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3D-BASIS-ME:Computer Program for Nonlinear Dynamic Analysis of Seismically Isolated Single and Multiple Structures and Liquid Storage Tanks

by

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

Technical Report NCEER-94-0010
April 12, 1994

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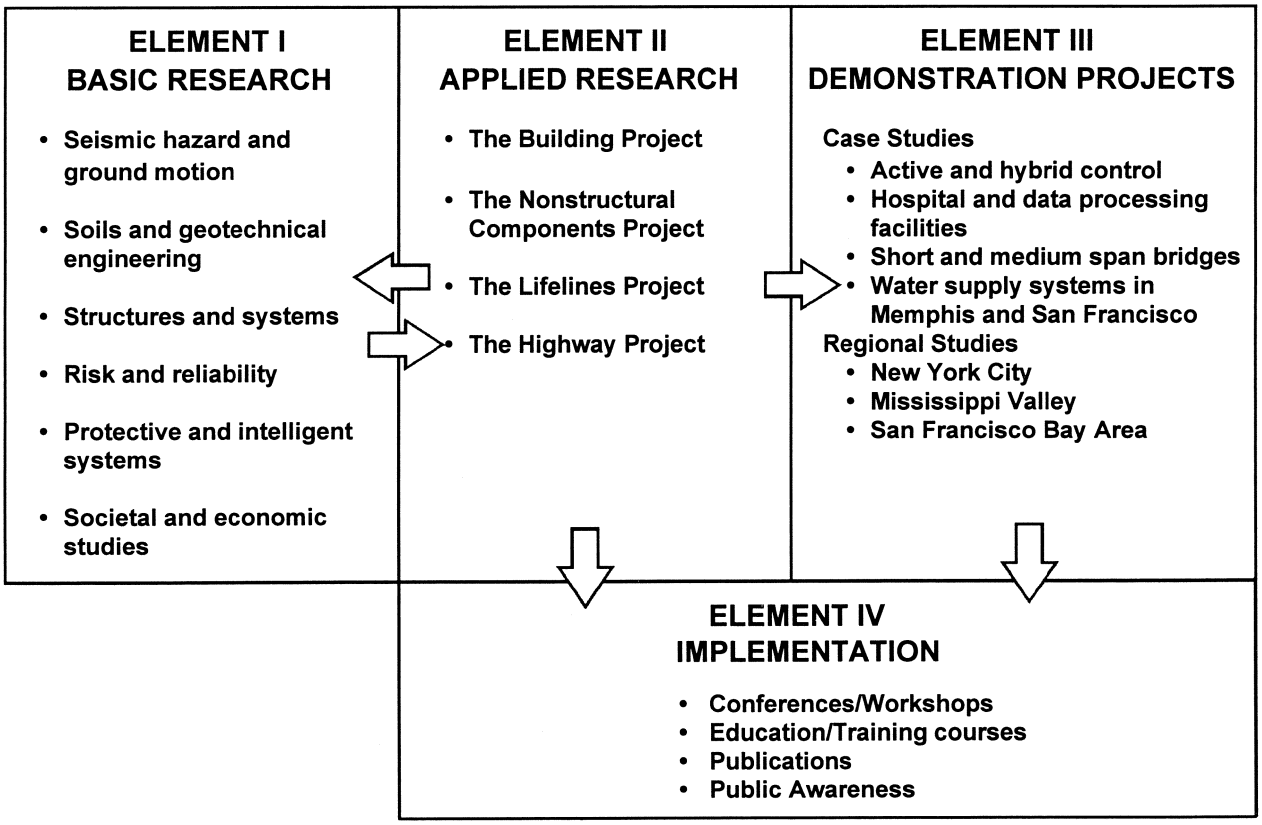
PREFACE

The National Center for Earthquake Engineering Research (NCEER) was established to expand and disseminate knowledge about earthquakes, improve earthquake-resistant design, and implement seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures in the eastern and central United States and lifelines throughout the country that are found in zones of low, moderate, and high seismicity.

NCEER's research and implementation plan in years six through ten (1991-1996) comprises four interlocked elements, as shown in the figure below. Element I, Basic Research, is carried out to support projects in the Applied Research area. Element II, Applied Research, is the major focus of work for years six through ten. Element III, Demonstration Projects, have been planned to support Applied Research projects, and will be either case studies or regional studies. Element IV, Implementation, will result from activity in the four Applied Research projects, and from Demonstration Projects.



Research in the **Building Project** focuses on the evaluation and retrofit of buildings in regions of moderate seismicity. Emphasis is on lightly reinforced concrete buildings, steel semi-rigid frames, and masonry walls or infills. The research involves small- and medium-scale shake table tests and full-scale component tests at several institutions. In a parallel effort, analytical models and computer programs are being developed to aid in the prediction of the response of these buildings to various types of ground motion.

Two of the short-term products of the **Building Project** will be a monograph on the evaluation of lightly reinforced concrete buildings and a state-of-the-art report on unreinforced masonry.

The **protective and intelligent systems program** constitutes one of the important areas of research in the **Building Project**. Current tasks include the following:

1. Evaluate the performance of full-scale active bracing and active mass dampers already in place in terms of performance, power requirements, maintenance, reliability and cost.
2. Compare passive and active control strategies in terms of structural type, degree of effectiveness, cost and long-term reliability.
3. Perform fundamental studies of hybrid control.
4. Develop and test hybrid control systems.

This is the latest in a series of NCEER technical reports documenting the development of the 3D-BASIS computer program, which is designed for nonlinear dynamic analysis of seismically isolated structures. In this report, the program is extended to include the simulation of the hysteretic behavior of friction pendulum bearings and linear and nonlinear viscous fluid dampers. The effects of overturning moment and vertical ground acceleration on the behavior of sliding bearings are also included.

ABSTRACT

3D-BASIS-ME is a special purpose program for the nonlinear dynamic analysis of seismically isolated multiple buildings and liquid storage tanks. New features of this program, which do not exist in the currently available class of 3D-BASIS programs, are new elements for modeling hysteretic stiffening behavior, for modeling the behavior of spherical sliding isolation systems and for modeling linear and nonlinear viscous fluid dampers. Furthermore, the effects of vertical ground motion and overturning moment on the behavior of sliding bearings have been included.

ACKNOWLEDGEMENTS

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SECTION 1

INTRODUCTION

3D-BASIS-ME represents an enhanced version of program 3D-BASIS-M (Tsopelas et al. 1991), which is an extension of program 3D-BASIS (Nagarajaiah et al. 1989, 1991b and 1993).

The 3DBASIS class of computer programs were developed for the nonlinear dynamic analyses of seismically isolated structures. Program 3D-BASIS was designed to analyze a single superstructure isolated building. Program 3D-BASIS-M was designed to analyze single as well as multiple superstructures with a single isolation basemat. It is suitable for the dynamic analysis of isolated structures which consist of several parts separated by thermal expansion joints. The program may also be used in the dynamic analysis of isolated liquid storage tanks in which the liquid-tank system is modeled by two multi-degree-of freedom systems, representing respectively the impulsive and convective effects.

Program 3D-BASIS-ME maintains the features of programs 3D-BASIS-M with the following enhancements:

1. The effects of overturning moment and vertical ground acceleration on the behavior of sliding bearings have been included.

2. A new stiffening hysteretic element with bidirectional interaction has been included. This element may be used in modeling the behavior of high damping rubber bearings at large strains.

3. A new element capable of modeling the behavior of spherical sliding isolation systems(such as the Friction Pendulum or FPS bearings) has been included.

4. A new viscous element has been included that produces output force which is proportional to a power of the velocity of motion of one end of the element with respect to the other end.

This report describes the enhanced program 3D-BASIS-ME and demonstrates its capabilities through a series of example analyses of an isolated liquid storage tank.

SECTION 2

OVERVIEW OF PROGRAM 3D-BASIS

Program 3D-BASIS (Nagarajaiah et al. 1989, Nagarajaiah et al. 1991b) 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 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.

A recently developed version of 3D-BASIS, called 3D-BASIS-TABS (Nagarajaiah et al. 1993), incorporates the modeling approach of ETABS (Wilson et al. 1975) into 3D-BASIS and allows for the calculation of time histories of superstructure member forces and joint displacements.

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.
4. Hysteretic element for sliding bearings.

2.2.1 Linear Elastic 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)

$$F_x = K_x(u_x^B - e_y^B\, u_r^B) \tag{2.1}$$

$$F_y = K_y(u_y^B + e_x^B\, u_r^B) \tag{2.2}$$

$$T = K_r u_r^B + K_y e_x^B u_y^B - K_x e_y^B u_x^B \tag{2.3}$$

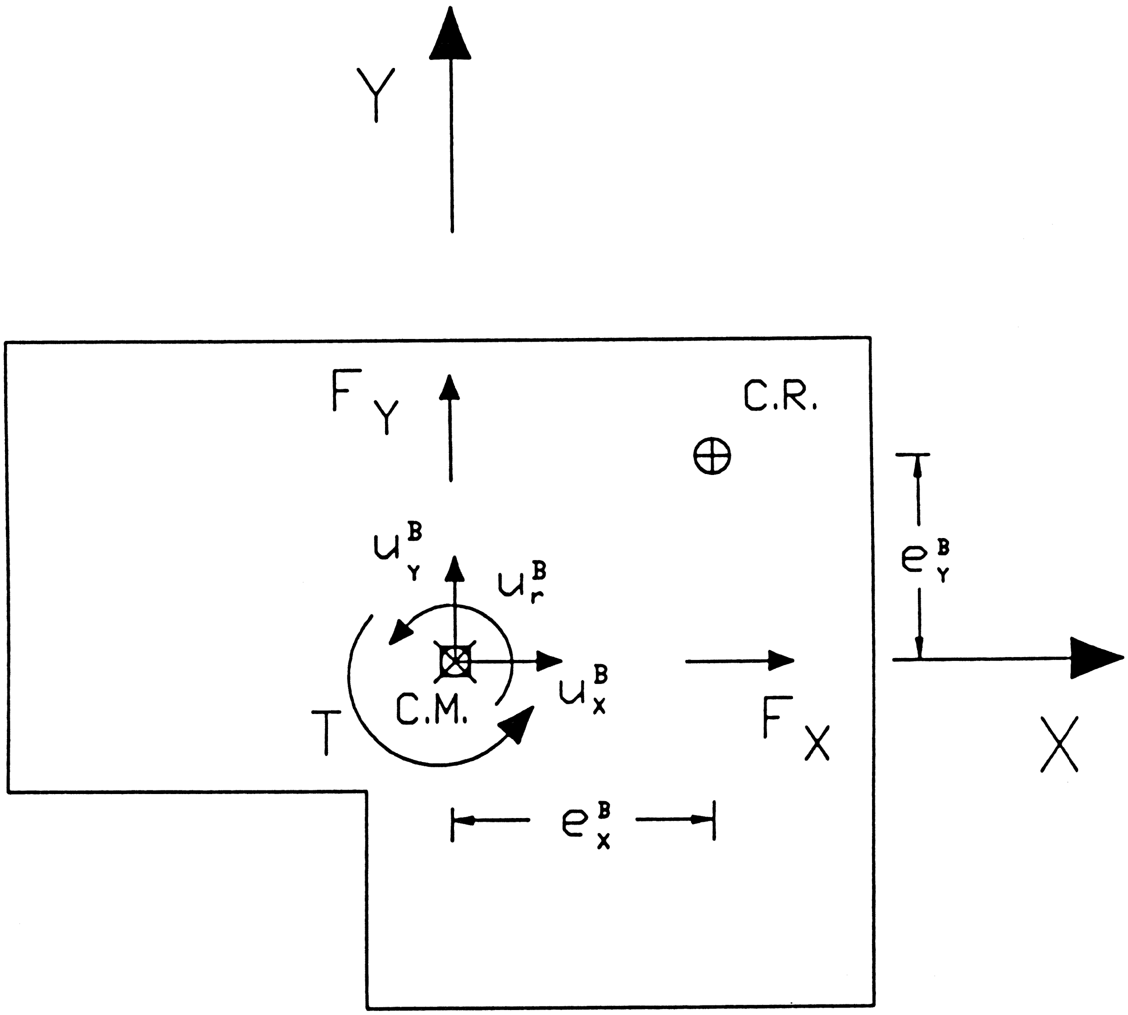


Figure 2-1 Displacements and Forces at the Center of Mass of a Rigid Diaphragm

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 :

$$F_x = C_x(\dot{u}_x^B - e_y^C \dot{u}_r^B) \tag{2.4}$$

$$F_y = C_y(\dot{u}_y^B + e_x^C \dot{u}_r^B) \tag{2.5}$$

$$T = C_r \dot{u}_r^B + C_y e_x^B \dot{u}_y^B - C_x e_y^B \dot{u}_x^B \tag{2.6}$$

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 :

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

in which, α is the post-yielding to pre-yielding stiffness ratio, F^y is the yield force and Y is the yield displacement, as illustrated in Figure 2-2. Z_x and Z_y are dimensionless variables governed by the following system of differential equations which was proposed by Park et al. 1986 :

$$\begin{Bmatrix} \dot{Z}_x & Y \\ \dot{Z}_y & Y \end{Bmatrix} = \begin{Bmatrix} A & \dot{U}_x \\ A & \dot{U}_y \end{Bmatrix} - \begin{pmatrix} Z_x^2(\gamma Sgn(\dot{U}_x Z_x) + \beta) & Z_x Z_y(\gamma Sgn(\dot{U}_y Z_y) + \beta) \\ Z_x Z_y(\gamma Sgn(\dot{U}_x Z_x) + \beta) & Z_y^2(\gamma Sgn(\dot{U}_y Z_y) + \beta) \end{pmatrix} \begin{Bmatrix} \dot{U}_x \\ \dot{U}_y \end{Bmatrix} \tag{2.8}$$

in which A, γ and β are dimensionless quantities that control the shape of the hysteresis loop. Furthermore, U_x, U_y and $\dot{U}_x$, $\dot{U}_y$ represent the displacements and velocities that occur at the isolation element.

