CONTINUE

IF(NUMBEL.GT.0)THEN
C(J1,J1)=SUM1
C(J2,J2)=SUM2
ENDIF

DO 50 K=1,NP

IF(INELEM(K,2).NE.1) GO TO 50

C(J3,J3)=C(J3,J3)+PC(K,2)*XP(K)**2+PC(K,1)*YP(K)**2
C(J1,J3)=C(J1,J3)-PC(K,1)*YP(K)
C(J2,J3)=C(J2,J3)+PC(K,2)*XP(K)

50 CONTINUE

C(J3,J1)=C(J1,J3)
C(J3,J2)=C(J2,J3)

ENDIF

RETURN

END

C*******************************************************************************
TRANSF *******

SUBROUTINE TRANSF(T,E1,R,XN,YN,NF,NE)

*******************************************************************************

C SUBROUTINE FOR ASSEMBLING THE TRANSFORMATION MATRIX.
C DEVELOPED BY..........................SATISH NAGARAJAIAH.....OCT 1990
MODIFIED BY........................PANAGIOTIS TSOPelas...APR 1991

C IMPLICIT REAL*8(A-H,O-Z)
C COMMON /MAIN /NB,NP,MNF,MNE,NFE,MXF
C COMMON /STEP /TSI,TSR
C JMAX IS MAX ELEMENT
C E1(NFE),T(3+MNF+3,MNE+3),R(3*MNF+3,3)
C + ,NF(NB),NE(NB),XN(MNF),YN(MNF)
C
C DO 20 J=1,3*MNF+3
C DO 10 K=1,3+MNE
C T(J,K)=0.0
C 10 CONTINUE
C DO 15 JK=1,3
C R(J,JK)=0.0
C 15 CONTINUE
C DO 20 CONTINUE
C
N1=0
C DO 100 I=1,NB
C N1=N1+NF(I)
C DO 110 J=1,NF(I)
C J1=3*N1-3*NF(I)+3*(J-1)+1
C J2=J1+1
C J3=J1+2
C R(J1,1)=1
C R(J2,2)=1
C R(J3,3)=1
C R(J1,3)=-YN(N1+1-J)
C R(J2,3)=+YN(N1+1-J)
C 110 CONTINUE
C 100 CONTINUE
C R(3*MNF+1,1)=1
C R(3*MNF+2,2)=1
C R(3*MNF+3,3)=1
C
N1=0
N2=0
N3=0
DO 40 I=1,NB
DO 45 J=1,NE(I)
DO 50 K=1,3*NF(I)
I1=N3+3*NF(I)*(J-1)+K
T(N1+K,N2+J)=E1(I1)
50 CONTINUE
45 CONTINUE
40 CONTINUE
DO 60 I=1,NE(I)
N1=N1+3*NF(I)
N2=N2+NE(I)
N3=N3+3*NF(I)*NE(I)
60 CONTINUE
40 CONTINUE
DO 70 J=1,3*MNF+3
DO 60 K=1,3
T(J,K)=R(J,K)
60 CONTINUE
70 CONTINUE
C RETURN
C END
C
C******************************************************************************
C STIFF2
C******************************************************************************

C SUBROUTINE STIFF2(W1,PS,XP,YP,SE,INELEM)

C******************************************************************************
C SUBROUTINE FOR ASSEMBLING THE REDUCED STIFFNESS MATRIX
C USING THE EIGENVALUES.
C DEVELOPED BY.........................SATISH NAGARAJAIAH.....OCT 1990
C MODIFIED BY.........................PANAGIOTIS TSOPELAS....APR 1991
C
C******************************************************************************
C
IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN/ NR,NP,MNF,MNF,NFF,MXF
COMMON /STEP/ TSI,TSR
COMMON /STIFF/ SXE,SYE,STE,EXE,EYE
DIMENSION W1(MNE),PS(NP,2),SE(MNE+3,MNE+3),INELEM(NP,2)
DIMENSION XP(NP),YP(NP)
C
DO 10 J=1,MNE+3
DO 10 K=1,MNE+3
SE(J,K)=0.0
10 CONTINUE

DO 30 J=1,MNE
SE(J,J)=W1(J)
30 CONTINUE

J1=MNE+1
J2=MNE+2
J3=MNE+3
SXY=SXE+SYE+STE
IF(SXY.EQ.0) GO TO 35
SE(J1,J1)=SXE
SE(J2,J2)=SYE
SE(J3,J3)=STE
SE(J1,J3)=SXE*EYE
SE(J2,J3)=SYE*EYE
35 CONTINUE

SUM1=0.
SUM2=0.\nNUMBEL=0
DO 40 K=1,NP
40 CONTINUE

IF(INELEM(K,2).NE.1) GO TO 50
SUM1=SUM1+PS(K,1)
50 CONTINUE

SUM1=SUM1+PS(K,1)
IF(INELEM(K,2).NE.1) GO TO 50
SE(J3,J3)=SE(J1,J3)+PS(K,2)*XP(K)**2+PS(K,1)*YP(K)**2
SE(J1,J3)=SE(J1,J3)-PS(K,1)*YP(K)
SE(J2,J3)=SE(J2,J3)+PS(K,2)*XP(K)
50 CONTINUE

SE(J3,J1)=SE(J1,J3)
SE(J3,J2)=SE(J2,J3)
RETURN
END

C******************************************************************************
SUBROUTINE SOLUTION
+( W1, E1, XN, YN, H
+ PS, ALP, YF, YD
+ FMAX, DF, PA, FN, XP
+ YP, CORDX, CORDY, X, Y
+ SE, CM, C, SK, CMT
+ R, T, A, AC, V
+ VC, D, DDE, DELF, PTU
+ FH, RTS, PT, F, FX
+ FY, FXP, FYP, ZX, ZY
+ ZXP, ZYP, FNXY, FXTEM,FYTEM
+ XTEM, YTEM, TEMP1, TEMP2, TEMPT3, TEMPT4
+ TEMP32, DAMAX, DMAX, DIAME, ATIMEF
+ SUMF, SUMFT, SUMB, SMMBT, SMMB
+ C2, PACC, PDEF, C2T, BAS1
+ BAS2, BAS3, BAS4, B, DX
+ D, DXY, DXY, DX, DXY, DYT
+ OVMX, OVMY, OAX, OAY, OVT
+ OVT
+ NF, NEINELEM, IP, ICOR )

C******************************************************************************
C SUBROUTINE FOR SOLUTION OF THE EQUATIONS OF MOTION AND OUTPUT OF
C TIME HISTORY RESULTS AND/OR PEAK RESPONSE VALUES.
C DEVELOPED BY.....................................SATISH NAGARAJAIAH.....OCT 1990
C MODIFIED BY.....................................PANAGIOTIS TSOPPELAS....APR 1991

C******************************************************************************
IMPLICIT REAL*8(A-H,O-Z)
COMMON /STEP /TSI,TSR
COMMON /GENBASE /ISEV,LOR
COMMON /PRINT /LTMH,IPROF,KPD,KPF,INP
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MXF
COMMON /HYS1 /WBE,WGM
COMMON /STIFF /SXE,SYE,STE,EXE,EYE
COMMON /MASS1 /CMXB,CMYB,CMRB
COMMON /DAMP1 /CBX,CBY,CBT,ECX,ECY
COMMON /INT /FMNDRM,BET,GAM,TOL
COMMON /LOAD1 /XTM,IDAT,TIME,FTSR,ULF,INDIGACC
COMMON /DIREC /DRIN(3),DRIN(4)

CHARACTER*1 DRIN
CHARACTER*2 DRIN
DIMENSION ALP(NP,2),YF(NP,2),YN(NP,2),FMAX(NP,2),DF(NP,2)
+ PS(NP,2),PA(NP,2),FN(NP),XP(NP),YP(NP)
+ W1(MNE),E1(NFE)
+ X(MNF),YN(MNF),H(MNF+NB)
+ X(LOR),Y(LOR)
+ NF(NB),NE(NB),INELEM(NP,2)
+ CM(NME+3,MNE+3),CM(NME+3,MNE+3),CM(NME+3,MNE+3)
+ T(MMF+2,MNE+3),R(MMF+3,3,MCM+3*MNF+3,3+MNF+3)
+ SK(MNE+3,MNE+3)
+ A(MNE+3),V(MNE+3),AC(MNE+3),VC(MNE+3)
+ D(MNE+3,2),DDE(MNE+3)
+ PTU(MNE),FH(MNE+3),AC(MNE+3),VC(MNE+3)
+ TEMP1(MNE+3,3*MNF+3),TEMP2(3*MNF+3,1)
+ TEMP3(MNE+3,3*MNF+3),TEMP32(MNE+3,3)
+ FX(NP),FY(NP),FYP(NP),FXTEM(NP),FYTEM(NP)
+ ZX(NP),ZY(NP),ZXP(NP),ZXP(NP),ZXTEM(NP),ZYTEM(NP)
+ FNXY(NP),F(3*MNF+3)
+ DELF(MNE+3)