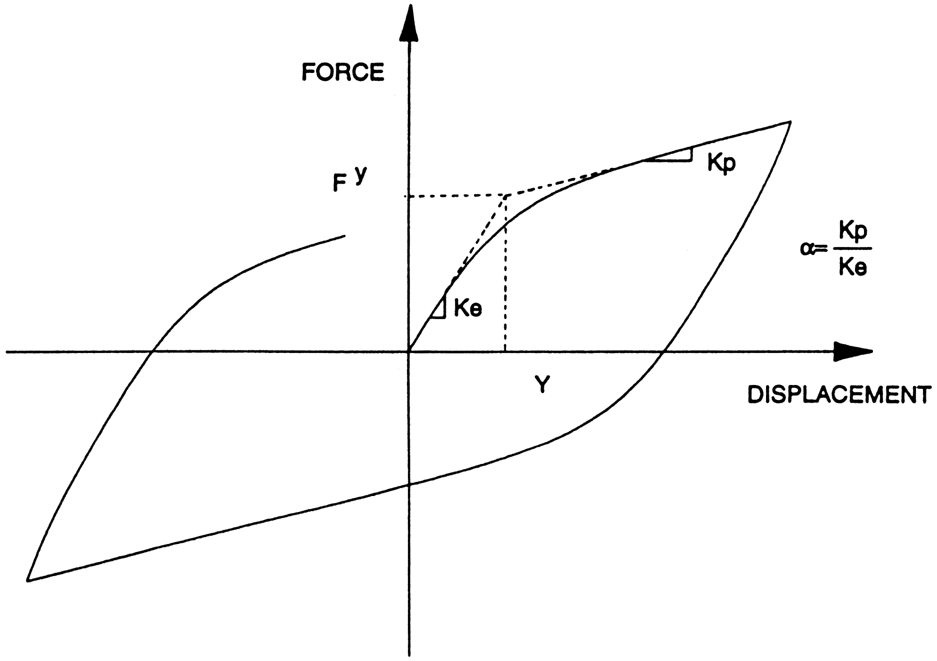


Figure 2-2 Hysteretic Element for Elastomeric Bearings and Steel Dampers. For Elastoplastic Behavior $\alpha = 0$.

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 $A/(\beta + \gamma) = 1$:

$$Z_x = \cos\theta, \qquad Z_y = \sin\theta \tag{2.9}$$

where θ is the angle specifying the instantaneous direction of motion

$$\theta = \tan^{-1}(\dot{U}_y/\dot{U}_x) \tag{2.10}$$

Equations 2.7 and 2.9 indicate that the interaction curve of the element is circular. To demonstrate this, consider motion along an angle θ 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 θ and given by

$$F = (F_x^2 + F_y^2)^{1/2} = \left\{ (1-\alpha)^2 F^{y2} + \alpha^2 \frac{F^{y2}}{Y^2} U^2 + 2\alpha(1-\alpha) \frac{F^{y2}\, U}{Y} \right\}^{1/2} \tag{2.11}$$

Equation 2.11 clearly describes a circle. At the lower limit of inelastic behavior, i.e. $U = Y$, Equation 2.11 reduces to $F = F^y$ which demonstrates that the yield force of the element is equal to F^y 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.

This element may be used in modeling the behavior of low damping rubber bearings, high damping rubber bearings in the range of strain prior to stiffening and lead-rubber bearings.

2.2.4 Biaxial Element for Sliding Bearings

For flat sliding bearings, the mobilized forces are described by the equations (Constantinou et al. 1990, Mokha et al. 1993)

$$F_x = \mu_s N Z_x, \quad F_y = \mu_s N Z_y \tag{2.12}$$

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

$$\dot{U} = (\dot{U}_x^2 + \dot{U}_Y^2)^{1/2} \tag{2.13}$$

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 :

$$\mu_s = f_{\max} - (f_{\max} - f_{\min}) \exp(-a \mid \dot{U} \mid) \tag{2.14}$$

in which, $f_{\max}$ is the maximum value of the coefficient of friction and $f_{\min}$ is the minimum (at $\dot{U} = 0$) value of the coefficient of friction as shown in Figure 2-3. Furthermore, a is a parameter which controls the variation of the coefficient of friction with velocity. Values of parameters $f_{\max}$, $f_{\min}$ and a for interfaces used in sliding bearings have been reported in Constantinou et al. 1990 and Mokha et al. 1991. In general, parameters $f_{\max}$, $f_{\min}$ and a are functions of bearing pressure and angle θ, though the dependency on θ is usually not important.

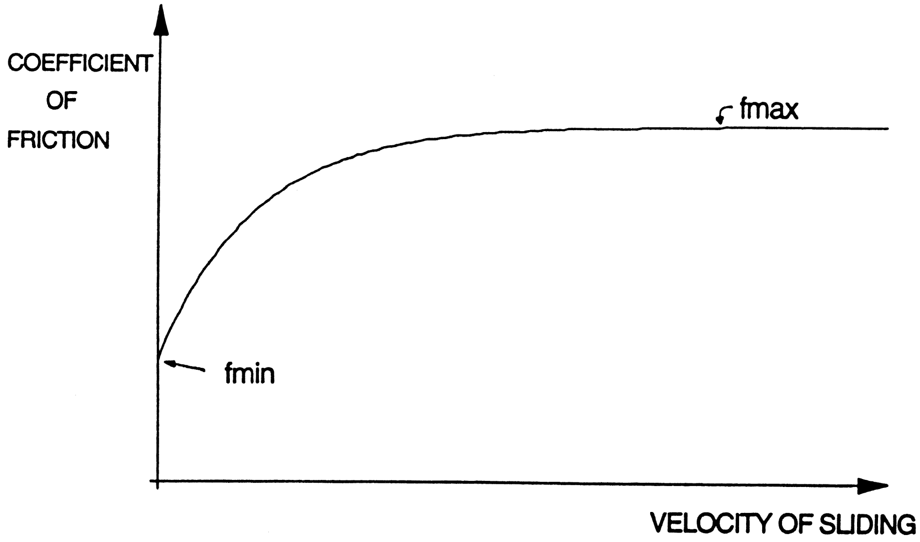


Figure 2-3 Model of Coefficient of friction in Program 3D-BASIS. The Model Collapses to the Coulomb Model when $f_{\max} = f_{\min}$.

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.

SECTION 3

PROGRAM 3D-BASIS-M

Program 3D-BASIS-M (Tsopelas et al. 1991) 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. The same options available in 3D-BASIS were 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.

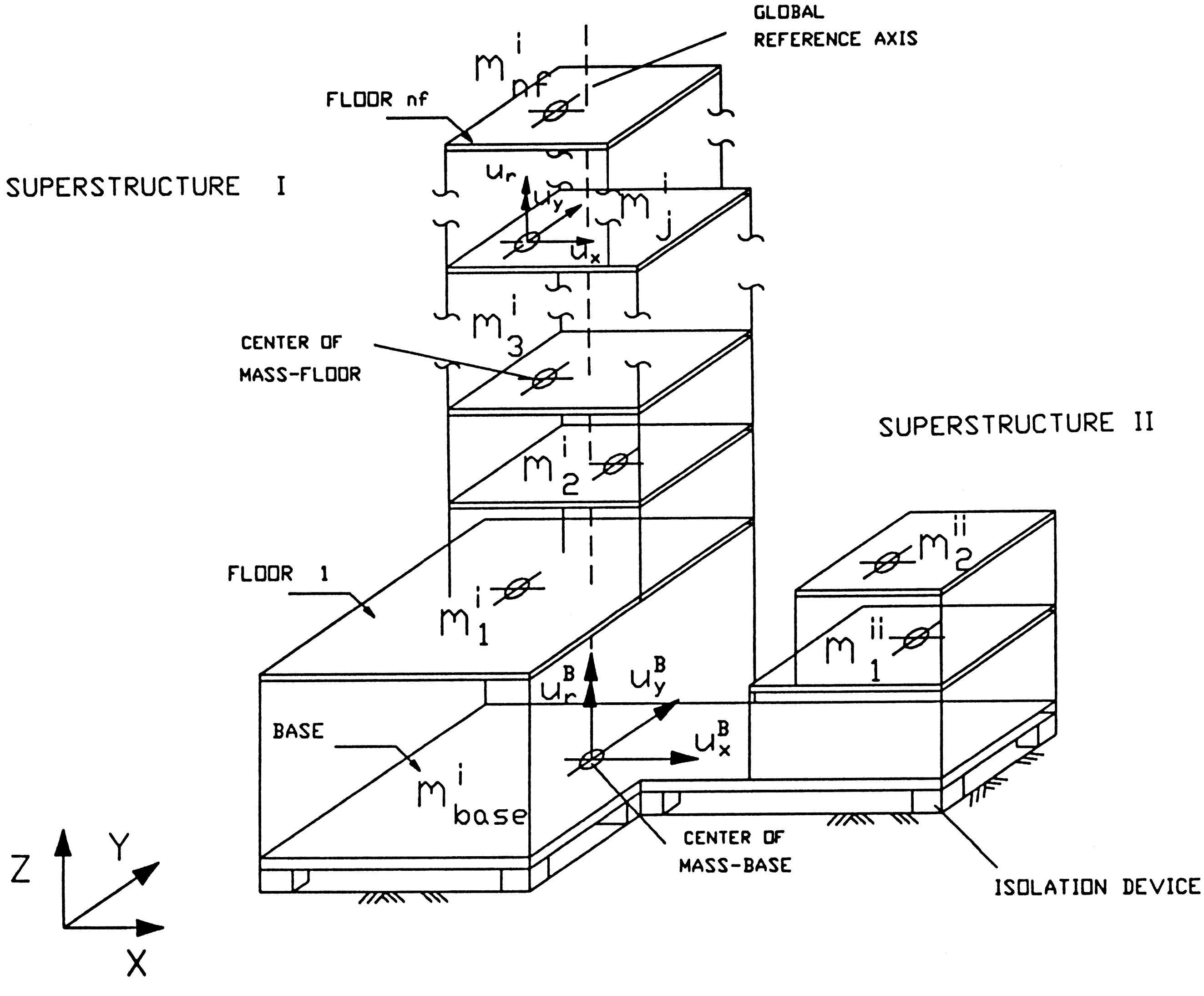


Figure 3-1 Multiple Building Isolated Structure.

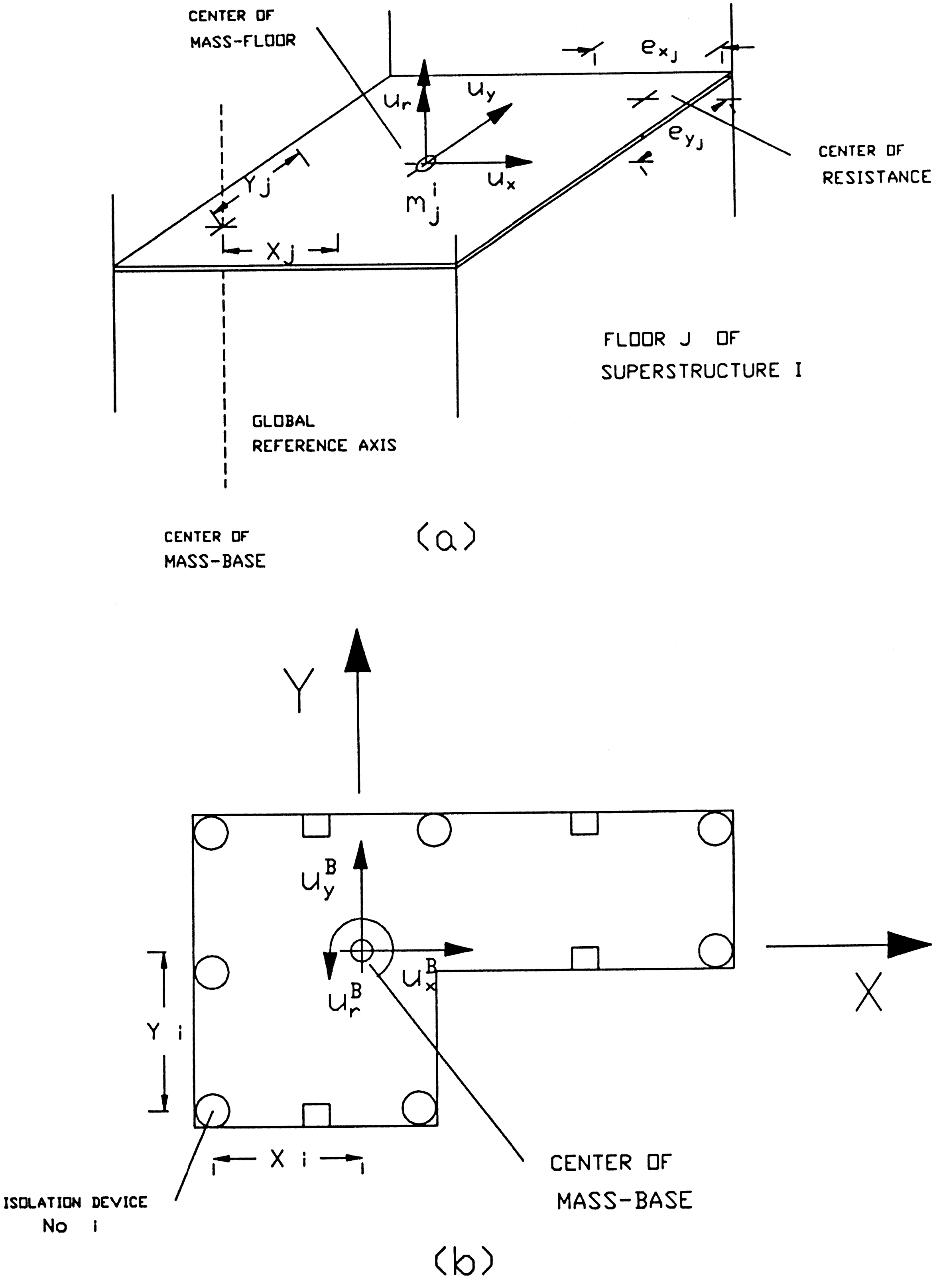


Figure 3-2 Degrees of Freedom and Details of a Typical Floor and Base : (a) Isometric View of Floor j of Superstructure i; (b) Plan of Base.

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 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. $\mathbf{u}^i_j$ is the relative displacement vector of the center of mass of floor (j) of superstructure (i) with respect to the base, $\mathbf{u}_b$ is the relative displacement vector of the center of mass of the base with respect to the ground and $\mathbf{u}_g$ is the ground displacement vector. Each one of the these vectors has translational X, Y components and rotation about the vertical axis.

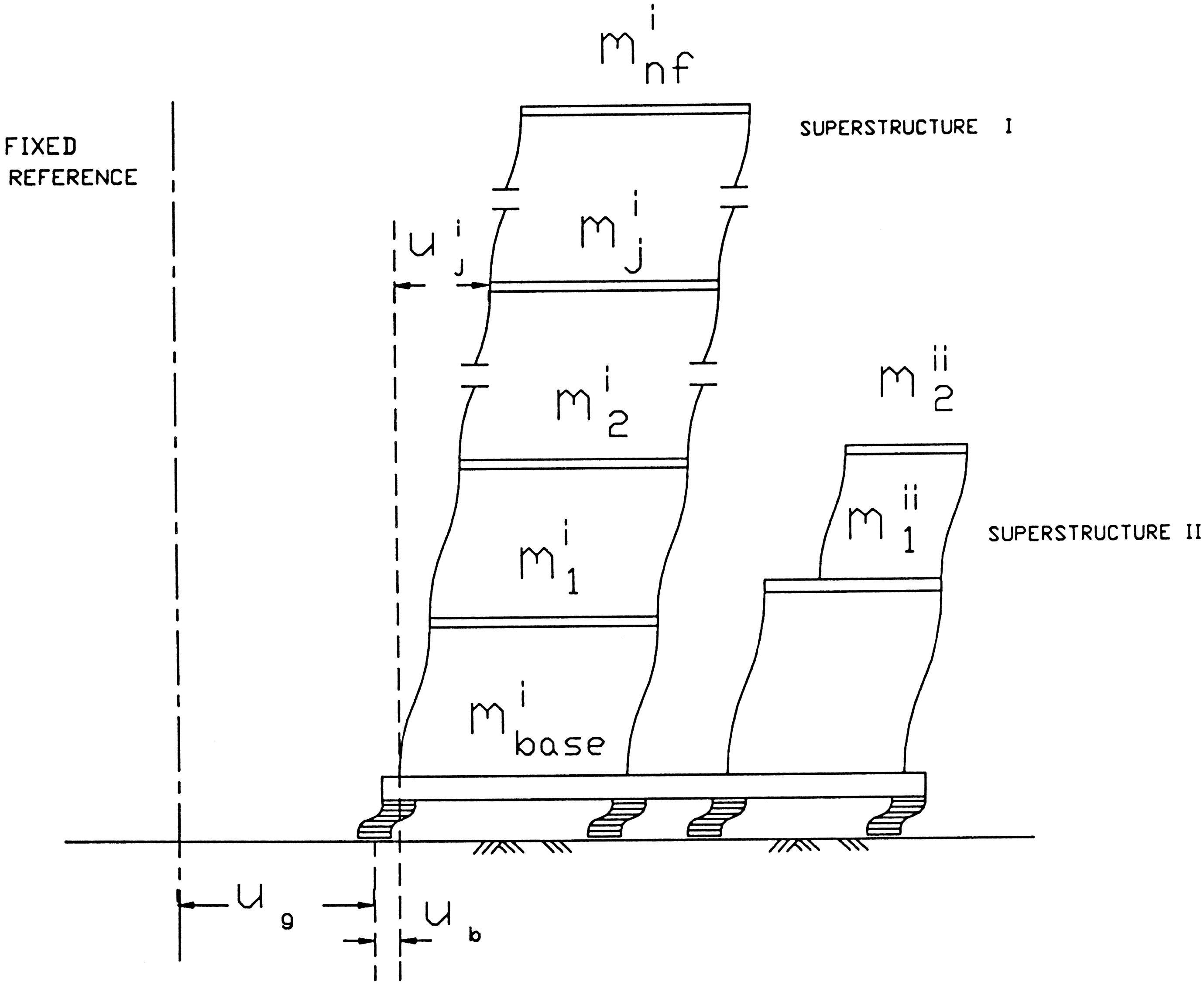


Figure 3-3 Displacement Coordinates of Isolated Structure.

The equations of motion of the part of the structure above the base (superstructures) are :

$$\mathbf{M}_{N_b\times N_b}\ddot{\mathbf{u}}_{N_b\times 1}+\mathbf{C}_{N_b\times N_b}\dot{\mathbf{u}}_{N_b\times 1}+\mathbf{K}_{N_b\times N_b}\mathbf{u}_{N_b\times 1}=-\mathbf{M}_{N_b\times N_b}\mathbf{R}_{N_b\times 3}\{\ddot{\mathbf{u}}_b+\ddot{\mathbf{u}}_g\}_{3\times 1} \tag{3.1}$$

In the above equations **M**, **C** and **K** are the combined mass, damping and stiffness matrices of the superstructure buildings, **u** is the combined displacement vector relative to the base and **R** is a transformation matrix which transfers the base ($\ddot{\mathbf{u}}_b$) and ground ($\ddot{\mathbf{u}}_g$) 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. $\mathbf{N_b}$ 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

$$\begin{pmatrix} \mathbf{m}^1 & 0 & 0 & 0 & 0 \\ 0 & .. & 0 & 0 & 0 \\ 0 & 0 & \mathbf{m}^i & 0 & 0 \\ 0 & 0 & 0 & .. & 0 \\ 0 & 0 & 0 & 0 & \mathbf{m}^{ns} \end{pmatrix} \begin{Bmatrix} \ddot{\mathbf{u}}^1 \\ .. \\ \ddot{\mathbf{u}}^i \\ .. \\ \ddot{\mathbf{u}}^{ns} \end{Bmatrix} + \begin{pmatrix} \mathbf{c}^1 & 0 & 0 & 0 & 0 \\ 0 & .. & 0 & 0 & 0 \\ 0 & 0 & \mathbf{c}^i & 0 & 0 \\ 0 & 0 & 0 & .. & 0 \\ 0 & 0 & 0 & 0 & \mathbf{c}^{ns} \end{pmatrix} \begin{Bmatrix} \dot{\mathbf{u}}^1 \\ .. \\ \dot{\mathbf{u}}^i \\ .. \\ \dot{\mathbf{u}}^{ns} \end{Bmatrix}$$

$$+ \begin{pmatrix} \mathbf{k}^1 & 0 & 0 & 0 & 0 \\ 0 & .. & 0 & 0 & 0 \\ 0 & 0 & \mathbf{k}^i & 0 & 0 \\ 0 & 0 & 0 & .. & 0 \\ 0 & 0 & 0 & 0 & \mathbf{k}^{ns} \end{pmatrix} \begin{Bmatrix} \mathbf{u}^1 \\ .. \\ \mathbf{u}^i \\ .. \\ \mathbf{u}^{ns} \end{Bmatrix} = - \begin{pmatrix} \mathbf{m}^1 & 0 & 0 & 0 & 0 \\ 0 & .. & 0 & 0 & 0 \\ 0 & 0 & \mathbf{m}^i & 0 & 0 \\ 0 & 0 & 0 & .. & 0 \\ 0 & 0 & 0 & 0 & \mathbf{m}^{ns} \end{pmatrix} \begin{Bmatrix} \mathbf{r}^1 \\ .. \\ \mathbf{r}^i \\ .. \\ \mathbf{r}^{ns} \end{Bmatrix} [\ddot{\mathbf{u}}_b + \ddot{\mathbf{u}}_g] \tag{3.2}$$

In Equations 3.2, $\mathbf{m}^i$, $\mathbf{c}^i$, and $\mathbf{k}^i$ and the mass, damping and stiffness matrices of superstructure (i). These matrices are of dimensions $3nf^i$ where nf^i is the number of floors in superstructure (i). It should be noted that matrices $\mathbf{m}^i$ are diagonal and contain the mass and mass moment of inertia of each floor. The range of index (i) varies between one and ns, the number of superstructures. $\mathbf{u}^i$ is the displacement vector of superstructure (i) relative to the base. Further, $\mathbf{r}^i$ 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) :

$$\mathbf{r}^i = \begin{pmatrix} \mathbf{R}_{nf^i} \\ .. \\ \mathbf{R}_{j^i} \\ .. \\ \mathbf{R}_1 \end{pmatrix} \tag{3.3}$$

where

$$\mathbf{R}_{j^i} = \begin{pmatrix} 1 & 0 & -\mathbf{Y}_j \\ 0 & 1 & \mathbf{X}_j \\ 0 & 0 & 1 \end{pmatrix} \tag{3.4}$$

in which $\mathbf{X}_j$, $\mathbf{Y}_j$ 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:

$$\mathbf{R}^T_{3\times N_b}\mathbf{M}_{N_b\times N_b}\{\ddot{\mathbf{u}}_{N_b\times 1}+\mathbf{R}_{N_b\times 3}\{\ddot{\mathbf{u}}_b+\ddot{\mathbf{u}}_g\}_{3\times 1}\}+\mathbf{M}_{b_{3\times 3}}\{\ddot{\mathbf{u}}_b+\ddot{\mathbf{u}}_g\}_{3\times 1}+\mathbf{C}_{b_{3\times 3}}\{\dot{\mathbf{u}}_b\}_{3\times 1}+\mathbf{K}_{b_{3\times 3}}\{\mathbf{u}_b\}_{3\times 1}+\{\mathbf{f}_N\}_{3\times 1}=0 \tag{3.5}$$

in which $\mathbf{M}_b$ is the mass matrix of the base, $\mathbf{C}_b$ is the resultant damping matrix of viscous elements of the isolation system, $\mathbf{K}_b$ is the resultant stiffness matrix of elastic elements of the isolation system at the center of mass of the base and $\mathbf{f}_N$ is a vector containing the forces mobilized in the nonlinear elements of the isolation system.

Employing modal reduction :

$$\mathbf{u}^i_{3nf^i}=\Phi^i_{3nf^i\times ne^i}\mathbf{Y}^i_{ne^i\times 1} \tag{3.6}$$

where Φ^i is the orthonormal modal matrix relative to the mass matrix of superstructure (i), $\mathbf{Y}^i$ is the modal displacement vector of superstructure (i) relative to the base and ne^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

$$\begin{pmatrix} \mathbf{I} & \Phi^T\mathbf{MR} \\ \mathbf{R}^T\mathbf{M}\Phi & \mathbf{R}^T\mathbf{MR}+\mathbf{M}_b \end{pmatrix}_{(M_b+3)\times(M_b+3)} \begin{Bmatrix} \ddot{\mathbf{Y}} \\ \ddot{\mathbf{u}}_b \end{Bmatrix}_{(M_b+3)\times 1} + \begin{pmatrix} 2\xi\omega & \mathbf{0} \\ \mathbf{0} & \mathbf{C}_b \end{pmatrix}_{(M_b+3)\times(M_b+3)} \begin{Bmatrix} \dot{\mathbf{Y}} \\ \dot{\mathbf{u}}_b \end{Bmatrix}_{(M_b+3)\times 1}$$

$$+\begin{pmatrix} \omega^2 & \mathbf{0} \\ \mathbf{0} & \mathbf{K}_b \end{pmatrix}_{(M_b+3)\times(M_b+3)} \begin{Bmatrix} \mathbf{Y} \\ \mathbf{u}_b \end{Bmatrix}_{(M_b+3)\times 1} + \begin{Bmatrix} \mathbf{0} \\ \mathbf{f}_N \end{Bmatrix}_{(M_b+3)\times 1} = -\begin{Bmatrix} \Phi^T \;\; \mathbf{M} \;\; \mathbf{R} \\ \mathbf{R}^T \;\; \mathbf{M} \;\; \mathbf{R} \; + \; \mathbf{M}_b \end{Bmatrix}_{(M_b+3)\times 3} \{\ddot{\mathbf{u}}_g\}_{3\times 1} \tag{3.7}$$

in which M_b is the total number of eigenvectors for all superstructures retained in the analysis, and ξ and ω 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 :

$$\tilde{M}\ddot{\tilde{y}}_t+\tilde{C}\dot{\tilde{y}}_t+\tilde{K}\tilde{y}_t+f_t=\tilde{P}_t \tag{3.8}$$

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

$$\tilde{M}\ddot{\tilde{y}}_{t+\Delta t}+\tilde{C}\dot{\tilde{y}}_{t+\Delta t}+\tilde{K}\tilde{y}_{t+\Delta t}+f_{t+\Delta t}=\tilde{P}_{t+\Delta t} \tag{3.9}$$

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

$$\tilde{M}\Delta\ddot{\tilde{y}}_{t+\Delta t}+\tilde{C}\Delta\dot{\tilde{y}}_{t+\Delta t}+\tilde{K}\Delta\tilde{y}_{t+\Delta t}+\Delta f_{t+\Delta t}=\tilde{P}_{t+\Delta t}-\tilde{M}\ddot{\tilde{y}}_t-\tilde{C}\dot{\tilde{y}}_t-\tilde{K}\tilde{Y}_t-f_t \tag{3.10}$$

Accordingly, the response of the multiple building superstructure and base is represented by the modal coordinate vectors $\ddot{\tilde{y}}_t$, $\dot{\tilde{y}}_t$ and $\tilde{y}_t$.