C DIMENSION ANC(3),VNC(3),FHTEMP(3),ERR(3)
+ AB(3),DB(3),VNY(3),AN(3),AP(3),VNP(3),DN(3,2),UG(3,1)
C-- ARRAYS FOR THE PRINT OUT
DIMENSION DMAX(3*MNF+3), AMAXF(3*MNF+3), BMAXF(3,2)
+ , DTIME(3*MNF+3), ATIMEF(3*MNF+3)
+ , SUMF(MNF,3), SUMFT(MNF,3), SUMB(NB,3), SMMBT(NB,3), SMMB(NB,3)
+ , IP(INP), C1(2,2), C2(2,NB,2), C1T(2,2), C2T(2,NB,2)
+ , PACC(2,3*MNF+3,5), PDEF(2,3*MNF+3,5), BAS1(NB,3,2), BAS2(NB,3,2)
+ , BAS3(NB,3,2), BAS4(NB,3,2)
+ , B(NB*MNF+6)*6)
+ , DX(INP), DY(INP), DXY(INP), DXY(INP), DXT(INP), DYT(INP)
+ , DX(INP), DY(INP), DXY(INP), DXY(INP), DXT(INP), DYT(INP)
+ , DX(INP), DY(INP), DXY(INP), DXT(INP), DYT(INP)
DIMENSION ICOR(NB), CORDX(NB,6), CORDY(NB,6)
C C--ARRAYS FOR OVERTURNING MOMENTS--
DIMENSION OVMX(NB,2), OVMY(NB,2), OAX(MNF+NB), OAY(MNF+NB)
+ , OXT(NB), OYTN(NB)
+ , TIMPR(2)
IF (TLMH.EQ.1) THEN
  OPEN (UNIT=50, FILE='BASE', STATUS='NEW')
  IF (INP.GT.0) THEN
    WRITE (50,1002) (I(1),I=1,INP)
  ENDIF
ENDIF
DO 360 I=1, MNE+3
A(I)*=0.0
V(I)*=0.0
360 CONTINUE
DO 361 I=1, NP
FXP(I)=0
FYP(I)=0
ZXP(I)=0
ZYP(I)=0
361 CONTINUE
DO 370 I=1, 3
VNI(I)=0.0
ANI(I)=0.0
ANP(I)=0.0
VNP(I)=0.0
370 CONTINUE
DO 378 I=1, 3
DO 375 J=1, 2
375 CONTINUE
DO 378 I=1, 3
DO 375 J=1, 2
378 CONTINUE
DO 380 I=1, MNE+3
380 CONTINUE
DO 380 I=1, MNE+3
380 CONTINUE
DO 391 I=1, 3*MNF+3
DMAX(I)=0.0
391 CONTINUE
DO 392 I=1, 3*MNF+3
AMAXF(I)=0.0
392 CONTINUE
DO 393 I=1, 3
DO 393 J=1, 2
393 CONTINUE
DO 394 I=1, MNE+3
FHI(I)=0.0
394 CONTINUE
DO 395 I=1, NP
ZX(I)=0
395 ZY(I)=0
C-23
IDAT = 2
TIME = 0.0
PTSR = TSR
KPRINT = 1
KPRINT = 1
PRINT = 0
PRINT1 = 0
TSIT = TSI
KPDT = KPD
KPFT = KPF
J1 = 3 * MNF + 3
J2 = MNE + 3
CALL TRANSF(T, E1, R, XN, YN, NF, NE)
CALL TMULT(T, CM, TEMP1, J1, J2, J1)
CALL MULT(TEMP1, T, CMT, J2, J1, J2)
CALL STIFF2(W1, PS, XP, YP, SE, INELEM)
IT = 1
IF (TIME .GT. (LOR - 1) * TSR) GO TO 2000
DUM = V(MNE + 1)**2 + V(MNE + 2)**2
VEL = DSQRT(DUM)
DISP = DSQRT(DN(1, 1)**2 + DN(2, 1)**2)
TSIP = TSJ
TSI = TSIT
IF (KVSTEP.EQ.2) THEN
IF (VEL.LE.20 .AND. VEL.GT.15) THEN
TSI = TSIT * 0.875
ELSE IF (VEL.LE.15 .AND. VEL.GT.10) THEN
TSI = TSIT * 0.75
ELSE IF (VEL.LE.10 .AND. VEL.GT.5 ) THEN
TSI = TSIT * 0.625
ELSE IF (VEL.LE.5 .AND. VEL.GT.0 ) THEN
TSI = TSIT * 0.5
END IF
ELSE IF (KVSTEP.EQ.1) THEN
TSI = TSIT
END IF
IF (IT.LE.2) GO TO 55
IF (TSI.EQ.TSIP) GO TO 50
CONTINUE
DT = TSI
A1 = 1/(BET + (DT**2))
A2 = 1/(BET * DT)
A3 = 1/(2 * BET)
A4 = GAM/(BET * DT)
A5 = GAM / BET
A6 = DT * (GAM / (2 * BET) - 1)
J1 = MNE + 3
DO 100 I = 1, J1
DO 90 J = 1, J1
100 CONTINUE
100 CONTINUE
90 CONTINUE
C-24
ITER1=0
J1=MNE+3
CALL LOAD(TEMP31,TEMP32,T,R,CM,Y,X,UG,PTU,IT)
DO 452 I=1,MNE+3
452 DLF(I)=U
451 CONTINUE
DO 470 I=1,MNE+3
DUM=0.0
DO 460 J=1,MNE+3
460 DUM=DUM+CMT(I,J)*A(J)-C(I,J)*V(J)-SE(I,J)*D(J,1)
RTS(I)=PTU(I)+DUM+FH(I)-DFL(I)
470 CONTINUE
DO 550 I=1,MNE+3
DUM=0.0
DO 500 J=1,MNE+3
500 DUM=DUM+CMT(I,J]*(A2*V(J)+A3*A(J))+C(I,J)**(A5*V(J)+A6*A(J))
PT(I)=RTS(I)+DUM
550 CONTINUE
IF(IT.LE.2 OR.TSI.NE.TSIP)THEN
CALL GAUSS(SK,PT,MNE+3,MNE+3,1,1)
END IF
DO 920 I=1,MNE+3
920 DDE(I)=PT(I)
DO 950 I=1,MNE+3
D(I,2)=D(I,1)+DDE(I)
AC(I)=A(I)+A1+DDE(I)-A3+V(I)
VC(I)=V(I)-A4*DDE(I)-A5*V(I)-A6*A(I)
950 CONTINUE
DO 1000 I=1,3
1000 II=MNE+1
DN(I,2)=D(II,2)
ANC(I)=AC(II)
VNC(I)=VC(II)
DO 1050 I=1,NP
1050 FXP(I)=FX(I)
FYP(I)=FY(I)
ZXP(I)=ZX(I)
ZYP(I)=ZY(I)
1050 CONTINUE
CALL BEARING(ERR,FN,FXP,FYP,XP,YP,DN,VNC,VN,ANC,AN,FH,
IT,ZXP,ZYP,FNX,Y,ALP,YF,YD,FMAX,DF,PA,IENELEM,DFL)
SUN=0.0
SUM=SUM+ERR(I)**2
DO 1250 I=1,3
1250 CONTINUE
RTOL=DQRT(SUM)/FMNORM
IF(RTOL.GT.TOL)ITER=1
ITER=ITER+1
IF (ITER.GT.200)THEN
WRITE (7,*) ITER1
STOP
END IF

IF (ITER.EQ.1) GO TO 451

DO 1400 I=1,NP
  FX(I) = FXP(I)
  FY(I) = FYP(I)
  ZX(I) = ZXPI
  ZY(I) = ZYP(I)
1400

DO 1800 I=1,MNE+3.
  A(I) = AC(I)
  V(I) = VC(I)
1800  D(I,1) = D(I,2)

DO 1846 I=1,MNE+3
  FH(I) = FH(I) + DELF(I)
1846

1847

DO 1850 I=1,3
  ANP(I) = ANP(I)
  VNP(I) = VNP(I)
  DN(I,1) = DN(I,2)
  AN(I) = ANC(I)
  VN(I) = VN(C(I)
1850  CONTINUE

IF(DABS(VEL).LE.30) THEN
  KPF = TSIT/TSI*KPF
  KPD = TSIT/TSI*KPD
ELSE IF(DABS(VEL).GT.20) THEN
  KPF = KPF
  KPD = KPD
END IF

DO 1870 I=1,3*MNF
  SUM = SUM
DO 1860 J=1,MNE
  SUM = SUM + (I,J)*D(J,2)
1860  CONTINUE
1870  CONTINUE

TEMP3(I,1) = SUM

TEMP3(2*MNF+1,1) = D(MNE+1,2)
TEMP3(3*MNF+2,1) = D(MNE+2,2)
TEMP3(3*MNF+3,1) = D(MNE+3,2)

C -- MAX BEARINGS DISPLACEMENTS

IF(INP.GT.0) THEN
  DO 1875 I=1,INP
    DISX = DN(1,1)-DN(3,1)*YP(IP(I))
    DISY = UN(2,1)+UN(3,1)*XP(IP(I))
    IF(DABS(DISX).GT.DABS(DX(I))) THEN
      DX(I) = DISX
      DXY(I) = DISY
      DXT(I) = TIME
    ENDIF
    IF(DABS(DISY).GT.DABS(DY(I))) THEN
      DY(I) = DISY
      DXY(I) = DISY
      DYT(I) = TIME
    ENDIF
 1875  CONTINUE
ENDIF

C -- WRITE BEARINGS DISPLACEMENTS AND FORCES (TIME HISTORIES)---

IF(LTMH.EQ.1) THEN
  IF(INP.GT.0) THEN
    IF(I.EQ.KPRINT) THEN
      WRITE(50,BOO1) TIME, DRIN1(1), (DN(1,1)-DN(3,1)*YP(IP(J)), J=1,INP)
C--MAX DISPLACEMENTS------

DO 1880 I=1,3*MNF+3
   IF (DABS(TMP3(I,1)).GT.DABS(DMAX(I)))THEN
      DMAX(I)=TMP3(I,1)
      DTME(I)=TIME
   ENDIF
1880 CONTINUE

C--ESTIMATION OF DRIFTS FOR EACH BUILDING

L 1=1
   L 2=L 1 + NB*MXF*6
   L 3=L 2 + NB*MXF*6
   L 4=L 3 + NB*MXF*6
   L 5=L 4 + NB*MXF*6
   L 6=L 5 + NB*MXF*6
   L 7=L 6 + NB*MXF*6

CALL DRIFTS(TIME,TMP3,XN,YN,NF,H,ICOR,CORDX,CORDY,
   + B(L1),B(L2),B(L3),B(L4),B(L5),B(L6),0)

C--TEMPORARILY RETAIN THE DEFLECTIONS IN 'F' ARRAY---

DO 1885 I=1,3*MNF+3
   F(I)=TMP3(I,1)
1885 CONTINUE

C-------ACCELERATION COMPUTATION

CALL MULT(T,A,TMP3,3*MNF+3,MNE+3,1)

DO 1890 U=1,3
   SUM=0.0
   UU UBYU U=1,3
   SUM=SUM+R(I,U)*UG(J,1)*ULF
1890 CONTINUE

TIMEF(I)=TIME

C-- ACCELERATIONS IN ' TEMP3 ' ARRAY AT THIS POINT

C--MAX ACCELERATIONS--

DO 1915 I=1,3*MNF+3
   IF(DABS(TMP3(I,1)).GT.DABS(AMAXF(I)))THEN
      AMAXF(I)=TMP3(I,1)
      ATIMEF(I)=TIME
   ENDIF
1915 CONTINUE

C IF(LTMH.EQ.1) THEN

C-------------------------PRINT DEFLECTIONS AND ACCELERATIONS------

CALL WDEFA(TIME,F,TMP3,NF,IT,KPRINT,PRINT,0)

C-------------------------

ENDIF

C--PROFILES FOR MAX BASE DISPLACEMENTS---

IF(IPROF.EQ.1) THEN

DO 1916 I=1,2
   IF(DABS(F(3*MNF+I)).GT.DABS(C1(I,1)))THEN
      DO 1917 J=1,3*MNF+3
         PACC(I,J,1)=TEMPS(J,1)
1917 CONTINUE
1916 CONTINUE