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, 1990, 1991a and 1991b. In the pseudo-force method, the incremental nonlinear force vector $\Delta f_{t+\Delta t}$ 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 Δt_{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 :

$$\Delta t_{stick} = \Delta t_{slip} \left[1 - \exp\left(-\frac{\dot{u}^2}{B} \right) \right] \tag{3.11}$$

in which, $\dot{u}$ is the resultant velocity at the center of mass of the base, Δt_{stick} is the reduced time step when the base velocity is low ($\Delta t_{slip} > \Delta t_{stick} > \Delta t_{slip}/nl$, nl is an integer to introduce the desired reduction) and B 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-I SOLUTION ALGORITHM

A. Initial Conditions:

1. Form stiffness matrix $\tilde{\mathbf{K}}$, mass matrix $\tilde{\mathbf{M}}$, and damping matrix $\tilde{\mathbf{C}}$. Initialize $\tilde{\mathbf{u}}_0$, $\dot{\tilde{\mathbf{u}}}_0$ and $\ddot{\tilde{\mathbf{u}}}_0$.
2. Select time step Δt, set parameters $\delta = 0.25$ and $\theta = 0.5$, and calculate the integration constants:

$$a_1 = \frac{1}{\delta(\Delta t)^2};\quad a_2 = \frac{1}{\delta \Delta t};\quad a_3 = \frac{1}{2\delta};\quad a_4 = \frac{\theta}{\delta \Delta t};\quad a_5 = \frac{\theta}{\delta};\quad a_6 = \Delta t(\frac{\theta}{2\delta} - 1)$$

3. Form the effective stiffness matrix $\mathbf{K}^* = a_1\tilde{\mathbf{M}} + a_4\tilde{\mathbf{C}} + \tilde{\mathbf{K}}$
4. Triangularize $\mathbf{K}^*$ 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 $\Delta f^i_{t+\Delta t}$ = 0 in iteration i = 1.
2. Calculate the effective load vector at time $t + \Delta t$:

$$\mathbf{P}^*_{t+\Delta t} = \Delta\tilde{\mathbf{P}}_{t+\Delta t} - \Delta f^i_{t+\Delta t} + \tilde{\mathbf{M}}(a_2\dot{\tilde{\mathbf{u}}}_t + a_3\ddot{\tilde{\mathbf{u}}}_t) + \tilde{\mathbf{c}}(a_5\dot{\tilde{\mathbf{u}}}_t + a_6\ddot{\tilde{\mathbf{u}}}_t)$$
$$\Delta\tilde{\mathbf{P}}_{t+\Delta t} = \tilde{\mathbf{P}}_{t+\Delta t} - (\tilde{\mathbf{M}}\ddot{\tilde{\mathbf{u}}}_t + \tilde{\mathbf{C}}\dot{\tilde{\mathbf{u}}}_t + \tilde{\mathbf{K}}\tilde{\mathbf{u}}_t + \mathbf{f}_t)$$

3. Solve for displacements at time $t + \Delta t$: $\mathbf{K}^*\Delta\mathbf{u}^i_{t+\Delta t} = \mathbf{P}^*_{t+\Delta t}$
4. Update the state of motion at time $t + \Delta t$:

$$\ddot{\tilde{\mathbf{u}}}_{t+\Delta t} = \ddot{\tilde{\mathbf{u}}}_t + a_1\Delta\tilde{\mathbf{u}}^i_{t+\Delta t} - a_2\dot{\tilde{\mathbf{u}}}_t - a_3\ddot{\tilde{\mathbf{u}}}_t;\quad \dot{\tilde{\mathbf{u}}}_{t+\Delta t} = \dot{\tilde{\mathbf{u}}}_t + a_4\Delta\tilde{\mathbf{u}}^i_{t+\Delta t} - a_5\dot{\tilde{\mathbf{u}}}_t - a_6\ddot{\tilde{\mathbf{u}}}_t;\quad \tilde{\mathbf{u}}_{t+\Delta t} = \tilde{\mathbf{u}}_t + \Delta\tilde{\mathbf{u}}^i_{t+\Delta t}$$

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 $\Delta f^{i+1}_{t+\Delta t}$.
7. Compute

$$Error = \frac{\| \Delta f^{i+1}_{t+\Delta t} - \Delta f^i_{t+\Delta t} \|}{Ref.\,\mathrm{Max}\,.Moment}$$

Where $\| . \|$ is the euclidean norm

8. If Error ≥ tolerance, further iteration is needed, iterate starting form step B-1 and use $\Delta f^{i+1}_{t+\Delta t}$ as the pseudo-force and the state of motion at time t, $\tilde{\mathbf{u}}_t$, $\dot{\tilde{\mathbf{u}}}_t$ and $\ddot{\tilde{\mathbf{u}}}_t$.
9. If Error ≤ tolerance, no further iteration is needed, update the nonlinear force vector:

$$\mathbf{f}_{t+\Delta t} = \mathbf{f}_t + \Delta\mathbf{f}^{i+1}_{t+\Delta t}$$

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.

SECTION 4

ENHANCEMENTS IN PROGRAM 3D-BASIS-ME

4.1 Stiffening Biaxial Hysteretic Element

The element is appropriate for modeling the behavior of high damping rubber bearings. Typically, these bearings exhibit higher stiffness at large strains. The element is formed by combining the elastoplastic version ($\alpha = 0$) of the biaxial hysteretic element of Section 2.2.3 and a stiffening bilinear spring.

The resultant force, F, in the stiffening bilinear spring is described by

$$F = \begin{cases} K_1 U & , \quad U \leq D_1 \\ \dfrac{(K_2 - K_1)}{(D_2 - D_1)} \dfrac{(U - D_1)^2}{2} sgn(U) + K_1 U & , \quad D_1 < U \leq D_2 \\ \dfrac{(K_1 - K_2)(D_1 + D_2)}{2} sgn(U) + K_2 U & , \quad U > D_2 \end{cases} \tag{4.1}$$

where K_1 is the tangent stiffness which is mobilized for displacements less than the limit D_1 and K_2 is the higher tangent stiffness which is mobilized for displacements larger than the limit D_2, as illustrated in Figure 4-1. Furthermore, U is the resultant displacement

$$U = (U_x^2 + U_y^2)^{1/2} \tag{4.2}$$

The components of the force F in the two orthogonal directions are

$$F_{xs} = F \cos\theta , \qquad F_{ys} = F \sin\theta \tag{4.3}$$

where

$$\theta = \theta^* \qquad \text{when} \qquad U_x , \quad U_y > 0 \tag{4.4a}$$

$$\theta = \theta^* + \pi/2 \qquad \text{when} \qquad U_x < 0 , \quad U_y > 0 \tag{4.4b}$$

$$\theta = \theta^* + \pi \qquad \text{when} \qquad U_x , \quad U_y < 0 \tag{4.4c}$$

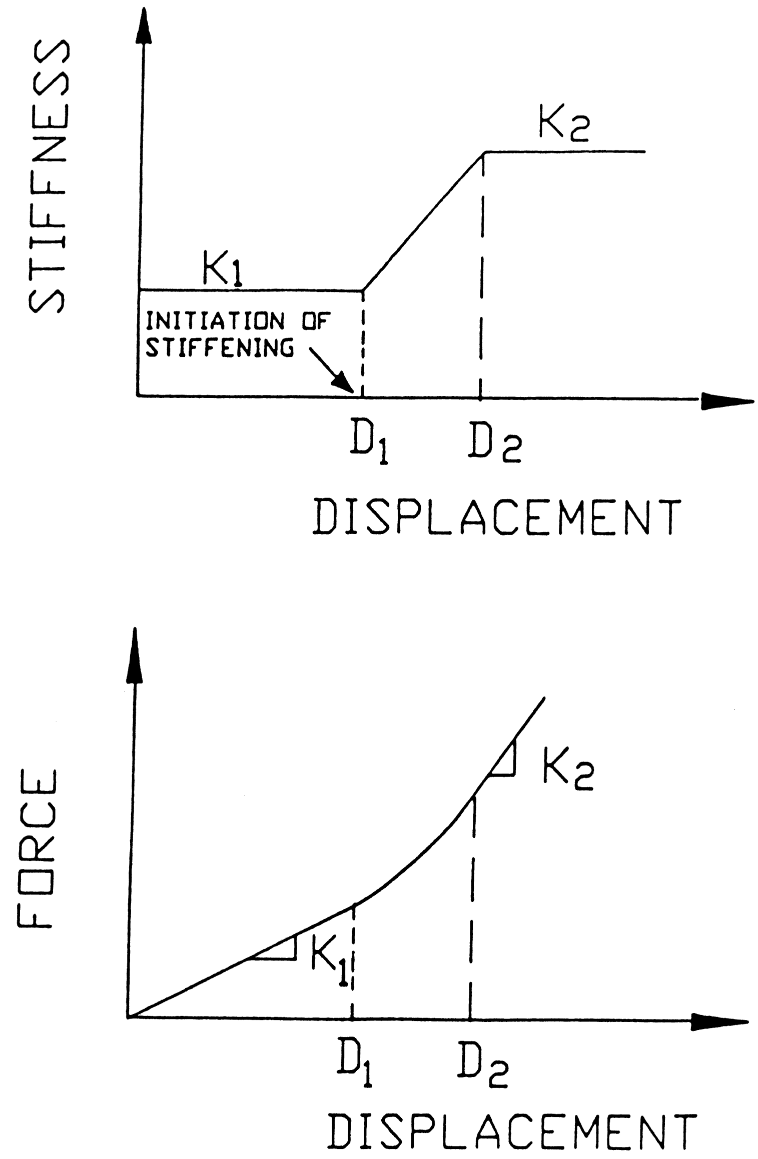


Figure 4-1 Model of Stiffening Bilinear Spring.

$$\theta = -\theta^* \qquad \text{when} \qquad U_x > 0\,, \quad U_y < 0 \tag{4.4d}$$

$$\theta = \pi/2 \quad \text{and} \quad U = U_y \qquad \text{when} \qquad U_x = 0 \tag{4.4e}$$

$$\theta = 0 \qquad \text{and} \quad U = U_x \qquad \text{when} \qquad U_y = 0 \tag{4.4f}$$

and

$$\theta^* = \tan^{-1}\left(\frac{|\,U_y\,|}{|\,U_x\,|}\right) \tag{4.5}$$

The complete model consits of the combination of components given by Equations 2.7, with $\alpha = 0$ and F^y=Q, and 4.3 :

$$F_x = Q\,Z_x + F_{xs}\,, \qquad\qquad F_y = Q\,Z_y + F_{ys} \tag{4.6}$$

These relations are depicted graphically in Figure 4-2. The uniaxial version of the model is recovered by replacing the off-diagonal elements in Equation 2.8 by zeroes and by enforcing Equations 4.4e or 4.4f.

To illustrate the capabilities of this model, we consider the modeling of the behavior of a high damping rubber bearing based on data from testing of scaled specimens. The test data on the scaled specimens, obtained at pressure of 10 MPa and frequency of 0.5 Hz, are: tangent shear modulus for shear strain $\gamma = 0.5$ to 1.0 G=0.8 MPa, equivalent damping ratio (per 1991 UBC) $\beta = 0.10$ at shear strain $\gamma = 1.0$, displacement limits D_1=1.2T and D_2=1.3T, yield displacement Y=0.07T, where T=total rubber thickness. Furthermore, the tangent stiffness beyond the displacement limit D_2 is K_2=2K_1.

The bearing to be modeled is made of the same material and has the same shape factor as the tested scaled specimens. The bearing has bonded rubber diameter D=500 mm and total rubber thickness T=150 mm.

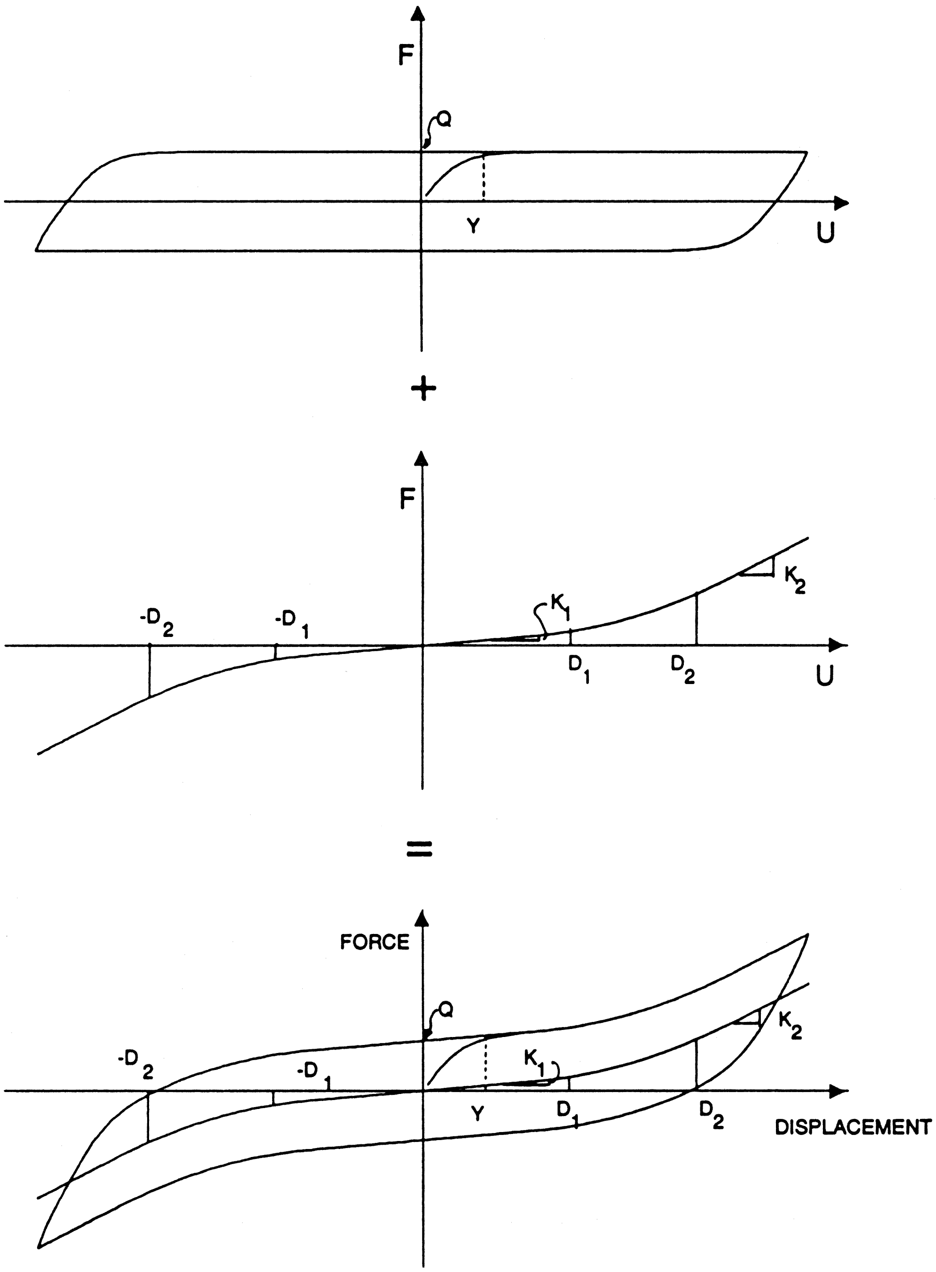


Figure 4-2 Stiffening Hysteretic Model in Program 3D-BASIS-ME.

The tangent stiffness K_1 (see Figure 4-2) is determined from

$$K_1 = \frac{GA}{T} \tag{4.7}$$

where $A = \pi D^2/4$ is the bonded rubber area. The force Q (see Figure 4-2) is determined from

$$Q = \frac{\pi \beta K_1 U}{2 - \pi \beta} \tag{4.8}$$

where $\beta = 0.1$ (equivalent viscous damping ratio) at U=T (shear strain $\gamma = 1.0$). It follows that K_1=1.05 kN/mm, K_2=2.10 kN/mm, Q=29.35 kN, D_1=180 mm, D_2=195 mm, Y=10.5 mm. The mathematical model of Equations 4.1 to 4.6 is constructed from these data and analytically determined loops of force vs displacement are shown in Figures 4-3 to 4-5.

In Figure 4-3 the imposed displacement is harmonic with amplitudes of 240 mm and 176.8 mm along the X axis. The computed loop in the X direction shows the anticipated stiffening behavior in the motion with U_0=240 mm, whereas in the loop for displacement amplitude less than D_1, it does not. In Figure 4-4 the imposed motion is also harmonic with amplitudes of 240 mm and 176.8 mm along a 45° axis. The loops in that direction are identical to that of Figure 4-3. The loops at the largest displacement amplitude in the X and Y directions show stiffening behavior despite that the displacement amplitude is 169.7 mm, thus less than the limit D_1=180 mm. This of course, was expected since the amplitude of the resultant displacement is 240 mm, thus more than the limit D_1.

Figure 4-5 shows loops of force vs displacement in bi-directional motion of elliptical shape (X and Y displacements of motion out of-phase). The peculiar shape of the loop in the Y direction bears a similarity to loops recorded in tests with bidirectional motion of other isolation devices (Mokha 1993).

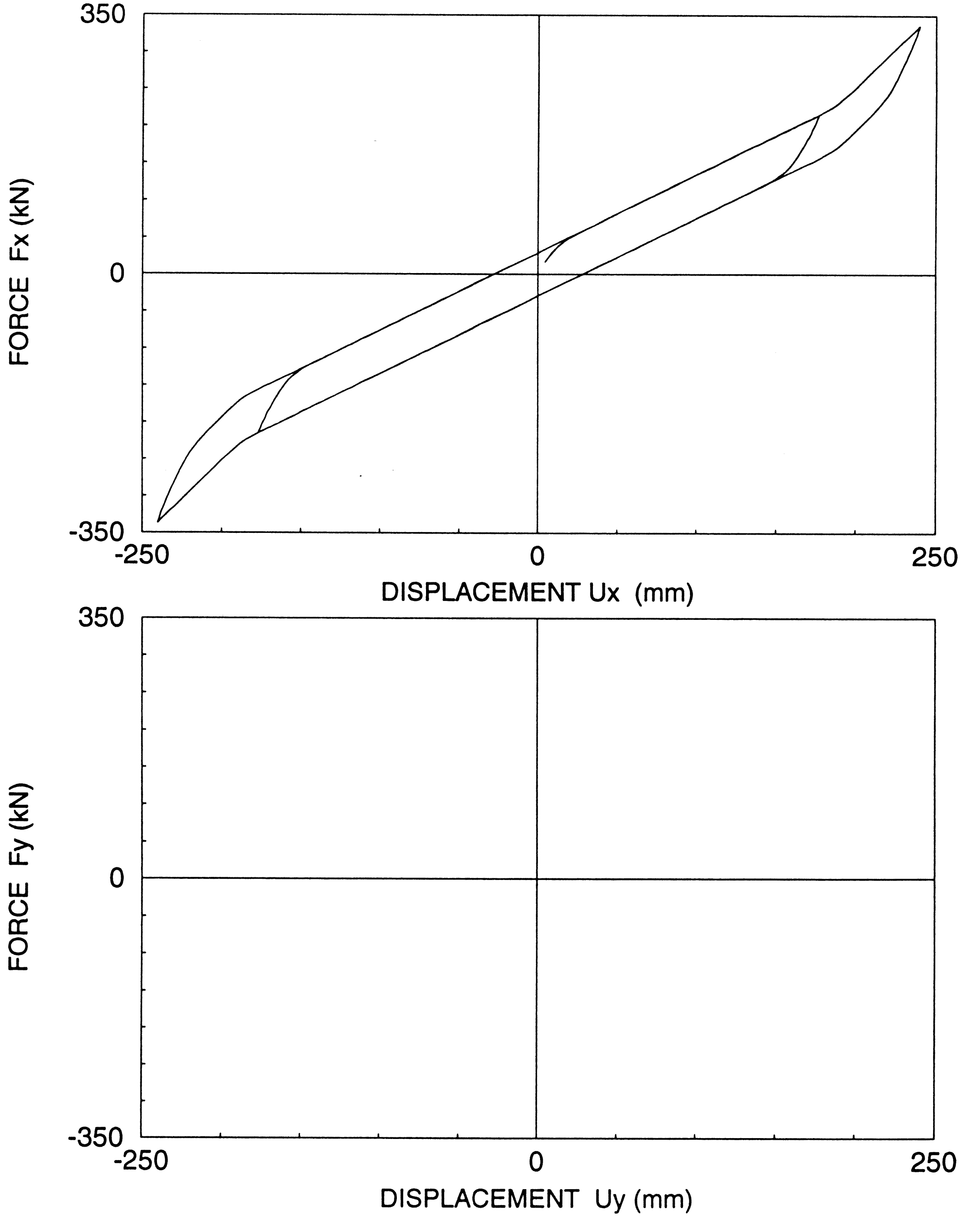


Figure 4-3 Force-Displacement Loops of High Damping Rubber Bearing in X and Y Directions for Motion $U_x = U_0 \sin(2\pi f t)$, $U_y = 0, f = 0.5Hz$, $U_0 = 240mm$ and 176.8 mm.

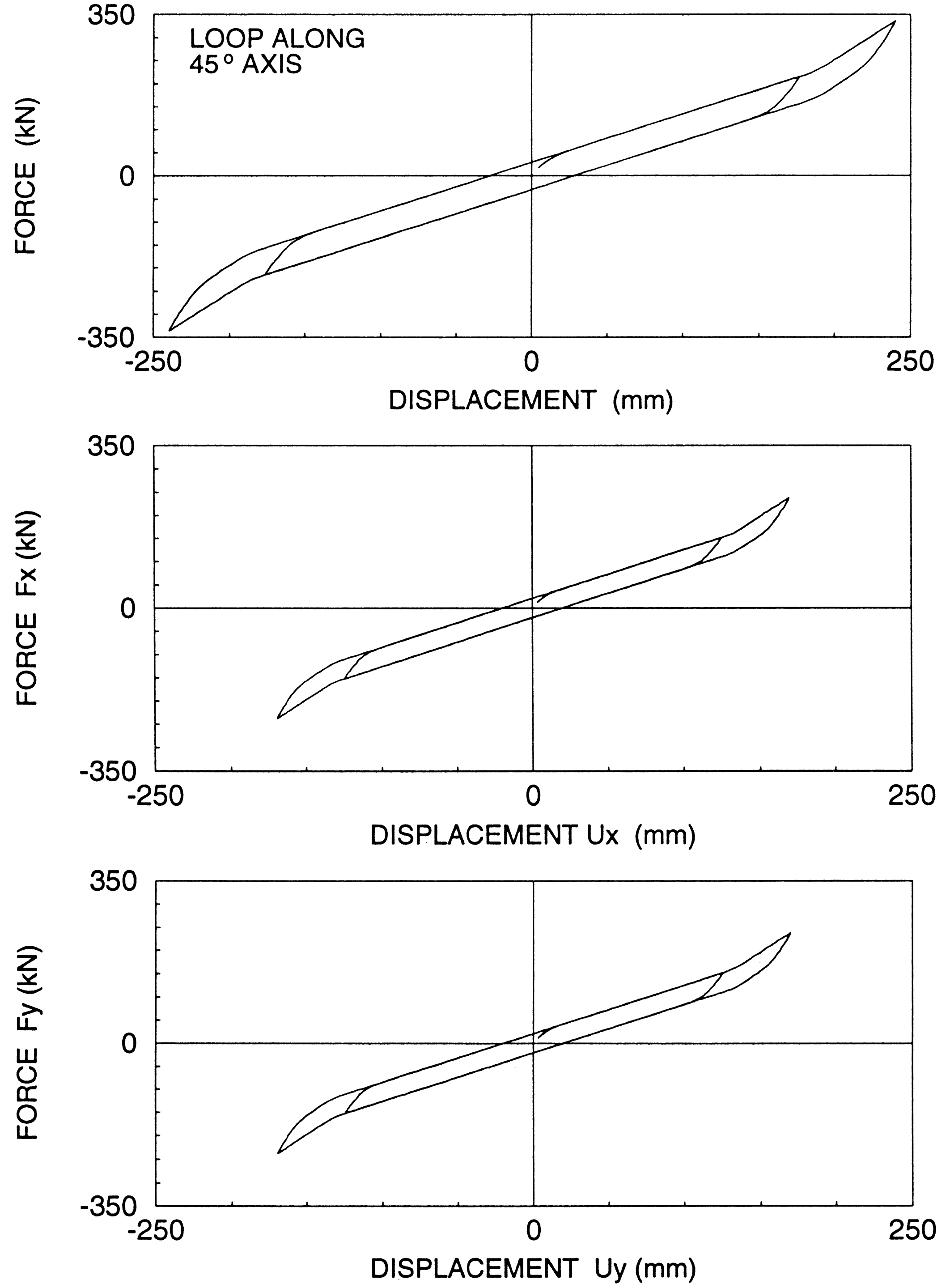


Figure 4-4 Force-Displacement Loops of High Damping Rubber Bearing Along 45° Angle and in X and Y Directions for Motion $U_x = U_0 \sin(2\pi ft)$, $U_y = U_0 \sin(2\pi ft)$, $f = 0.5Hz$, $U_0 = 125mm$ and 169.7 mm.

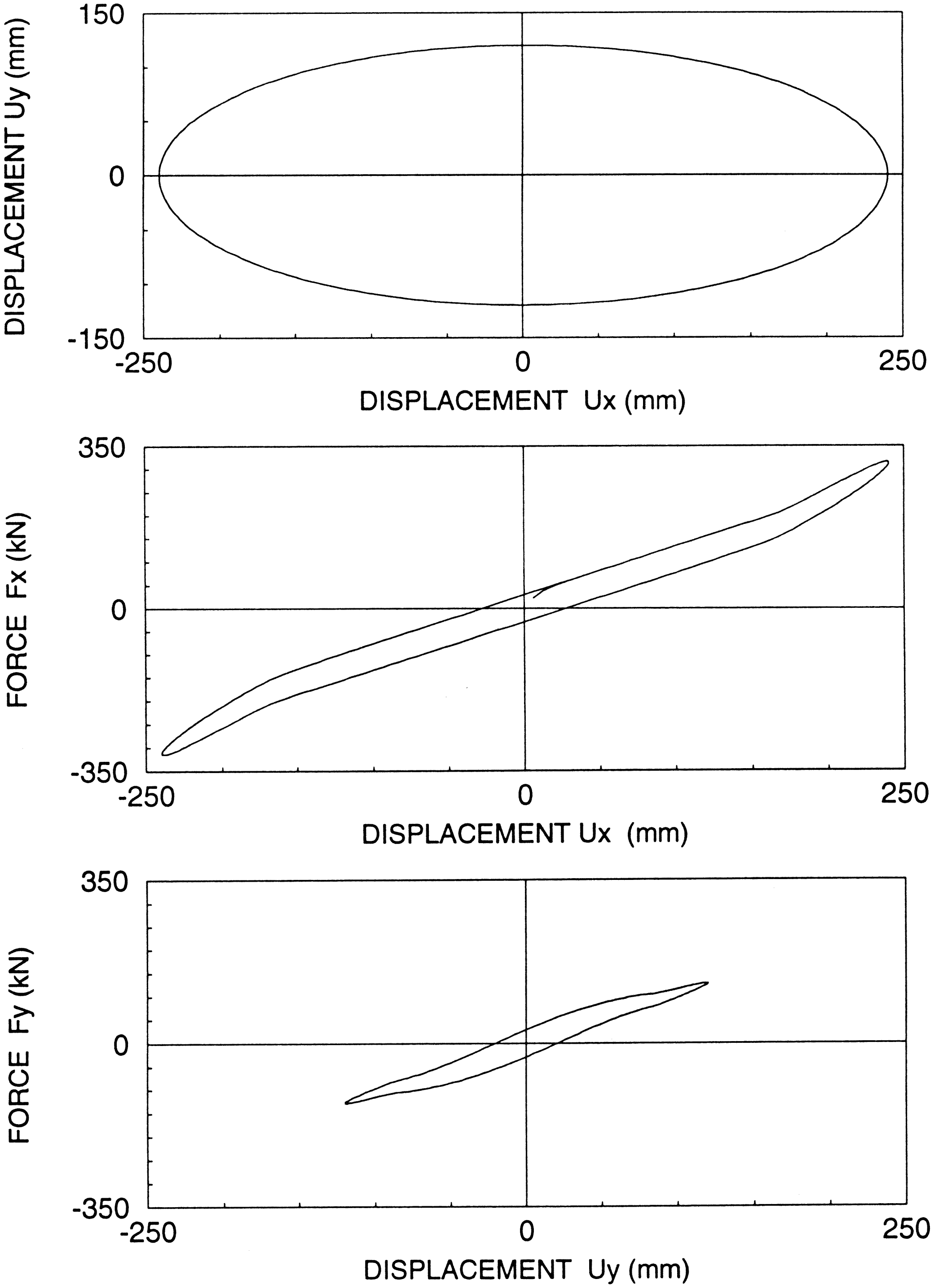


Figure 4-5 Force-Displacement Loops of High Damping Rubber Bearing in X and Y Directions for Motion $U_x = 2U_0 \sin(2\pi f t)$, $U_y = U_0 \cos(2\pi f t)$, $f = 0.5Hz$, $U_0 = 120mm$.