C-27
PDEF(I,J,1)=F(J)
1917 CONTINUE
C1(I,1)=F(3*MNFI)
C1T(I,1)=TIME
ENDIF
1916 CONTINUE
C--PROFILES FOR MAX ACCEL IN EACH BUILDING----
N1=0
DO 1918 K=1,NB
DO 1919 I=1,2
IF(DABS(TEMP3(N1+I,1)).GT.DABS(C2(I,K,1)))THEN
BAS1(K,1,I)=TEMP3(3*MNF+1,1)
BAS1(K,2,I)=TEMP3(3*MNF+2,1)
BAS1(K,3,I)=TEMP3(3*MNF+3,1)
BAS3(K,1,I)=F(3*MNF+1)
BAS3(K,2,I)=F(3*MNF+2)
BAS3(K,3,I)=F(3*MNF+3)
DO 1921 J=1,3*NF(K)
PAcc1(I,N1+J,2)=TEMP3(N1+J,1)
PDef(I,N1+J,2)=F(N1+J)
1921 CONTINUE
C2(I,K,1)=TEMP3(N1+I,1)
C2T(I,K,1)=TIME
ENDIF
1919 CONTINUE
N1=N1+3*NF(K)
1918 CONTINUE
ENDIF
C--NOW KEEP THE DEFLECTIONS IN THE TEMP1 ARRAY
DO 1925 I=1,3*MNFI+3
TEMP1(I,1)=F(I)
1925 CONTINUE
C-------FORCE COMPUTATION
DO 1930 I=1,3*MNFI+3
SUM=0.0
DO 1920 J=1,3*NF(K)
SUM=SUM+CM(I,J)*TEMP3(J,1)
1920 CONTINUE
F(I)=SUM
1930 CONTINUE
C MAXIMUM FORCES AT FLOORS
DAMPF1=CBX*VN(1)
DAMPF2=CBY*VN(2)
DAMPF3=CBT*VN(3)
FISI1=DAMPF1+SXE*D(MNE+1,2)+FH(MNE+1)+F(3*MNF+1)
FISI2=DAMPF2+SYE*D(MNE+2,2)+FH(MNE+2)+F(3*MNF+2)
FISI3=DAMPF3+STE*D(MNE+3,2)+FH(MNE+3)+F(3*MNF+3)
C--CALCULATE OVERTURNING MOMENTS
C ABOVE BASE AT THE LEVEL OF FIRST STOREY
QVMX=0.0
QVYX=0.0
QVY=0.0
N1=0
N2=0
DO 1950 K=1,NB
QVMX(K,1)=.0
QVY(K,1)=.0
N2=N2+NF(K)+1
1950 CONTINUE
DO 1951 J=1,NF(K)
QVMX(K,1)=QVMX(K,1)+F(N1+3*(J-1)+1)*(H(N2+1-J)-H(N2-NF(K)))+
QVY(K,1)=QVY(K,1)+F(N1+3*(J-1)+2)*(H(N2+1-J)-H(N2-NF(K)))
1951 CONTINUE
C-28
0507  \( N1=N1+3*NF(K) \)
0508  
0509  1955  \( \text{ALENX=ALEN} \)
0510  \( \text{ALENY=ALEN} \)
0511  DO 1957 I=1,NP
0512  C  \( \text{FNXY(I)=FN(I)+OVMX*XP(I)/(ALENX*DABS(YP(I)))} \)
0513  C  \( +OVMY*YP(I)/(ALENY*DABS(YP(I))) \)
0514  U14  \( \text{FNXY(I)=FN(I)} \)
0515  1957 CONTINUE
0516  1950 CONTINUE
0517  
0518  N1=0
0519  N2=0
0520  DO 1952 K=1,NB
0521  IF(DABS(OVNX(K,1)).GT.DABS(OVNX(K,2)))THEN
0522  \( \text{OVNX(K,2)=OVNX(K,1)} \)
0523  \( \text{OVXT(K)=TIME} \)
0524  DO 1953 I=1,NF(K)
0525  \( \text{OAX(N2+I)=F(N1+3*(I-1)+1)} \)
0526  1953 CONTINUE
0527  \( \text{OAX(N2+NF(K)+1)=F(3*MNF+1)} \)
0528  ENDIF
0529  IF(DABS(OVNY(K,1)).GT.DABS(OVNY(K,2)))THEN
0530  \( \text{OVNY(K,2)=OVNY(K,1)} \)
0531  \( \text{OVYT(K)=TIME} \)
0532  DO 1954 I=1,NF(K)
0533  \( \text{OAY(N2+I)=F(N1+3*(I-1)+2)} \)
0534  1954 CONTINUE
0535  \( \text{OAY(N2+NF(K)+1)=F(3*MNF+2)} \)
0536  ENDIF
0537  N1=N1+3*NF(K)
0538  N2=N2+NF(K)+1
0539  1952 CONTINUE
0540  
0541  C  \( \text{BASE SHEAR (STRUCTURE LEVEL)} \)
0542  
0543  SUM4=0.0
0544  SUM5=0.0
0545  SUM6=0.0
0546  N1=0
0547  DO 1960 I=1,NB
0548  
0549  DO 1962 J=1,3
0550  1962 SUMB(I,J)=0.0
0551  SUM1=0.0
0552  SUM2=0.0
0553  SUM3=0.0
0554  N1=N1+3*NF(I)
0555  
0556  DO 1964 K=1,NF(I)
0557  U16  \( \text{U1=U1+3*(K-1)} \)
0558  SUM1=SUM1+U(J+1)
0559  SUM2=SUM2+U(J+2)
0560  SUM3=SUM3+U(J+3)
0561  IF(DABS(SUM1).GT.DABS(SUMF(N1/3-NF(I)+K,1))) THEN
0562  \( \text{SUMF(N1/3-NF(I)+K,1)=SUM1} \)
0563  ENDIF
0564  IF(DABS(SUM2).GT.DABS(SUMF(N1/3-NF(I)+K,2))) THEN
0565  \( \text{SUMF(N1/3-NF(I)+K,2)=SUM2} \)
0566  ENDIF
0567  IF(DABS(SUM3).GT.DABS(SUMF(N1/3-NF(I)+K,3))) THEN
0568  \( \text{SUMF(N1/3-NF(I)+K,3)=SUM3} \)
0569  ENDIF
0570  CONTINUE
0571  
0572  SUMB(I,1)=SUM1

C-29
0579  SUMB(I,2)=SUM2
0580  SUMB(I,3)=SUM3
0581
0582  IF(DABS(SUM1).GT.DABS(SMNB(I,1))) THEN
0583     SMNB(I,1)=SUM1
0584     SMNB(I,1)=TIME
0585  ENDIF
0586  IF(DABS(SUM3).GT.DABS(SMNB(I,3))) THEN
0587     SMNB(I,3)=SUM3
0588     SMNB(I,3)=TIME
0589  ENDIF
0590  IF(DABS(SUM3).GT.DABS(SMNB(I,3))) THEN
0591     SMNB(I,3)=SUM3
0592     SMNB(I,3)=TIME
0593  ENDIF
0594  SUM4=SUM4+SUM1
0595  SUM5=SUM5+SUM2
0596  SUM6=SUM6+SUM2
0597
0598  1960  CONTINUE
0599
0600
0601  C--PROFILES FOR MAX STRUCTURAL SHEAR IN EACH BUILDING----
0602
0603  IF(IPROF.EQ.1) THEN
0604     N1=0
0605     DO 1665 K=1,NB
0606     DO 1666 I=1,2
0607     IF(DABS(SUMB(K,I))).GT.DABS(C2(I,K,2))THEN
0608         BAS2(K,1,I)=TEMP3(3*MNF+1,1)
0609         BAS2(K,2,I)=TEMP3(3*MNF+2,1)
0610         BAS2(K,3,I)=TEMP3(3*MNF+3,1)
0611         BAS4(K,1,I)=TEMP1(1,3*MNF+1)
0612         BAS4(K,2,I)=TEMP1(1,3*MNF+2)
0613         BAS4(K,3,I)=TEMP1(1,3*MNF+3)
0614         DO 1667 J=1,3*NF(K)
0615             PACC(I,N1+J,3)=TEMP3(N1+J,1)
0616             PDEF(I,N1+J,3)=TEMP1(1,N1+J)
0617      1667 CONTINUE
0618     C2(I,K,2)=SUMB(K,I)
0619     C2T(I,K,2)=TIME
0620   1666 CONTINUE
0621   1966 CONTINUE
0622     N1=N1+3*NF(K)
0623   1965 CONTINUE
0624
0625  ENDIF
0626
0627  C BASE SHEAR (BEARINGS LEVEL)
0628
0629  FIS1=-(SUM4+F(3*MNF+1))
0630  FIS2=-(SUM5+F(3*MNF+2))
0631  FIS3=-(SUM6+F(3*MNF+3))
0632
0633  IF(DABS(FIS1).GT.DABS(BMAXF(1,1))) THEN
0634     BMAXF(1,1)=FIS1
0635     BMAXF(1,2)=TIME
0636  ENDIF
0637  IF(DABS(FIS2).GT.DABS(BMAXF(2,1))) THEN
0638     BMAXF(2,1)=FIS2
0639     BMAXF(2,2)=TIME
0640  ENDIF
0641  IF(DABS(FIS3).GT.DABS(BMAXF(3,1))) THEN
0642     BMAXF(3,1)=FIS3
0643     BMAXF(3,2)=TIME
0644  ENDIF
0645
0646  C--PROFILES FOR MAX BASE SHEARS---
0647
0648  IF(IPROF.EQ.1) THEN
0649     DO 1700 I=1,2
0650
C-30
IF (DABS(BMAXF(I,1)),GT,DABS(C1(I,2))) THEN
  DO 1971 J=1,3,MNF+3
  DO 1933 PAC(I,J,4)=TEMP3(I,J,1)
  DO 1954 PDEF(I,J,4)=TEMP1(I,J,1)
  1971 CONTINUE
  C1(I,2)=BMAXF(I,1)
  C1T(I,2)=TIME
ENDIF
1970 CONTINUE

IF (LTMH.EQ.1) THEN
  CALL WFORC(TIME,SWBH,FISI1,FISI2,FISI3,NF,IT,
             + KPRINT1,PRINT1,0)
C----WRITE FORCE PROFILES FOR MAX OVERTURNING MOMENTS
C-------------AND MAX STRUCTURAL SHEARS

N1=0
N2=0
WRITE(7,10001)
DO 1956 K=1,NB
  N2=N2+1
  WRITE(7,10002) K,OVXT(K),OVMK(K,2),C2T(1,K,2),SUMF(N2-K,1)
  WRITE(7,10004) (NF(K)+1-J,DAX(N2-(NF(K)+1)+J))
  +,PACC(1,N1+3*(J-1)+1,13)*CM(N1+3*(J-1)+1,N1+3*(J-1)+1)
  +,J=1,NF(K))
  WRITE(7,10005) ' BASE ',DAX(N2)
  +,BAS2(K,1,1)*CM(3*MNF+1,3*MNF+1)
  +,'FORCE AT C.M. OF ENTIRE BASE'
N1=N1+3*NF(K)
1956 CONTINUE

N1=0
N2=0
WRITE(7,10003)
DO 1958 K=1,NB
  N2=N2+1
  WRITE(7,10002) K,OVYT(K),OVMY(K,2),C2T(2,K,2),SUMF(N2-K,2)
  WRITE(7,10004) (NF(K)+1-J,CAY(N2-(NF(K)+1)+J))
  +,PACC(2,N1+3*(J-1)+2,3)*CM(N1+3*(J-1)+2,N1+3*(J-1)+2)
  +,J=1,NF(K))
  WRITE(7,10005) ' BASE ',CAY(N2)
  +,BAS2(K,2,2)*CM(3*MNF+2,3*MNF+2)
  +,'FORCE AT C.M. OF ENTIRE BASE'
N1=N1+3*NF(K)
1958 CONTINUE

IF (LTMH.EQ.1) THEN
  CALL WDEFAC(TIME,F,TEMP3,NF,IT,KPRINT,PRINT,1)
  CALL WFORC(TIME,SWBH,FISI1,FISI2,FISI3,NF,IT,
             + KPRINT1,PRINT1,1)
ENDIF

C----WRITE MAX DISPL---
WRITE(7,7010)
N1=0
N2=0
C-31
0723 DO 1980 I=1,NB
0724 WRITE(7,7011) I
0725 DO 1985 J=1,NF(I)
0726 N2=N1+3*(J-1)
0727 WRITE(7,7050)NF(I)+1-J,(DTIME(N2+K),DMAX(N2+K),K=1,3)
0728 CONTINUE
0729 N1=N1+3*NF(I)
0730 CONTINUE
0731 WRITE(7,7051) ' BASE',(DTIME(3*MNF+K),DMAX(3*MNF+K),K=1,3)
0732 C--WRITE DRIFTS FOR EACH BUILDING--
0733 CALL DRIFTS(TIME,TEMP3,XN,YN,NF,H,ICOR,CORDX,CORDY,
0734 + ZN,B(L1),B(L2),B(L3),B(L4),B(L5),B(L6),1)
0735 C--WRITE MAX BEARINGS DISPLACEMENTS-----
0736 IF(INP.GT.0) THEN
0737 WRITE(7,8500)
0738 DO 2010 I=1,INP
0739 WRITE(7,8501) IP(I),DXT(I),DX(I),DXY(I),DYT(I),DYX(I),DY(I)
0740 CONTINUE
0741 ENDIF
0742 END
0743 C--WRITE MAX ACCEL--
0744 WRITE(7,7060)
0745 N1=0
0746 N2=0
0747 DO 1990 I=1,NB
0748 WRITE(7,7061) I
0749 DO 1995 J=1,NF(I)
0750 N2=N1+3*(J-1)
0751 WRITE(7,7070)NF(I)+1-J,(ATIMEF(N2+K),AMAXF(N2+K),K=1,3)
0752 CONTINUE
0753 N1=N1+3*NF(I)
0754 CONTINUE
0755 WRITE(7,7071) ' BASE',(ATIMEF(3*MNF+K),AMAXF(3*MNF+K),K=1,3)
0756 C--WRITE MAXIMUM STRUCTURAL SHEARS-----
0757 WRITE(7,9100)
0758 DO 2570 I=1,NB
0759 WRITE(7,9101) I,(SMBT(I,K),SMBB(I,K),K=1,3)
0760 CONTINUE
0761 2570 CONTINUE
0762 C--WRITE MAX BASE SHEARS---
0763 WRITE(7,6999)
0764 WRITE(7,7100)(BMAXF(I,2),BMAXF(I,1),I=1,3)
0765 C--WRITE MAXIMUM STORY SHEARS--
0766 WRITE(7,9000)
0767 N2=0
0768 DO 2550 I=1,NB
0769 WRITE(7,9001) I
0770 DO 2560 J=1,NF(I)
0771 WRITE(7,9002)NF(I)+1-J,(SUMFT(N2+J,K),SUMF(N2+J,K),K=1,3)
0772 CONTINUE
0773 N2=N2+NF(I)
0774 CONTINUE
0775 2560 CONTINUE
0776 C--WRITE PROFILES FOR TIME WHERE MAX BASE DISPLACEMENT OCCURS
0777 IF(IPROF.EQ.1) THEN
0778 C THE BASE DISPL AND ACCEL ARE IN THE POINT
0779 C WHERE THE C.M. OF FIRST FLOOR IS
0780 C-32
WRITE(7,8599)
DO 2500 I=1,2
IF(I.EQ.1) WRITE(7,8600) C1T(I,1)
IF(I.EQ.2) WRITE(7,8601) C1T(I,1)
N1=0
N2=0
DO 2510 K=1,NB
N2=N2+NF(K)
WRITE(7,8602) K
DO 2511 J=1,NF(K)
WRITE(7,8603) NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,1)
WRITE(I,N1+3*(J-1)+2,1)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,2)
WRITE(I,N1+3*(J-1)+2,2)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,3)
WRITE(I,N1+3*(J-1)+2,3)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
C--WRITE PROFILES FOR MAX ACCELERATION IN EACH BUILDING--
C
CTHE BASE DISPL AND ACCEL ARE IN THE POINT
C WHERE THE C.M. OF FIRST FLOOR IS
WRITE(7,8699)
N1=0
N2=0
DO 2520 K=1,NB
N2=N2+NF(K)
WRITE(7,8700) K
DO 2521 I=1,2
IF(I.EQ.1) WRITE(7,8701) C2T(I,K,1)
IF(I.EQ.2) WRITE(7,8702) C2T(I,K,1)
WRITE(7,8703)
DO 2522 J=1,1,NF(K)
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,2)
WRITE(I,N1+3*(J-1)+2,2)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,3)
WRITE(I,N1+3*(J-1)+2,3)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
C--WRITE PROFILES FOR MAX ACCELERATION IN EACH BUILDING--
C
CTHE BASE DISPL AND ACCEL ARE IN THE POINT
C WHERE THE C.M. OF FIRST FLOOR IS
WRITE(7,8799)
N1=0
N2=0
DO 2530 K=1,NB
N2=N2+NF(K)
WRITE(7,8700) K
DO 2531 I=1,2
IF(I.EQ.1) WRITE(7,8801) C2T(I,K,2)
IF(I.EQ.2) WRITE(7,8802) C2T(I,K,2)
WRITE(7,8703)
DO 2532 J=1,1,NF(K)
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,2)
WRITE(I,N1+3*(J-1)+2,2)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
WRITE(I,N1+3*NF(K)+1-J,PDEF(I,N1+3*(J-1)+1,1)
WRITE(I,N1+3*(J-1)+1,1),PDEF(I,N1+3*(J-1)+2,3)
WRITE(I,N1+3*(J-1)+2,3)
IF(J.EQ.AF(K)) WRITE(7,8604) ' BASE'
C-33
C -- WRITE PROFILES FOR MAX BASE SHEARS ----
C THE BASE DISPL AND ACCEL ARE IN THE POINT
C WHERE THE C.M. OF FIRST FLOOR IS

WRITE(7,8899)
DO 2540 I=1,2
IF(I.EQ.1) WRITE(7,8900) C1T(I,2)
IF(I.EQ.2) WRITE(7,8901) C1T(I,2)
N1=0
N2=0
DO 2541 K=1,NB
N2=N2+NF(K)
WRITE(7,8602) K
DO 2542 J=1,NF(K)
WRITE(7,8603) NF(K)+J-1,PDEF(I,N1+3*(J-1)+1,4)
PACC(I,N1+3*(J-1)+1,4),PDEF(I,N1+3*(J-1)+2,4)
ENDF
2541 CONTINUE
2540 CONTINUE