4.2 Element for Friction Pendulum (FPS) Bearing

The principles of operation of the FPS bearing have been established by Zayas et al. 1987, Mokha et al. 1990 and Constantinou et al. 1993. These principles are, of course, valid for all types of spherical sliding bearings. A cross section view of an FPS bearing is shown in Figure 4-6. The bearing consists of a spherical sliding surface and an articulated slider which is faced with a high pressure capacity bearing material. The bearing may be installed as shown in Figure 4-6 or upside-down with the spherical surface facing down rather than up. In both installation methods the behavior is identical.

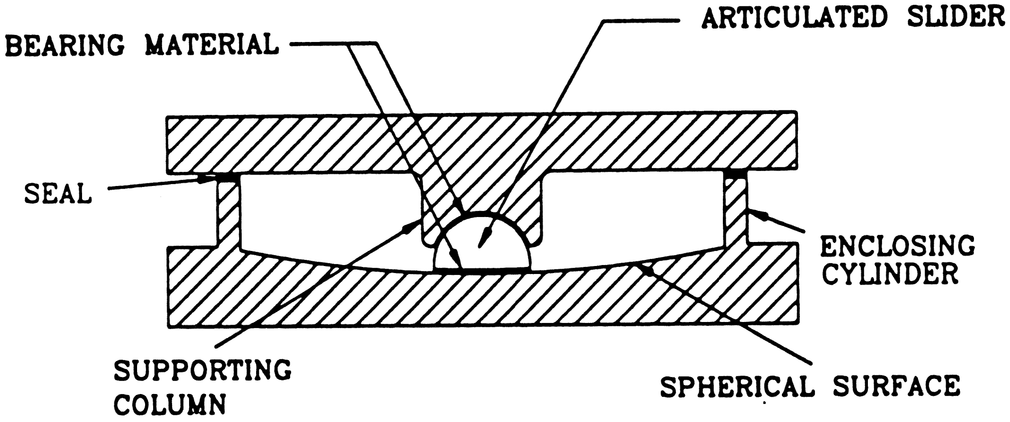


Figure 4-6 FPS Bearing Section.

The force-displacement relation of an FPS bearing in any direction is given by

$$F = \frac{N}{R}U + \mu_s N sgn(\dot{U}) \tag{4.9}$$

in which R is the radius of curvature of the spherical sliding surface, N is the normal load and μ_s is the coefficient of the sliding friction. In cases in which the normal load may be assumed to be constant and equal to the carried weight W_i, modeling of an FPS bearings may be accomplished by combining the linear elastic element of Section 2.2.1, using stiffness $K_{x_i} = K_{y_i} = W_i/R$, and the biaxial element for sliding bearing of Section 2.2.4, using $N=W_i$. To reduce computational effort, all the linear elastic elements may be combined in a global element described by translational stiffnesses $K_x = K_y = \Sigma W_i/R$ (ΣW_i =total weight) and corresponding rotational stiffness K_r and associated eccentricities e_x^B and e_y^B (see Section 2.2.1 and Nagarajaiah et al. 1989 and 1991). This has been the approach followed in programs 3D-BASIS and 3D-BASIS-M.

In general, the vertical load on an isolation bearing does not remain constant but rather varies as a result of the vertical ground motion and the effect of overturning moment. For vertically rigid structures, the normal load on an FPS bearing is

$$N = W_i\left(1 + \frac{\ddot{U}_v}{g} + \frac{N_{OM}}{W_i}\right) \tag{4.10}$$

where W_i is the weight, $\ddot{U}_v$ is the vertical ground acceleration (positive when the direction is upwards) and N_{OM} is the additional axial force due to the overturning moment effects (N_{OM} is positive when compressive).

The direct effects of variations in the normal load on the behavior of the FPS bearing are to instantaneously change the stiffness and friction force. Another indirect effect is to change the coefficient of friction which is pressure dependent. Modeling of the behavior of FPS bearings to this detail is important in the accurate estimation of the forces in individual bearings. However, use of $N=W_i$ rather than Equation 4.10 results in nearly the same global isolation system response and superstructure response. This has been demonstrated by comparison of analytical results to shake table results of a seven-story model in which the axial forces on individual bearings varied from 0 to $2W_i$, W_i being the gravity load (Al-Hussaini et al. 1994).

The forces in the FPS element of program 3D-BASIS-ME are described by

$$F_x = \frac{N}{R} U_x + \mu_s N Z_x \,, \qquad F_y = \frac{N}{R} U_y + \mu_s N Z_y \tag{4.11}$$

which Z_x and Z_y are described by Equation 2.8 and N is described by Equation 4.10. Program 3D-BASIS-ME requires user-supplied routines to

a) Calculate the additional axial force on individual bearings from overturning moments about the two horizontal orthogonal axes, and

b) Describe the variation of coefficient $f_{\max}$ in Equation 2.14 with bearing pressure.

Details of these routines are given in Section 4.6.

4.3 New Biaxial Element for Sliding Bearings

The new biaxial element for flat sliding bearings in program 3D-BASIS-ME is again described by Equations 2.12 to 2.14 and 2.8 with the exeption that N is not constant but rather described by Equation 4.10. The element requires the user-supplied routines described in Sections 4.2 and 4.6. It should be noted that when $\ddot{U}_v$ is not given and when the user-supplied routine returns zero for the additional axial load N_{OM} (eq. 4.10), the model collapses to the original constant normal load ($N=W_i$) model of programs 3D-BASIS and 3D-BASIS-M.

4.4 Linear Elastic Element

This element can be used to model the behavior of helical steel springs, rubber springs or other devices that exhibit linear elastic behavior.

The model of linear elastic element in program 3D-BASIS-ME is identical with the one available in programs 3D-BASIS and 3D-BASIS-M. In those programs, the properties of the linear elastic elements were combined automatically by the program in one global element, whereas in 3D-BASIS-ME the program is dealing with each element independently. The forces generated in each element are

$$F_x = K_x U_x, \qquad F_y = K_y U_y \tag{4.12}$$

where K_x, K_y and U_x, U_y are the stiffnesses and displacements of the element in X and Y directions, respectively.

It should be noted that the option of using one global linear elastic element that combines the properties of a linear elastic isolation system is also available in the program 3D-BASIS-ME (see Section 2.2.1 and Appendix A, Section C2).

4.5 Viscous Element

This element is suitable for modeling the behavior of Fluid Viscous Dampers or other devices displaying viscous behavior. Specifically, fluid dampers which operate on the principle of fluid orificing produce an output force which is proportional to the power of the velocity. That power can take values in the range of 0.5 to 2.0 (Constantinou et al. 1992).

The mobilized forces on a viscous element are described by

$$F_x = C_x \, | \dot{U}_x |^{\alpha} \, sgn(\dot{U}_x) \tag{4.13}$$

$$F_y = C_y \, | \dot{U}_y |^{\alpha} \, sgn(\dot{U}_y) \tag{4.14}$$

where C_x, C_y and $\dot{U}_x$, $\dot{U}_y$ are damping coefficients and velocities experienced by viscous elements placed along the X or Y directions respectively, and α is a coefficient taking real positive values. For $\alpha = 1$, the linear viscous element is recovered. It should be noted that program 3D-BASIS-ME allows only the placement of dampers along the principal directions.

In the case of linear viscous devices, an alternative approach is possible. The properties can be combined in one global linear viscous element located at the center of mass of the base (see Section 2.2.2 and Appendix A, Section C3).

4.6 User-Supplied Routines in Program 3D-BASIS-ME

4.6.1 Routine for Additional Axial Load Due to Overturning Moment Effects

The routine (a function) has the form

FOVM(OVMX,OVMY,XP,YP,I)

in which I is the bearing number, XP and YP are arrays containing the bearing coordinated (XP(I)=X coordinate of bearing I etc.), and OVMX and OVMY are the overturning moments about the X and Y axes, as illustrated in Figure 4-7. Function FOVM is called by the main program at all time steps. The function returns to the main program the additional axial load FOVM on bearing I. FOVM is positive when compressive.

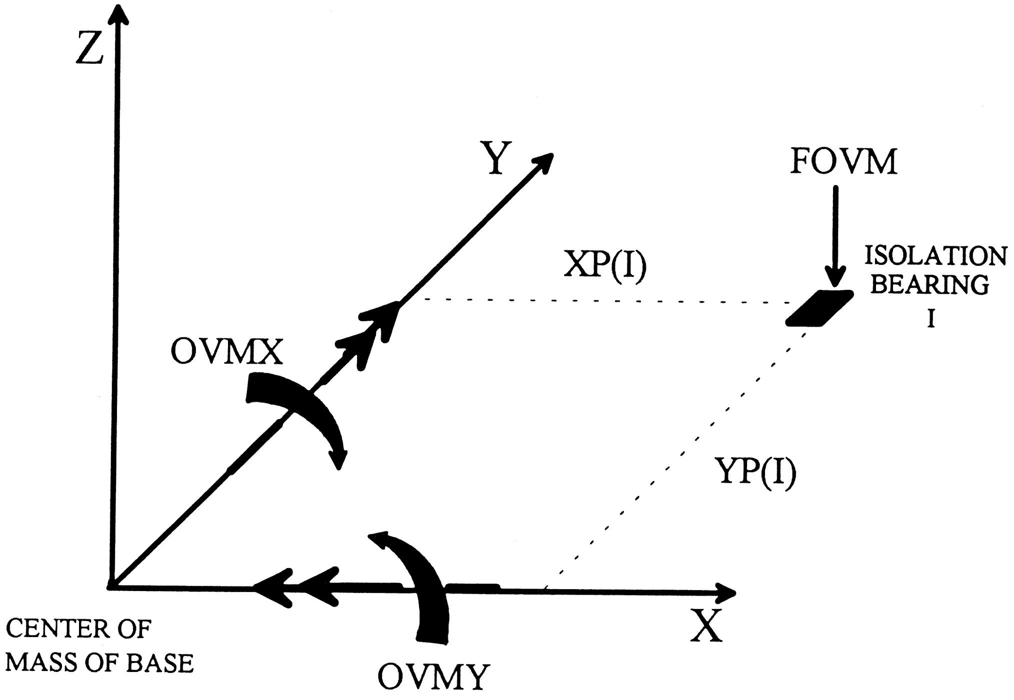


Figure 4-7 Definition of Overturning Moments OVMX and OVMY, and Additional Force FOVM.

It should be noted that we have assumed a unique relation between overturning moments and additional axial load on bearings. The user is cautioned that this is a simplification of a complex phenomenon. However, it is a commonly used engineering approximation. The report of Al Hussaini et al. 1994 provides valuable insight into the behavior of slender isolated structures with FPS bearings which are subjected to strong overturning moments.

To exclude the effect of the overturning moment on the additional axial force, function FOVM should be as follows:

```
FUNCTION FOVM(OVMX,OVMY,XP,YP,I)
IMPLICIT REAL *8
COMMON/MAIN1 / NB,NP,MNF,MNE,NFE,MXF
DIMENSION XP(NP),YP(I)
FOVM=0.D0
RETURN
END
```

This is the default version of function FOVM in 3DBASIS-ME.

4.6.2 Routine for Describing the Dependency of Parameter $f_{\max}$ on Bearing Pressure

Constantinou et al. 1990 and 1993 described the dependency on bearing pressure of the parameters in the model of friction in Equation 2.14. Specifically, the coefficient of sliding friction is given by

$$\mu_s = f_{\max} - (f_{\max} - f_{\min}) \exp(-a \mid \dot{U} \mid) \tag{4.15}$$

where a is nearly independent of pressure, whereas $f_{\min}$ is dependent on pressure for unfilled and glass-filled PTFE but nearly independent of pressure for the PTFE-composites used in the FPS bearings. Parameter $f_{\max}$ is generally dependent on bearing pressure. Since parameter $f_{\max}$ describes the maximum friction force that is transmitted through the bearing, its dependency on pressure is explicitly modeled in program 3D-BASIS-ME. However, the much less significant dependency on pressure of parameters a and $f_{\min}$ is neglected.