RETURN

1002 FORMAT(///6X,'ISOLATORS TIME HISTORIES...............')
101 2X,'TIME',1X,2X,10(1X,4X,12,4X))
1011 5000 FORMAT(/6X,'INST STIFF',3X,'FORCE',3X,'DISPL',3X,'Z',3X,'VEL')
1012 5010 FORMAT(15X,E15.7,1X)
1013 6000 FORMAT(/6X,'DISPLACEMENT...AT...FLOOR DEGREE OF FREEDOM'
1014 +,'TIME',7X,6(I3,7X))
1015 6002 FORMAT(6X,F6.3,1X,E10.4,1X)
1016 7000 FORMAT(/6X,'FORCE...AT...FLOOR DEGREE OF FREEDOM',/'
1017 15X,'(FINAL THREE DEGREES OF FREEDOM REPRESENT BASE SHEAR)',/
1018 15X,' - AT THE TOP OF THE BASE',/'
1019 11X,'TIME',7X,6(I3,7X))
1020 7001 FORMAT(/6X,'FORCE AT STRUCTURES LEVEL'
1021 7002 FORMAT(1X,F5.2,1X,12(E9.3,1X))
1022 7080 FORMAT(6X,'MAX. FORCE 2ND COLUMN AT BEARING LEVEL')
1023 7090 FORMAT(6X,'MAX. RESULTANT DISP, FORCE AND PERM DISP')
1024 7200 FORMAT(6X,'FORCE IN X AND Y DIR AT PA: ','15)
1025 7300 FORMAT(6X,F12.6,6X,F12.6,1X)
1026 7400 FORMAT(/6X,'BASE SHEARS'/
1027 +6X,'TIME',3X,'X DIRECTION',1X,'Y DIRECTION',/'
1028 +1X,'R DIRECTION')
1029 7401 FORMAT(6X,F6.3,1X,E10.4,2X))
1030 C
1031 6999 FORMAT(///6X,'MAXIMUM BASE SHEARS ...............',/'
1032 +6X,'TIME',1X,'FORCE X',/'
1033 +1X,'TIME',1X,'FORCE Y',1X,'TIME',1X,'Z MOMENT')
1034 7100 FORMAT(36X,F6.3,1X,E10.4)
1035 7010 FORMAT(/6X,'MAX. RELATIVE DISPLACEMENTS AT',/'
1036 +CENTER OF MASS OF LEVELS',/'
1037 +6X,/')
1038 +(WITH RESPECT TO THE BASE)
7011 FORMAT(/'SUPERSTRUCTURE : ','I2,
+ '/6X,' LEVEL','1X,' TIME ','1X,' DISPL 'X ','
+ '1X,' TIME ','1X,' DISPL 'Y ','1X,' TIME ','1X,' ROTATION '/)
7050 FORMAT(/'6X,' LEVEL','1X,' TIME ','1X,' DISPL 'X ',
+ '1X,' TIME ','1X,' DISPL 'Y ','1X,' TIME ','1X,' ROTATION '/
+ '/6X,A5,3(1X,F6.3,1X,E10.4))
7060 FORMAT(/'6X,' MAX. TOTAL ACCELERATIONS AT ',
+ 'CENTER OF MASS OF LEVELS')
7061 FORMAT(/'6X,' SUPERSTRUCTURE : ','I2,
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'X ',
+ '1X,' TIME ','1X,' ACCEL 'Y ',
+ '1X,' TIME ','1X,' ACCEL 'Z')
7070 FORMAT(/'6X,' MAX. BEARING DISPLACEMENTS'/
+ '/6X,8X,1X,' MAX DISPL 'X ',8X,5X
+ '/6X,1X,' MAX DISPL 'Y ',
+ '/6X,' MAX DISPL 'Z')
8001 FORMAT(/'6X,F6.3,1X,A2,1X,10(E10.4,1X))
8002 FORMAT(/'6X,F6.3,1X,A2,1X,10(E10.4,1X))
8500 FORMAT(/'6X,' MAXIMUM BEARING DISPLACEMENTS'/
+ '/6X,8X,1X,' MAX DISPL 'X ',8X,5X
+ '1X,' MAX DISPL 'Y ',
+ '/6X,' MAX DISPL 'Z')
8501 FORMAT(/'6X,F6.3,1X,A2,1X,10(E10.4,1X))
8599 FORMAT
8600 FORMAT(/'6X,' PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT'
+ '/6X,' MAXIMUM BASE DISPLACEMENT IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8601 FORMAT(/'6X,' MAXIMUM BASE DISPLACEMENT IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8602 FORMAT(/'6X,' SUPERSTRUCTURE : ','I2,
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'X ',
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'Y ',
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'Z')
8603 FORMAT(/'6X,F6.3,1X,A2,1X,10(E10.4,1X))
8604 FORMAT(/'6X,F6.3,1X,A2,1X,10(E10.4,1X))
8699 FORMAT
8700 FORMAT(/'6X,' SUPERSTRUCTURE : ','I2,
+ '/6X,' MAX ACCELERATION IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8701 FORMAT(/'6X,' MAX ACCELERATION IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8702 FORMAT(/'6X,' MAX ACCELERATION IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8703 FORMAT(/'6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'X ',
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'Y ',
+ '/6X,' LEVEL','1X,' TIME ','1X,' ACCEL 'Z')
8799 FORMAT
8800 FORMAT(/'6X,' MAXIMUM BASE SHEAR IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8801 FORMAT(/'6X,' MAXIMUM BASE SHEAR IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8802 FORMAT(/'6X,' MAXIMUM BASE SHEAR IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8899 FORMAT
8900 FORMAT(/'6X,' MAXIMUM BASE SHEAR IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
8901 FORMAT(/'6X,' MAXIMUM BASE SHEAR IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9000 FORMAT(/'6X,' MAXIMUM SHEAR IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9001 FORMAT(/'6X,' MAXIMUM SHEAR IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9002 FORMAT(/'6X,' MAXIMUM SHEAR IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9003 FORMAT(/'6X,' MAXIMUM SHEAR IN Z DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9004 FORMAT(/'6X,' MAXIMUM SHEAR IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9005 FORMAT(/'6X,' MAXIMUM SHEAR IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9006 FORMAT(/'6X,' MAXIMUM SHEAR IN Z DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9007 FORMAT(/'6X,' MAXIMUM SHEAR IN X DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9008 FORMAT(/'6X,' MAXIMUM SHEAR IN Y DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9009 FORMAT(/'6X,' MAXIMUM SHEAR IN Z DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9010 FORMAT(/'6X,' MAXIMUM SHEAR IN ' DIRECTION',
+ '/6X,' TIME ':'1X,F6.3)
9100 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9101 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9102 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9103 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9104 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9105 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9106 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9107 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9108 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9109 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
9110 FORMAT(/'6X,' MAXIMUM STRUCTURAL SHEARS',
+ '/6X,' TIME ':'1X,F6.3)
C******************************************************************************
SUBROUTINE DRIFTS (TIME,DEF,XN,YN,NF,H,ICOR,CORDX,CORDY,
AXD,AYD,PXD,PYD,PDXT,PDYT,INDEX)
C******************************************************************************
C SUBROUTINE FOR CALCULATING AND PRINTING INTERSTORY DRIFT RATINGS.
C DEVELOPED BY..................................PANAGIOTIS TSOPELAS....APR 1991
C******************************************************************************
IMPLICIT REAL*8 (A-H,O-Z)
COMMON /MAIN*1/NB,NP,MNF,MNE,NFE,MAX
DIMENSION DEF(3*MNF+3),NF(NB),XN(MNF),YN(MNF),H(MNF+NB)
DIMENSION ICOR(NB),CORDX(NB,6),CORDY(NB,6)
DIMENSION AXD(NB,MNF,6),AYD(NB,MNF,6),
PXD(NB,MNF,6),PYD(NB,MNF,6),
PDXT(NB,MNF,6),PDYT(NB,MNF,6)
IF(INDEX) 5,5,10
5 CONTINUE
N1=0
N2=0
DO 100 I=1,NB
N2=N2+NF(I)
100 CONTINUE
DO 110 J=1,NF(I)
110 CONTINUE
DO 120 L=1,ICOR(I)
IF(J.EQ.NF(I)) THEN
120 CONTINUE
N1=N1+3*NF(I)
ELSE
N1=N1+3*NF(I)
120 CONTINUE
ENDIF
0061 220 CONTINUE
0062 210 CONTINUE
0063 200 CONTINUE
0064
0065 GO TO 20
0066
0067 10 CONTINUE
0068
0069 N1=0
0070 WRITE(7,1000)
0071 DD 300 I=1,NB
0072 WRITE(7,1010) I
0073 WRITE(7,1011) ((L,CORDX(I,L),CORDY(I,L)),L=1,ICOR(I))
0074 KS2=1
0075
0076 400 KS3=KS2+2
0077 KS4=ICOR(I)
0078 IF(KS3.LE.ICOR(I))KS4=KS3
0079 WRITE(7,1020)(L,L=KS2,KS4)
0080 WRITE(7,1021)
0081 N1=N1+NF(I)+1
0082 DD 310 J=1,NF(I)
0083 WRITE(7,1030) NF(I)+1-U
0084 +,(PXDOT(I,J,L),PXD(I,J,L))/((H(N1+1-U)-H(N1-1-(J+1))))
0085 +,(PYDOT(I,J,L),PYD(I,J,L))/((H(N1+1-U)-H(N1-1-(J+1))))
0086 310 CONTINUE
0087
0088 KS2=KS2+2
0089 IF(ICOR(I).GT.KS2) GOTO 400
0090 200 CONTINUE
0091
0092 20 CONTINUE
0093
0094 RETURN
0095
0096 1000 FORMAT(/"MAXIMUM INTERSTORY DRIFT RATIOS"
0097 +HOW FOR EACH SUPERSTRUCTURE/)"
0098 1010 FORMAT(/"SUPERSTRUCTURE :",1X,I2)
0099 1011 FORMAT(/"COORDINATES OF COLUMN LINES"
0100 +"WITH RESPECT TO MASS CENTER OF BASE",
0101 +"/6X,C/L :",1X,"/X CORD :,",F10.3,
0102 +"/6X,7X,"/1X,"Y CORD :,",F10.3)
0103 1020 FORMAT(/"COLUMN LINES",
0104 +"/6X,3(15X,I1,14X))"
0105 1021 FORMAT(/"LEVEL",
0106 +"/6X,3(1X,"/TIME',5X,'X DIR',1X,'TIME',5X,'Y DIR'))"
0107 1030 FORMAT(6X,1X,12,2X,6(1X,F6.3,1X,E10.4))"
0108 END
0109
0110 C***********************************************************************
0111 SUBROUTINE WFORC(TIME,SUMB,FISI1,FISI2,FISI3,NF,IT,
0112 +KPRINT1,PRINT1,INDEX)
0113 C***********************************************************************
0114 C SUBROUTINE FOR PRINTING FORCE OUTPUT.
0115 C DEVELOPED BY........................PANAGIOTIS TSOPELAS...APR 1991
0116 C***********************************************************************
0117 C***********************************************************************
0118 IMPLICIT REAL*8 (A-H,O-Z)
0119 COMMON /MAIN /NB,NP,MNF,MNE,MFE,MXF
0120 COMMON /PRINT /LTMH,IPROF,KPD,KPF,INP
0121 COMMON /DIREC /DRIN(3),DRIN(4)
0122 CHARACTER*1 DRIN
0123 CHARACTER*2 DRIN1
0124 DIMENSION NF(NB),SUMB(NB,3)
0125 C
0126 C Mnf3=Mnf+3
0127 C
0128 C IF(INDEX) 5,5,10

C-37
CONTINUE
IF (IT.EQ.KPRINT) THEN
C---------------WRITE 30+... STRUCTURES BASE SHEARS-----
  KS1=0
  KS2=1
1985 KS3=KS2+9
  KS4=NB
  IF(KS3.LE.NB)KS4=KS3
  WRITE(30+KS1)TIME,KS2,KS4
  +,(SUMB(I,1),SUMB(I,2),SUMB(I,3),I=KS2,KS4)
  KS2=KS2+10
  KS1=KS1+1
  GO TO 1985
C---------------WRITE 40 BASE SHEARS-------------------
  WRITE (40)TIME,FISI1,FISI2,FISI3
  +,KPRINT=KPRINT+KPF
  PRINT1=PRINT1+1
ENDIF
GO TO 20
10 CONTINUE
  KS1=0
  KS2=1
2100 KS3=KS2+9
  KS4=NB
  IF(KS3.LE.NB)KS4=KS3
  WRITE (50,7000)KS2,(KS2+I,1=I,9)
  RENN (30+KS1)
  II=1,PRINT1
  READ (30+KS1)TIME,KS2,KS4
  +,(SUMB(I,1),SUMB(I,2),SUMB(I,3),I=KS2,KS4)
  WRITE (50,7002)TIME,DRIN(1),(SUMB(I,1),I=KS2,KS4)
  WRITE (50,7003)DRIN(2),(SUMB(I,2),I=KS2,KS4)
  WRITE (50,7003)DRIN(3),(SUMB(I,3),I=KS2,KS4)
2250 CONTINUE
  KS2=KS2+10
  KS1=KS1+1
  GO TO 2100
  RENN(40)
  WRITE(50,7400)
  DO 2400 II=1,PRINT1
  READ (40) TIME,FISI1,FISI2,FISI3
  WRITE (50,7401)TIME,FISI1,FISI2,FISI3
2400 CONTINUE
20 CONTINUE
RETURN
7000 FORMAT(/6X,'FORCE AT STRUCTURES LEVEL (STRUCTURAL SHEARS)',/2X,'TIME',1X,'DIRC',1X,10(E10.4,1X))
7002 FORMAT(1X,F6.3,1X,2X,A1,1X,1X,10(E10.4,1X))
7003 FORMAT(1X,6X,1X,2X,A1,1X,1X,10(E10.4,1X))
7400 FORMAT(/6X,'FORCE AT BASE LEVEL (BASE SHEAR)/'2X,'TIME',5X,'X DIRECTION',5X,'Y DIRECTION',5X,'R DIRECTION')
7401 FORMAT(1X,F6.3,6X,3(E10.4,6X))
7402 CONTINUE
--- C-38 ---
C****************************************************************************** WDEFAC **********
SUBROUTINE WDEFAC(TIME, DF, AC, NF, IT, KPRINT, PRINT, INDEX)