The user-supplied routine (function) has the form

FFMAX(FRMAX,FRMIN,FNOR,I)

in which I is the bearing number, FNOR is the normal load on bearing I, which includes the gravity, vertical ground motion and overturning moment effects, normalized by the weight W_i on the bearing. Furthermore, FRMAX and FRMIN are, respectively, the supplied, through the INPUT, parameters f_{max0} and f_{min0} under almost zero static pressure of bearing I. Function FFMAX returns the value of $f_{\max}$ at the bearing pressure resulting from the instantaneous normal load. Note that parameter $f_{\min}$ is assumed indepenndent of pressure, that is $f_{min0} = f_{\min}$.

For example, consider the case in which the dependency on pressure of parameter $f_{\max}$ is neglected. Function FFMAX should be

```
FUNCTION FFMAX(FRMAX,FRMIN,FNOR,I)
IMPLICIT REAL *8
COMMON/MAIN1 / NB,NP,MNF,MNE,NFE,MXF
FFMAX=FRMAX
RETURN
END
```

This is the default version of function FFMAX in 3DBASIS-ME.

Consider now the case of pressure dependent parameter $f_{\max}$. Figure 4-8 shows the assumed dependency on pressure of parameter $f_{\max}$.It is typical of the behavior of sliding bearings (Soong and Constantinou 1994). An accurate representation of the variation of parameter $f_{\max}$ with pressure can be accounted for by using the following expresion

$$f_{\max} = f_{max0} - (f_{max0} - f_{maxp}) \tanh(\varepsilon p) \tag{4.16}$$

where p is the pressure, f_{maxp} is the maximum coefficient of friction at very high pressures, f_{max0} is the vakue of the coefficient at zero pressure, ε is a constant that controls the transition of $f_{\max}$ between very low and very high pressures.

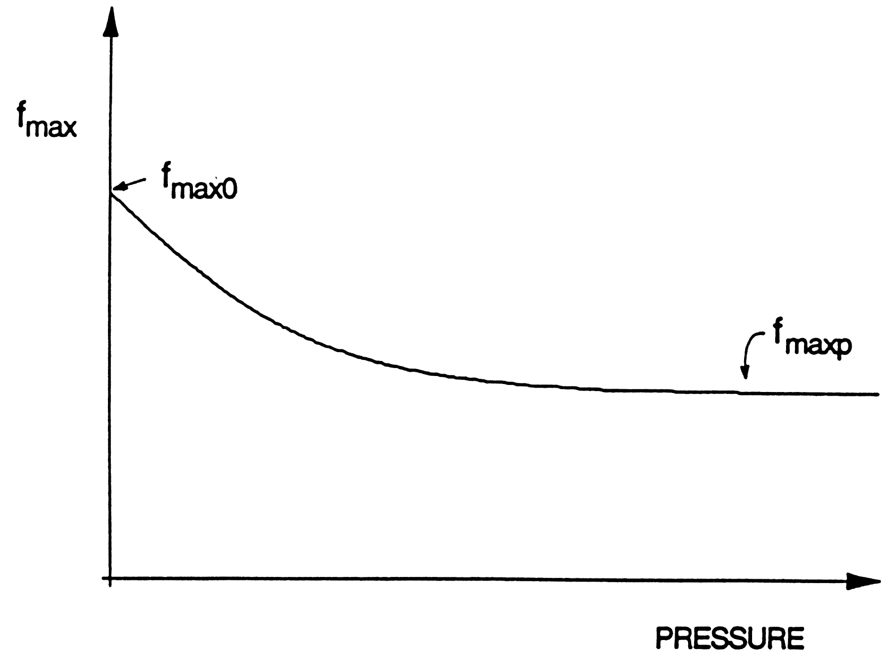


Figure 4-8 Variation of Friction Parameter f_{max} with Pressure.

As an example, Constantinou et al. 1993 gave the following values for the parameters of a bearing at pressure of 17.2 MPa : f_{max0}=0.12, f_{maxp}=0.05, ε=0.012 (p is in units of MPa). For this case function FFMAX should be of the form :

```
FUNCTION FFMAX(FRMAX,FRMIN,FNOR,I)
IMPLICIT REAL *8
COMMON/MAIN1 / NB,NP,MNF,MNE,NFE,MXF
DIMENSION P(500)
DATA/P(J)=17.2,J= 1,../
    etc.  etc.

PRES=FNOR*P(I)
FFMAX=FRMAX-0.07*DTANH(0.012*PRES)
RETURN
END
```

Note that P(J) contains the bearing pressure under static conditions of bearing J. Quantity PRES is the instantaneous bearing pressure in units of MN/m^2 or MPa.

4.7 Validation of Model of FPS Bearing

The validity of the model of FPS bearings in program 3D-BASIS-ME is investigated by comparison of the predictions of the model to experimental results. The experimental results were obtained in shaking table testing of an isolated structure, in which the FPS bearings were subjected to lateral motion under normal load of varying magnitude.

Al-Hussaini (1994) reported test results of a 7-story model structure supported by eight FPS bearings and tested in a variety of structural system configurations. One of these configurations is shown in Figure 4-9. The 7-story structure is a moment resisting frame with the isolators placed directly below the columns without connecting them to form an isolation basemat. The structure had a total weight of 212 kN (47.5 kips). The bearings had radius of curvature R=248 mm (9.75 in) and were loaded to an averege bearing pressure of about 110 MPa (16 ksi), for which the friction coefficient $f_{\max}$ was measured to be 0.06. Length scale factor in the experiments was 4.

The columns of the model above the isolation bearings were instrumented with strain gages so that measurements of axial and shear force could be made. In one test the table was excited with the 1971 San Fernando earthquake, record at Pacoima Dam, component S74W. While the command signal consisted of only horizontal motion, the shake table responded with additional vertical, roll and pitch motions, as a result of the large model weight and demand for high table velocity. The recorded horizontal and vertical acceleration histories of the table are shown in Figure 4-10. The recorded loops of bearing shear force versus bearing displacement of two FPS bearings (one interior and one exterior) are shown in Figure 4-11.

The loops have been also analytically constructed from the recorded histories of bearing displacement and axial bearing force by using Equations (4.11), (2.8), (2-14) and (4.15). That is U_x = recorded bearing displacement, $U_y = 0$, N = recorded axial force, and $\dot{U}_x$ and $\dot{U}_y$ were determined by numerical differentiation of the displacement histories. The parameters used were : $f_{max0} = 0.12$, $f_{maxp} = 0.05$, $f_{\min} = 0.04$, $\varepsilon = 0.012 \quad (MPa)^{-1}$ and $a = 0.0429 \quad s/mm$. The bearing pressure under

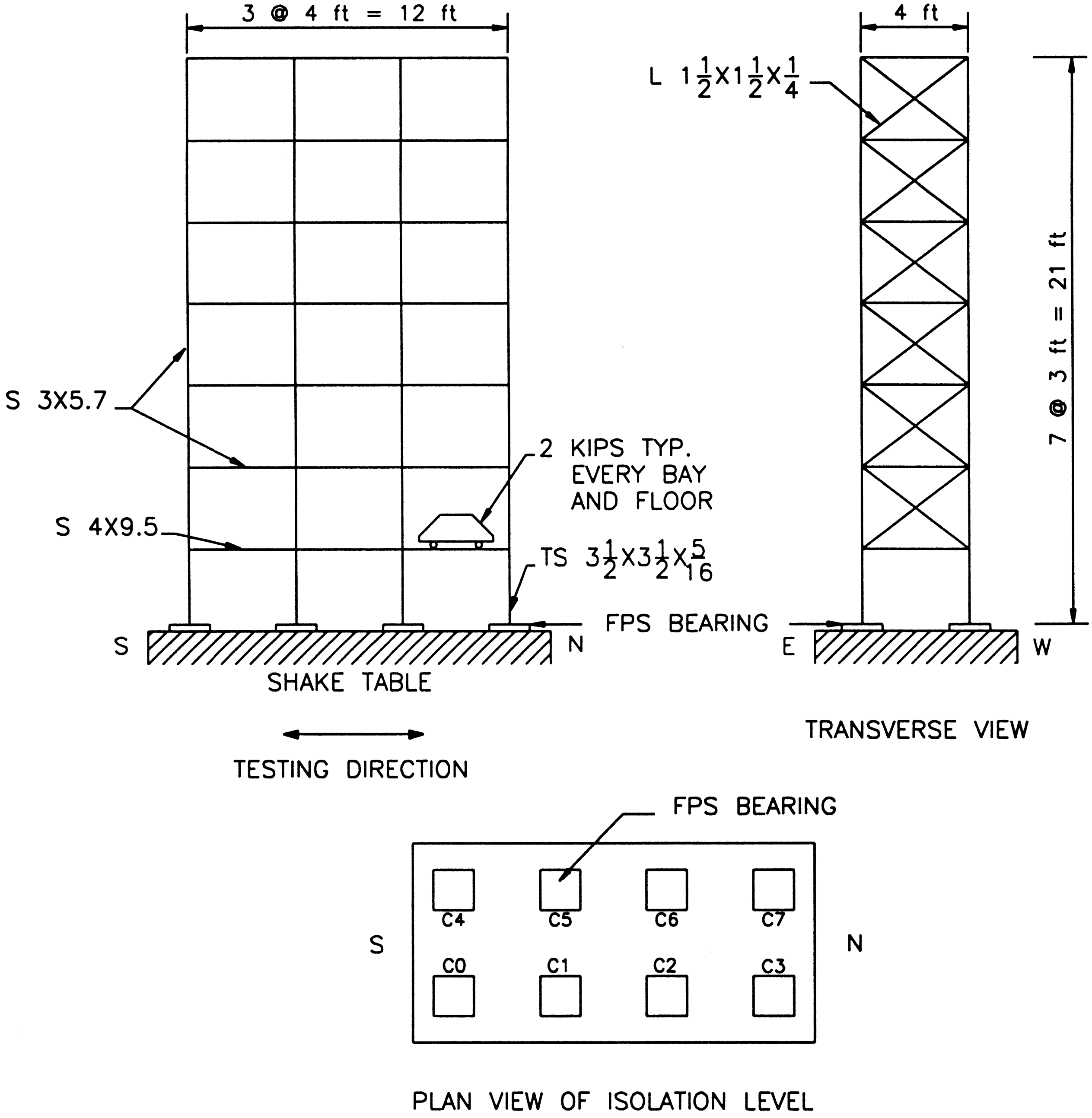


Figure 4-9 Model in Shake Table Testing of Al-Hussaini (1994).

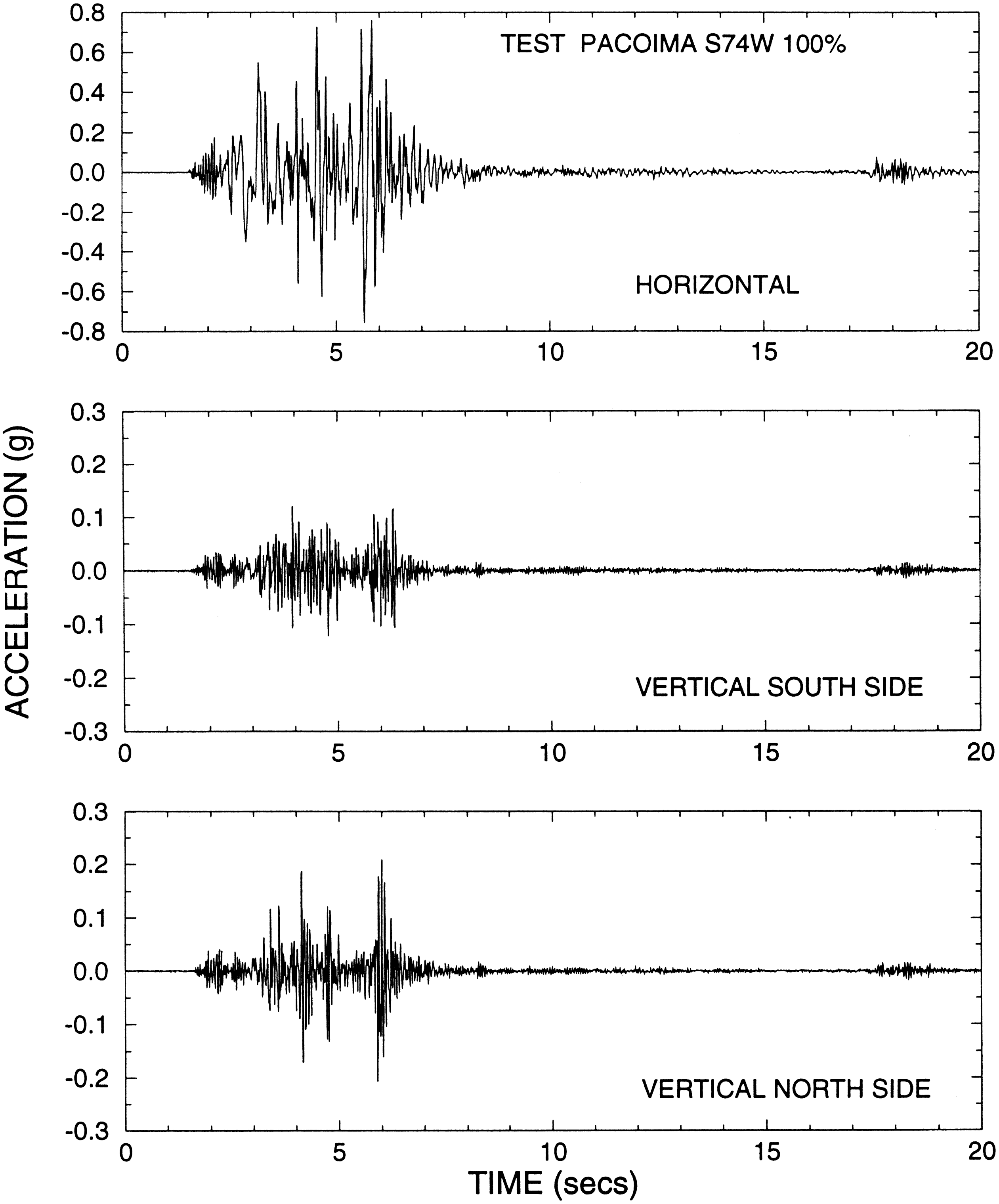
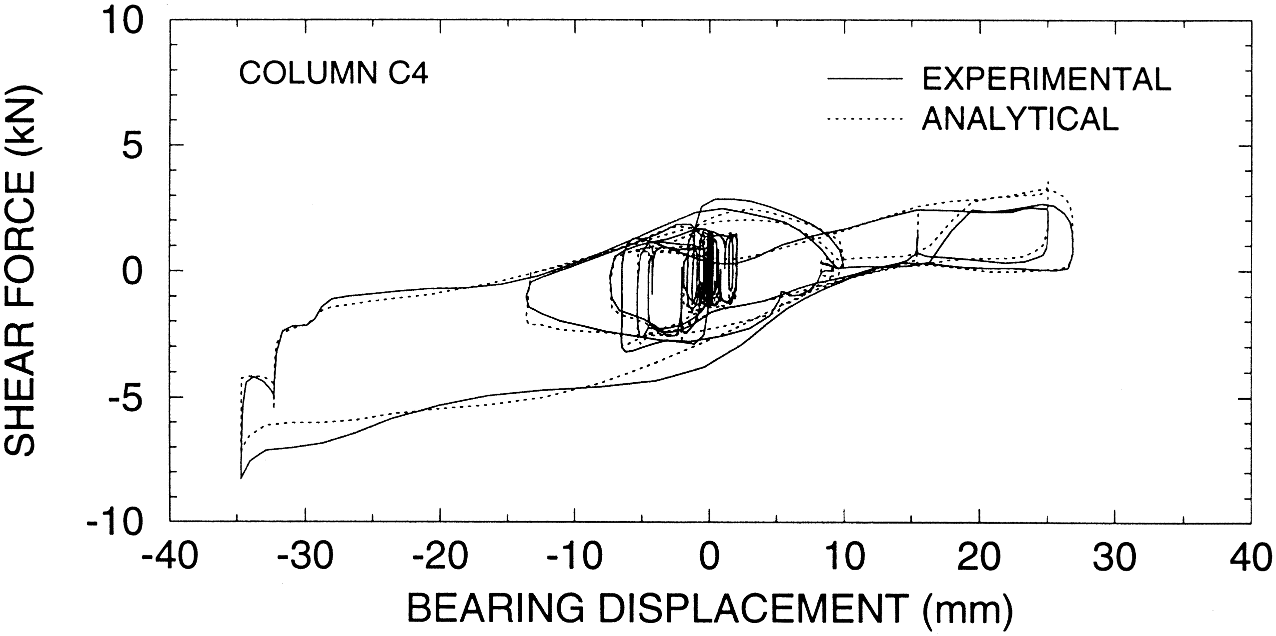