C******************************************************************************
C SUBROUTINE FOR PRINTING DISPLACEMENT AND ACCELERATION OUTPUT.
C DEVELOPED BY ....................... PANAGIOTIS TSOPELAS .... APR 1991
C******************************************************************************

IMPLICIT REAL*8 (A-H,O-Z)
COMMON /MAIN /NB, NP, MNF, MNE, NFE, MFX
COMMON /PRINT /LTMH, IPRFDF, KPD, KPF, INP
DIMENSION DF(3*MNF+3), NF(NB), AC(3*MNF+3)
MNF3=3*MNF+3

IF(INDEX) 5, 10
5 CONTINUE
IF(IT.EQ.KPRINT)THEN
N1=0
N2=0
DD = 10 I=1,NB
ISK = 50+I
DD = 120 J=1,NF(I)
N2=N1+3*(J-1)
IF(J.EQ.1) THEN
WRITE(ISK,1002) TIME, NF(I)+1-J,
+ (AC(N2+K),K=1,2), (DF(N2+K),K=1,3)
ELSE
WRITE(ISK,1003) NF(I)+1-J,
+ (AC(N2+K),K=1,2), (DF(N2+K),K=1,3)
ENDIF
120 CONTINUE
N1=N1+3*NF(I)
110 CONTINUE
WRITE(20)TIME,(AC(MNF3-(3-I)),I=1,2),(DF(MNF3-(3-I)),I=1,3)
KPRINT=KPRINT+KPD
PRINT=PRINT+1
END IF
GO TO 20

10 CONTINUE
WRITE(50,6000)
REWIND(20)
DO 2002 II=1,PRINT
READ(20)TIME,(AC(I),I=1,2),(DF(I),I=1,3)
2002 WRITE(50,6002) TIME,(AC(I),I=1,2),(DF(I),I=1,3)
20 CONTINUE
RETURN
1002 FORMAT(1X,F6.3,1X,I3,3X,2(E10.4,1X)),3(E10.4,1X))
1003 FORMAT(1X,F6X,1X,I3,3X,2(E10.4,1X)),3(E10.4,1X))
6000 FORMAT(/6X,'BASE ACCELERATIONS AND DISPLACEMENTS...AT...C.M.'
+ '/X', 'TIME', 'ACCEL X', 'ACCEL Y', 'ACCEL Z', 'DISPL X', 'DISPL Y', 'DISPL Z', 'ROTATION/)
6002 FORMAT(1X,F6.3,1X,5(E10.4,1X))
END

C******************************************************************************
C SUBROUTINE BEARING(ERR, FN, FX, FY, XP, YP, DN, VN, VNP, AN, ANP, FH, IT
+ .ZX, ZY, FNXY, ALP, YF, YD, FMAX, DF, PA, INELEM, DLF)

C-39
C **SUBROUTINE FOR STATE DETERMINATION AT BEARINGS.**
C DEVELOPED BY..........................SATISH NAGARAJAIAH....OCT 1990
C
C
IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN /NB,NP,MINF,MN1,MNF,MNE,MXF
COMMON /STEP /TSI,TSR
COMMON /HYS1 /WBE,HGWAM
DIMENSION FX(NP),FY(NP),TP(3,3),
+ TEMP(3,3),TEMP2(3,3),TEMP3(3,1),TEMP4(3,1),TEMP5(3,1),
+ XP(NP),YP(NP),DN(3,2),VN(3),VNP(3),AN(3),ANP(3),
+ FH(MNE+3),ZX(NP),ZY(NP),INELEM(NP,2),
+ PKI(2),FR(2),ERR(3),FN(NP),FNXY(NP),DFLM(MNE+3)
C +,ALP(NP,2),YF(NP,2),YD(NP,2),FMAX(NP,2),DF(NP,2),PA(NP,2)
DO 10 I=1,3
DO 10 J=1,3
TP(I,J)=0.0
10 CONTINUE
20 CONTINUE
DO 100 I=1,NP
IF(INELEM(I,2).LE.2) GO TO 100
J=1
TP(1,1)=1
TP(2,2)=1
TP(3,3)=1
TP(3,1)=-YP(I)
TP(3,2)=XP(I)
CALL TMULT(TP,DN,TEMP1,3,3,2)
CALL TMULT(TP,VN,TEMP2,3,3,1)
CALL TMULT(TP,VNP,TEMP3,3,3,1)
CALL TMULT(TP,AN,TEMP4,3,3,1)
CALL TMULT(TP,ANP,TEMP5,3,3,1)
IF(IT.EQ.1) THEN
FR(1)=0
FR(2)=0
ELSE
FR(1)=FX(I)
FR(2)=FY(I)
END IF
CALL HYS(IT,PKI,TEMP1,TEMP2,TEMP3,TEMP4,TEMP5,FR,I,ZX,ZY
+ ,FN,FNXY,ALP,YF,YD,FMAX,DF,PA,INELEM)
IF(I.EQ.1) THEN
FR(I)=FR(1)
FY(I)=FR(2)
100 CONTINUE
DUM1=0.0
DUM2=0.0
DUM3=0.0
DO 200 I=1,NP
DUM1=DUM1*FX(I)
DUM2=DUM2*FY(I)
DUM3=DUM3*XP(I)*XP(I)-FX(I)*YP(I)
200 CONTINUE
DELF1=DUM1-FH(MNE+1)
DELF2=DUM2-FH(MNE+2)
DELF3=DUM3-FH(MNE+3)
ERR(1)=DELF1-DELF(MNE+1)
ERR(2)=DELF2-DELF(MNE+2)
ERR(3)=DELF3-DELF(MNE+3)
DELFC(MNE+1)=DELFL1
DELFC(MNE+2)=DELFL2
DELFC(MNE+3)=DELFL3

C
RETURN
END

C*************************************************************** LUALY **********

SUBROUTINE LOAD(TMP1,TMP2,TR,CM,Y,X,UG,PTU,IT)

C SUBROUTINE TO FORM THE REDUCED LOAD VECTOR USING THE SPECIFIED
C GROUND ACCELERATION VECTOR.
C DEVELOPED BY ------------------------ SATHIY SAGARAIAH... OCT 1990
C
C
C***************************************************************

IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN /NB,NP,MNF,MNE,NFE,MAXF
COMMON /STEP /TSI,TSR
COMMON /GENBASE /ISEV,LOR
COMMON /LOAD1 /XTH,IDAT,TIME,PTSR,ULF,INDGACC
DIMENSION TEMP1(MNE+3,3,MNF+3),TEMP2(MNE+3,3,T(3*MNF+3,MNE+3))
+ ,R(3*MNF+3,3),CM(3*MNF+3,3),YL(T),UG(3,1),PTU(MNE+3)
+ ,X(LOR)

C
70 TIME=TIME+TSI

80 IF(TIME.GT.(LON-1)*TEN)GO TO 100

20 IF(TIME.LE.PTSR)GO TO 90

22 IDAT=IDAT+1

23 PTSR=PTSR+TSR

25 GO TO 80

90 IF(INDGACC.EQ.1)THEN

UG(1,1)=DGOS(XTH)*(X(IDAT)+(X(IDAT)-X(IDAT))*TSR)

UG(2,1)=DGOS(XTH)*(X(IDAT)+(X(IDAT)-X(IDAT))*TSR)

ELSE IF(INDGACC.EQ.2)THEN

UG(1,1)=(X(IDAT)-(X(IDAT)-X(IDAT))*TSR)

UG(2,1)=(X(IDAT)-(X(IDAT)-X(IDAT))*TSR)

END IF

30 UG(3,1)=0.0

40 CONTINUE

41 J1=3*MNF+3

42 J2=MNE+3

43 CALL TMC(T,CM,CM,F,CM,F)

45 CALL MUL(TMP1,R,TEMP2,U1,J1)

46 DO 200 I=1,MNF+3

47 SUM=0.0

50 DO 150 K=1,3

51 SUM=SUM+TESP(I,K)*UG(K,1)*ULF

60 CONTINUE

63 PTI=-SUM

70 CONTINUE

80 C

RETURN

C*************************************************************** HYS *****

SUBROUTINE HYS(TH,PKI,DN,VN,VNP,AN,ANP,FXY,I,ZXX,ZYY
+ ,FN,FNXY,ALP,YF,YD,YMER,DX,PA,INELE)

C
C-41
SUBROUTINE TO CALCULATE THE FORCES AT BEARINGS.

DEVELOPED BY SATISH NAGARAJAIAH...OCT 1990

C******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)
COMMON /MAIN/NB,NP,MNF,MNE,NF,M XF
COMMON /SIG1/ISI,ISK
COMMON /CON1/A1,A2,A3,A4,A5
COMMON /CON2/B1,B2,B3,B4,B5
COMMON /PARA/C1,C2,GAMA,BETA,Y(2)
COMMON /HYS1/WBET,WGAM

DIMENSION DN(3,2),VN(3),VNP(3),AN(3),ANP(3),FN(NP),FNXY(NP)
+ZXX(NP),ZYY(NP),FXY(2),PKI(2),DA(2),VRK(2),ARK(2),Z(2)
+APL(NP,2),YF(NP,2),YD(NP,2),FMAX(NP,2),EF(NP,2),PA(NP,2)
+INELEM(NP,2)

DIMENSION AJI(2,2),ZX(2),ZY(2),ZP(2,2),RK(2),RL(2)
+V(2,2)

DATA C1,C2 / 0.788675134595, -1.15470053838 /

GAMA=0.9
BETA=0.1

Y(1)=YD(I,1)
Y(2)=YD(I,2)

V1=(VNP(1)+VN(1))/2
V2=(VNP(2)+VN(2))/2

V(1,1)=V1
V(2,1)=V2

V(1,2)=V1
V(2,2)=V2

IF(INELEM(I,1).EQ.3)THEN

CALL UNIAXIAL(V1,ZXY,YD1)
ZXX(I)=ZXY
ZYY(I)=0.0

ELSE IF(INELEM(I,1).EQ.2)THEN

YD2=Y(2)
ZXY=ZYY(I)

CALL UNIAXIAL(V2,ZXY,YD2)
ZYY(I)=ZXY
ZXX(I)=0.0

IF(INELEM(I,2).EQ.3)THEN

FXY(1)=ALP(I,1)*YF(I,1)/YD(I,1)*DN(1,2)+(1-ALP(I,1))
+YF(I,1)*ZXX(I)
FXY(2)=ALP(I,2)*YF(I,2)/YD(I,2)*DN(2,2)+(1-ALP(I,2))
+YF(I,2)*ZYY(I)

IF(INELEM(I,1).EQ.1)THEN

C-42
FXY(2)=0
ELSE IF(INELEM(I,1).EQ.2) THEN
FXY(1)=0
END IF
END IF
IF(INELEM(I,2).EQ.4) THEN
IF(INELEM(I,1).EQ.1 .OR. INELEM(I,1).EQ.2) THEN
FMW1=FMAX(I,1)-DF(I,1)*DEXP(-PA(I,1)*DABS(VN(1)))
FMW2=FMAX(I,2)-DF(I,2)*DEXP(-PA(I,2)*DABS(VN(2)))
ELSE IF(INELEM(I,1).EQ.3) THEN
VELC=DSQRT(VN(1)**2+VN(2)**2)
FMW1=FMAX(I,1)-DF(I,1)*DEXP(-PA(I,1)*DABS(VELC))
FMW2=FMAX(I,2)-DF(I,2)*DEXP(-PA(I,2)*DABS(VELC))
END IF
FXY(1)=FMW1*FNXY(I)*ZXX(I)
FXY(2)=FMW2*FNXY(I)*ZYY(I)
END IF
C******************************************************************************
SUBROUTINE BIAXIAL(I,V,ZXX,ZYY,NP)
C******************************************************************************
SUBROUTINE TO CALCULATE THE HYSTERETIC PARAMETERS
DEVELOPED BY SATISH NAGARAJAN....OCT 1990
IMPLICIT REAL*8(A-K,O-Z)
COMM /STEP/ TSI,TSR
COMM /CON1/A1,A2,A3,A4,A5
COMM /CON2/B1,B2,B3,B4,B5
COMM /PARA/C1,C2,GAMA,BETA,Y(2)
DIMENSION ZXX(NP),ZYY(NP)
DIMENSION ZI(2,2),ZK(2,2),Z(2,2),ZP(2,2),RK(2,2),RL(2)
T=TSI
ZK(1,1)=ZXX(I)
ZK(1,2)=ZYY(I)
CALL CONSTD(V(1,1),V(2,1),ZK(1,1),ZK(1,2))
AJI(1,1)=C1*T*(2*B2*ZK(1,1)+2*B3*ZK(1,1)+B4*ZK(1,1)+B5*ZK(1,1))
AJI(2,2)=C1*T*(2*A2*ZK(1,1)+2*A3*ZK(1,2)+A4*ZK(1,2)+A5*ZK(1,2))
AJI(1,2)=-C1*T*(A4*ZK(1,2)+A5*ZK(1,2))
UJI1=AJI(1,1)-AJI(2,2)
UJI2=AJI(1,1)*AJI(2,2)-AJI(1,2)*AJI(2,1)
DO 40 II=1,2
DO 30 JI=1,2
30 AJI(JI,JJ)=AJI(JI,JJ)/DAJI
40 CONTINUE
DO 80 II=1,2
  SUM=0
  DO 60 JJ=1,2
    SUM=SUM+AJI(II JJ)*ZP(JJ 1)*T
  RK(II)=SUM
  60 CONTINUE

ZX(2)=ZX(1)+C2*RK(1)
ZY(2)=ZY(1)+C2*RK(2)

CALL CONST(V1 2 V2 2 ZX(2) ZY(2))

ZP(1 2)= A1-A2*ZX(2)**2-A3*ZX(2)**2
  + -A4*ZX(2)*ZY(2)-A5*ZX(2)*ZY(2)

ZP(2 2)= B1-B2*ZY(2)**2-B3*ZY(2)**2
  + -B4*ZX(2)*ZY(2)-B5*ZX(2)*ZY(2)

DO 120 II=1,2
  SUM=0
  DO 110 JJ=1,2
    SUM=SUM+AJI(II JJ)*ZP(JJ 2)*T
  RL(II)=SUM
  110 CONTINUE

ZX(1)=ZX(1)+0.75*RK(1)+0.25*RL(1)
ZY(1)=ZY(1)+0.75*RK(2)+0.25*RL(2)
ZXX(1)=ZX(1)
ZY(1)=ZY(1)

RETURN
END

C******************************************************************************
SUBROUTINE UNIAXIAL(V1,ZX1,YD)
C******************************************************************************

C******************************************************************************
C SUBROUTINE TO CALCULATE THE HYSTERETIC PARAMETERS
C DEVELOPED BY ................ SATISH NAGARAJAHIAH........ OCT 1990
C******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)
COMMON /STEP/ TSI TSR
COMMON /PARA/C1 C2 GAMMA BETA Y2
COMMON /CONJ/A1 A2 A3
DIMENSION ZX(2) ZP(1 2)

NETA=2
T=TSI
ZX(1)=ZX1
CALL CONST(V1 ZX(1) YD GAMMA BETA)
ZP(1 1)= A1-A2*ZX(1)**2-NETA-A1*ZX(1)**NETA
AJI1=1+T*C1*NETA*ZX(1)**(NETA-1)*(A2 A3)
AJI=1/AJI1
RK = AJI * ZP(1, 1) * T
ZX(2) = ZX(1) + C2 * RK
CALL CONSTU(V1, ZX(2), YD, GAMMA, BETA)
ZX(1) = ZX(1) + 0.75 * RK + 0.25 * RL
ZX1 = ZX(1)
RETURN
END

C**********************************************************
CONST **********
SUBROUTINE CONST(VX, VY, ZX, ZY)
C**********************************************************
C SUBROUTINE TO CALCULATE THE HYSTERETIC PARAMETERS
C DEVELOPED BY ................ SATISH NAGARAJAIAH .... OCT 1990
C
IMPLICIT REAL*8 (A-H, O-Z)
COMMON /CON1/A1, A2, A3, A4, A5
COMMON /CON2/B1, B2, B3, B4, B5
COMMON /PARA/C1, C2, GAMMA, BETA, Y(2)
ONE = 1
SIGNX = DSIGN(ONE, VX * ZX)
SIGNY = DSIGN(ONE, VY * ZY)
A1 = VX / Y(1)
A2 = GAMMA * VX * SIGNX / Y(1)
A3 = BETA * VX / Y(1)
A4 = GAMMA * VY * SIGNY / Y(1)
A5 = BETA * VY / Y(1)
B1 = VY / Y(2)
B2 = GAMMA * VY * SIGNY / Y(2)
B3 = BETA * VY / Y(2)
B4 = GAMMA * VX * SIGNX / Y(2)
B5 = BETA * VX / Y(2)
RETURN
END

C**********************************************************
CONST**********************************************************
SUBROUTINE CONSTU(VX, ZX, YD, GAMMA, BETA)
C**********************************************************
C SUBROUTINE TO CALCULATE THE HYSTERETIC PARAMETERS
C-45
C DEVELOPED BY ............SATISH NAGARAJAIAH....OCT 1990

C

C**********************************************************************************

C

IMPLICIT REAL*8 (A-H,O-Z)
COMMON /CONU;/A1,A2,A3
ONE=1
SIGNX=DSIGN(DONE, VX*ZX)
A1=VX/YD
A2=GAMA*VX*SIGNX/YD
A3=BETA*VX/YD
RETURN
END

C**********************************************************************************

C******************************************************************************

C

SUBROUTINE MAX(A,B,MN)

C******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(MN),B(MN)
UU
IU
I=1,MN
IF(DABS(A(I)).GT.DABS(B(I)))B(I)=A(I)
10 CONTINUE
RETURN
END

C******************************************************************************

C******************************************************************************

C

SUBROUTINE MULT(A,B,C,NR,NT,NC)

C******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(NR,NT),B(NT,NC),C(NR,NC)

C

DD 200 I=1,NR
DD 200 J=1,NC
X=0.0
DD 100 K=1,NT
100 X=X+A(I,K)*B(K,J)
200 C(I,J)=X
RETURN
END

C******************************************************************************

C******************************************************************************

C

SUBROUTINE TMULT(A,B,C,NT,NR,NC)

C******************************************************************************

IMPLICIT REAL*8(A-H,O-Z)
DIMENSION A(NT,NR),B(NT,NC),C(NR,NC)

C

DD 200 I=1, NR
DD 200 J=1, NC
X=0.0
DD 100 K=1, NT
100 X=X+A(K,I)*B(K,J)
200 C(I,J)=X
RETURN
END

C

RETURN

END

C-46
SUBROUTINE TRANSP(A,AT,NR,NC)

C******************************************************************************

IMPLICIT REAL*(A-H,O-Z)
DIMENSION A(NK,NK),A1(NL,NL)

DO 100 I=1,NR
DO 100 J=1,NC
100 AT(J,I)=A(I,J)
RETURN
END

SUBROUTINE GAUSS(A,B,NEQ,LEQ,LL,M)
C******************************************************************************

IMPLICIT REAL*(A-H,O-Z)

**SYMMETRICAL EQUATION SOLVER**

C M = 0 TRIANGULARIZATION AND SOLUTION
C M = 1 TRIANGULARIZATION ONLY
C M = 2 FORWARD REDUCTION ONLY
C M = 3 BACKSUBSTITUTION ONLY
DIMENSION A(NEQ,NEQ),B(NEQ,LL)

IF(M.EQ.3) GO TO 800
IF(M.EQ.2) GO TO 500

**TRIANGULARIZATION**

DO 400 N=1,LEQ
400 IF(N.EQ.NEQ) GO TO 400
C
D = A(N,N)
IF(D.NE.0.0) GO TO 100
WRITE(6,2000) N
STOP

100 N1 = N + 1
C
DO 300 J=N1,NEQ
300 IF(A(N,J).EQ.0.0) GO TO 300
A(N,J) = A(N,J)/D
C
DO 200 I=J,NEQ
200 A(I,J) = A(I,J) - A(I,N)*A(N,J)
C
200 A(J,J) = A(I,J)
C
300 CONTINUE
300 CONTINUE
400 CONTINUE
400 CONTINUE

IF(NEQ,NEQ,1) A(NEQ,1) = LEQ
IF(M.EQ.1) RETURN

**FORWARD REDUCTION**

500 IF(NEQ,NEQ,1) LEQ = A(NEQ,1)
DO 700 N=1,LEQ
700 CONTINUE
C
IF(N.EQ.NEQ) GO TO 650

N1 = N + 1
C
DO 600 L=1,LL
600 B(I,L) = B(I,L) - A(N,I)*B(N,L)
C
650 DO 675 L=1,LL
675 B(N,L) = B(N,L)/A(N,N)
C
700 CONTINUE

C-47
C--------BACK-SUBSTITUTION-----------------------
0060 N = NEQ
0061 IF(NEQ.NE.1) LEQ = A(NEQ,1)
0062 IF(LEQ.NE.0) N = LEQ + 1
0063 B10 N1 = N
0064 N = N - 1
0065 IF(NEQ.NE.0) RETURN
0066 C
0067 DO 900 L=1,LL
0068 DO 900 J=N1,NEQ
0069 900 B(N,L) = B(N,L) - A(N,J)*B(J,L)
0070 GO TO B10
0071 C
0072 2000 FORMAT(/' * ERROR * +DIAGONAL TERM OF EQUATION ',I4,' = ZERO/')
0073 END
0074 C
0075 SUBROUTINE JACOBI (A,B,X,E,N,NFIG,NSMAX,N1)
0076 C
0077 C
0078 C  SUBROUTINE SOLVES EIGENVALUE PROBLEM AX = BXE WHERE
0079 C  A AND B ARE N X N SYMMETRIC MATRICES
0080 C  E IS A DIAGONAL MATRIX OF EIGENVALUES STORED AS A COLUMN
0081 C  X IS A N X N MATRIX OF EIGENVECTORS
0082 C  NSMAX IS THE MAXIMUM NUMBER OF SWEEPS TO BE PERFORMED
0083 C  NFIG IS THE NUMBER OF SIGNIFICANT FIGURES TO BE OBTAINED
0084 C
0085 C  IMPLICIT REAL*8 (A-H,O-Z)
0086 C  DIMENSION A(N1,N1),B(N1,N1),X(N1,N1),E(N1)
0087 C
0088 C--------INITIALIZATION--------------------------
0089 NT = 0
0090 NN = N-1
0091 RTDL = 0.1**(2*NFIG)
0092 EPS = 0.01
0093 DD 30 I=1,N
0094 DD 20 J=1,N
0095 20 XI(J) = 0.
0096 30 XI(I) = 1.
0097 IF(NEQ.1) GO TO B20
0098 C--------Sweep OFF-DIAGONAL TERMS FOR POSSIBLE REDUCTION---
0099 DD 800 M=1,NSMAX
0100 YMAX = 0.0
0101 DD 700 J=1,NN
0102 JJ = J+1
0103 DD 700 K=JJ,N
0104 C--------COMPARE WITH THRESHOLD VALUE-------------
0105 IF(A(K,K).LE.0.0) GO TO 1000
0106 IF(B(K,K).LE.0.0) GO TO 1000
0107 EA = DABS( (A(J,K))/A(J,J) )*A(J,K)/A(K,K) )
0108 EB = DABS( B(J,K)/B(J,J) )*B(J,K)/B(K,K) )
0109 Y = EA + EB
0110 IF(Y.GT.YMAX) YMAX = Y
0111 IF(Y.GT.YMAX) YMAX = Y
0112 IF(Y.GT.YMAX) YMAX = Y
0113 C--------CALCULATE TRANSFORMATIONS TERMS---------
0114 IF(B(J,J).LE.0.0) GO TO 1000
0115 IF(A(J,J).LE.0.0) GO TO 1000
0116 Y = B(J,J)/A(J,J) - B(J,J)/A(J,J)
0117 AK = B(J,J)/A(J,J) - (B(K,K)/A(J,J))*A(J,K)/A(K,K)
0118 AJ = B(J,J)/A(J,J) - (B(J,J)/A(J,J))*A(J,K)/A(K,K)
0119 D1 = y/2.
0120 D2 = y**2 + 4.*AK*AJ
0121 IF(D2.LT.0.0) GO TO 700
0122 D2 = DSQRT(D2)/2.
0123 Z = D1 + D2
0124 IF(1.D0) Z = D1 - D2
0125 IF(DABS(Z).GT.0.00001*Y) GO TO 80
0126 CA = 0.0
0127 CG = -A(J,K)/A(K,K)

C-48
GO TO 90
80 IF(Z.EQ.0.0) GO TO 1000
CA = AK/Z
CG = -AU/Z
C-------ZERO TERMS A(J,K) AND B(J,K)----------------------
90 DO 100 I=1,N
IF(I.EQ.J OR I.EQ.K) GO TO 100
A(J,I) = A(I,J) + CG*A(J,K)
A(K,I) = A(I,K) + CA*A(I,J)
A(I,J) = A(J,I)
A(I,K) = A(K,I)
B(J,I) = B(I,J) + CG*B(I,K)
B(K,I) = B(I,K) + CA*B(I,J)
B(I,J) = B(J,I)
B(I,K) = B(K,I)
100 CONTINUE
AK = A(K,K)
BK = B(K,K)
A(K,K) = AK + CA*(A(J,K) + A(J,K) + CA*(A(J,J))
B(K,K) = BK + CA*(B(J,K) + B(J,K) + CA*(B(J,J))
A(J,J) = A(J,J) + CG*(A(J,K) + A(J,K) + CG*AK)
B(J,J) = B(J,J) + CG*(B(J,K) + B(J,K) + CG*AK)
A(J,K) = 0.
B(J,K) = 0.
A(K,J) = 0.
B(K,J) = 0.
C------TRANSFORM EIGENVECTORS--------------------------
DO 200 I=1,N
XJ = X(I,J)
XK = X(I,K)
X(I,J) = XJ + CG*XK
X(I,K) = XK + CA*XJ
200 NT = NT + 1
700 CONTINUE
IF(YMAX.LT.RTOL) GO TO 820
EPS = 0.1*YMAX**3
800 CONTINUE
C-------SCALE EIGENVECTORS --------------------------
820 DO 845 J=1,N
IF(B(J,J).LE.0.0) GO TO 845
E(J) = A(J,J)/B(J,J)
BB = DSQRT(B(J,J))
IF(BB.EQ.0.0) GO TO 1000
845 X(K,J) = X(K,J)/BB
1000 IF(NN.EQ.0) return
845 CONTINUE
C-------ORDER EIGENVALUES AND EIGENVECTORS -------
DO 900 I=1,NN
JL = I+1
HT = E(I)
IM = I
DO 850 J=JL,N
IF(H.T.LT.E(J)) GO TO 850
850 HT = E(J)
IM = J
850 CONTINUE
E(IM) = E(I)
E(I) = HT
DO 900 J=1,N
HT = X(J,I)
X(J,IM) = X(J,IM)
900 X(J,IM) = HT
CALL MTP1(X,E,N1,N1)
C CALL MATPRT(X,N1,N1,N,N)
C CALL MATPRT(E,N1,1,1,N1)
C
RETURN
1000 WRITE(6,3000)
WRITE(6,3000)
C-49
0100 FORMAT( 'SUBSPACE VECTORS ARE NOT INDEPENDENT - continue')
0101 GO TO 820
0102 END
0103
0104 SUBROUTINE MTP1(A,B,IISIZE,JJSIZE)
0105
0106 COMMON /DIRECT/DRIN(3),DRIN1(4)
0107 CHARACTER*1 DRIN
0108 CHARACTER*2 DRIN1
0109 DIMENSION A(IISIZE,JJSIZE),B(JJSIZE)
0110 C
0111 PI=4.DO+DASIN(1.DO)
0112 WRITE(7,1032)
0113 WRITE(7,1033)(J,B(J),2.DO+PI/DSQRT(B(J)),J=1,JJSIZE)
0114 DO 154 L=1,JJSIZE,6
0115 IH=L+5
0116 IF(IH.GT.JJSIZE) IH=JJSIZE
0117 WRITE(7,2033) (J,J=L,IH)
0118 DO 153 N=1,IISIZE/3
0119 LN=IISIZE/1-N
0120 NN=LN*(N-1)
0121 DO 156 J=1,0
0122 WRITE(7,2034) LN,DRIN(J),(A(NN+J,K),K=L,IH)
0123 152 CONTINUE
0124 153 CONTINUE
0125 154 CONTINUE
0126 C
0127 RETURN
0128 1032 FORMAT(/6X,'EIGENVALUES AND EIGENVECTORS (3D SHEAR'
0129 + ' BUILDING REPRESENTATION)...')
0130 1033 FORMAT(/6X,'MODE NUMBER',5X,'EIGENVALUE',9X,'PERIOD'')
0131 + (6X,'I7.7X,E12.6X,E12.6)
0132 2033 FORMAT(/6X,'MODE SHAPES',/)
0133 + 6X,'LEVEL',8X,6(5X,I2,4X))
0134 2034 FORMAT(/6X,I5.2X,A1.2X,12F10.7)
0135 END
0136
0137 IMPLICIT REAL*8 (A-H,O-Z)
0138 INTEGER RTCOL
0139 DIMENSION A(IISIZE,JJSIZE)
0140 C
0141 NPAGES=(JJSIZE-1)/9+1
0142 DO 20 I=1,1,NPAGES
0143 LTCDL=9*(I-1)+1
0144 RTCOL=9*I
0145 IF (RTCOL.GT.JJSIZE) RTCOL=JJSIZE
0146 WRITE (7,50) (K,K=RTCOL,RTCOL)
0147 DO 10 J=1,IISIZE
0148 WRITE (7,60) (A(J,K),K=RTCOL,RTCOL)
0149 10 CONTINUE
0150 20 CONTINUE
0151 50 FORMAT(/6X,'COLUMN:','14.3X,9(10.3X),/
0152 + 6X,' ROW'/)
0153 60 FORMAT(6X,'ROW',13.1X,1PG13.5)
0154 C
0155 RETURN
0156 END
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NCEE-90-0004  "Catalog of Strong Motion Stations in Eastern North America," by R.W. Busby, 4/3/90, (PB90-251984)/AS.