Figure 4-10 Recorded Horizontal and Vertical Accelerations of Shake Table in Test of Model Structure with Pacoima Dam S74W Input.



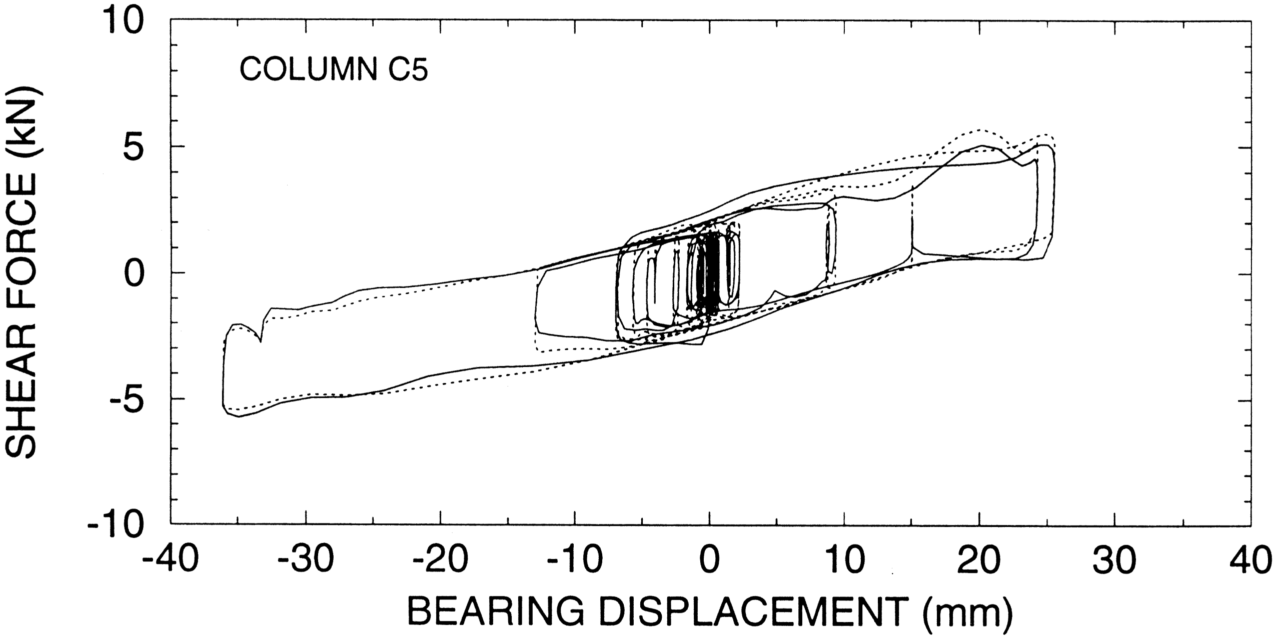


Figure 4-11 Recorded and Analytically Predicted Force-Displacements Loops of Exterior (C4) and Interior (C5) Bearings in Pacoima Dam S74W Test.

static conditions was set at 120 MPa for the interior bearing and at 220 MPa at the exterior bearing. The analytical results are compared to the experimental results in Figure 4-11. The agreement is very good.

In another test the structure was excited with the 1940 El Centro earthquake, components S00E and vertical. Figure 4-12 shows the recorded table accelerations. The shake table response was unstable with extremely high frequency vertical motion, which reached a peak acceleration 0.6 g (it should have been only 0.21 g). The recorded loops of the bearing shear force versus bearing displacement of one exterior and one interior bearings are shown in Figure 4-13. The analytically determined loops, obtained by the same model and using the same parameters, are compared to the experimental ones in Figure 4-13. Again the agreement is very good.

Of interest is to note in Figure 4-13 the significant variations in shear force of the interior (C5) bearing. These variations could not be caused by variations in the friction force alone. Rather, they are caused by variations in both the restoring force (that is, force NU/R in Equation 4.9) and friction force.

Finally, the dynamic response of the tested model in the 1940 El Centro S00E plus vertical input (Figure 4-12) was computed with program 3D-BASIS-ME. The analytical model was based on the experimentally determined modal properties of the structure (Al-Hussaini 1994). The overturning moment effects on the axial bearing load was accounted for by assuming a linear distribution of axial load. Time histories of isolation system displacement and base shear-displacement loops are compared in Figure 4-14. They compare well.

We may conclude that satisfactory experimental evidence has been provided for the validity of the FPS bearing (and other spherical sliding bearings) model in 3D-BASIS-ME.

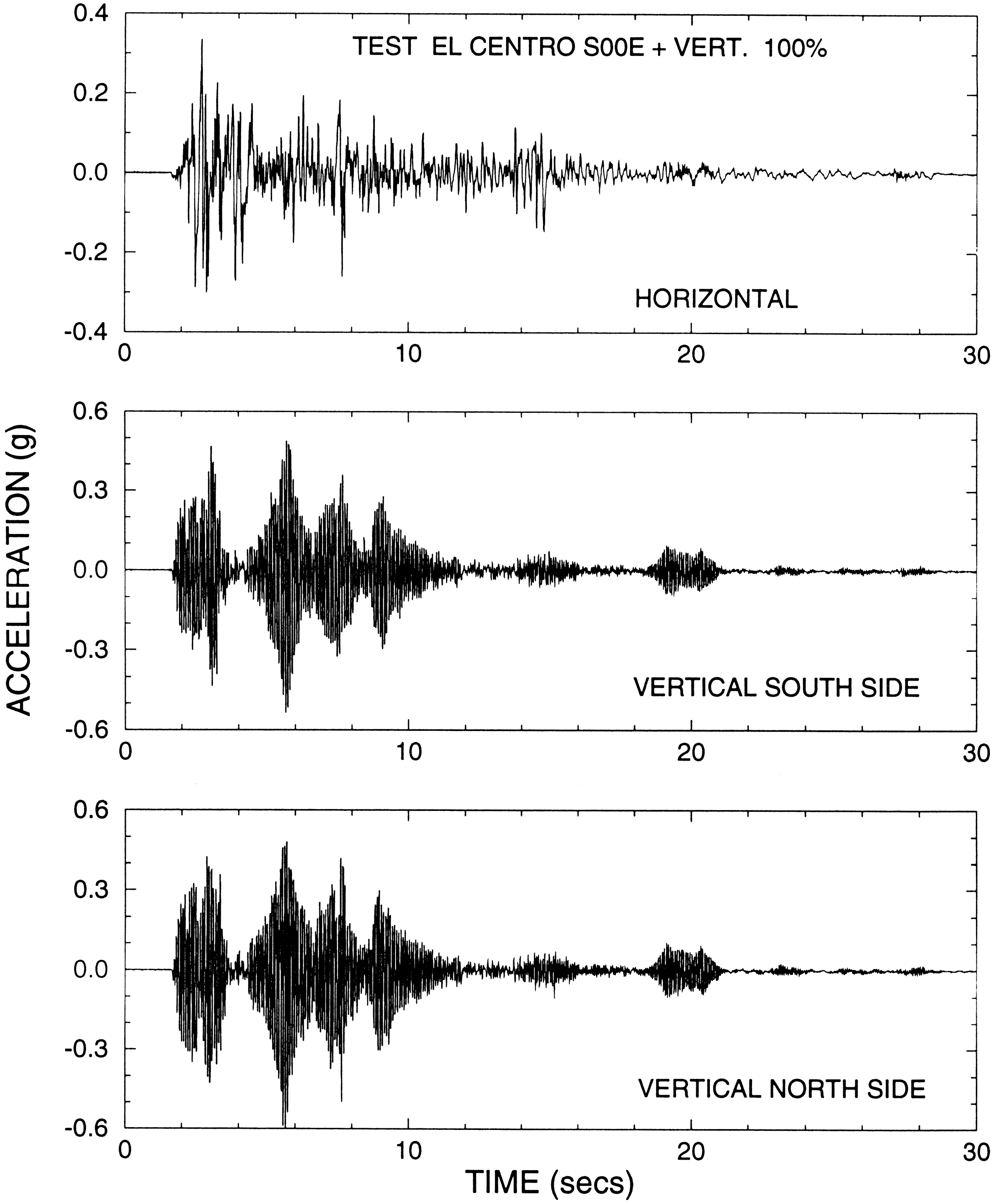
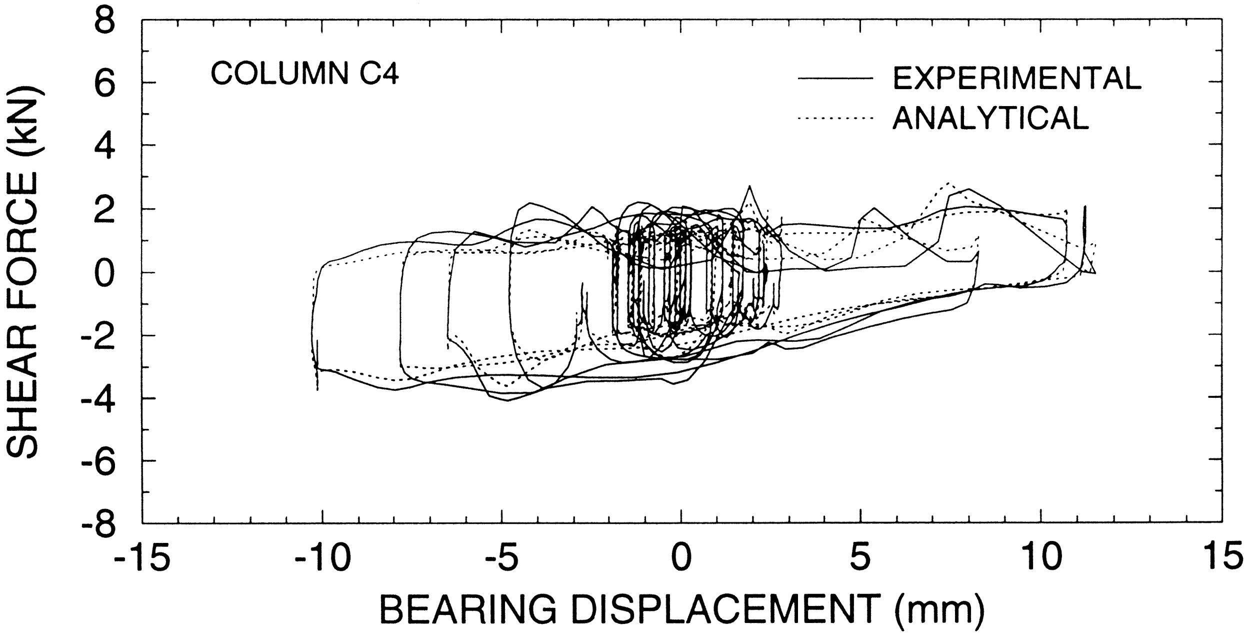


Figure 4-12 Recorded Horizontal and Vertical Accelerations of Shake Table in Test of Model Structure with El Centro S00E plus Vertical Input.



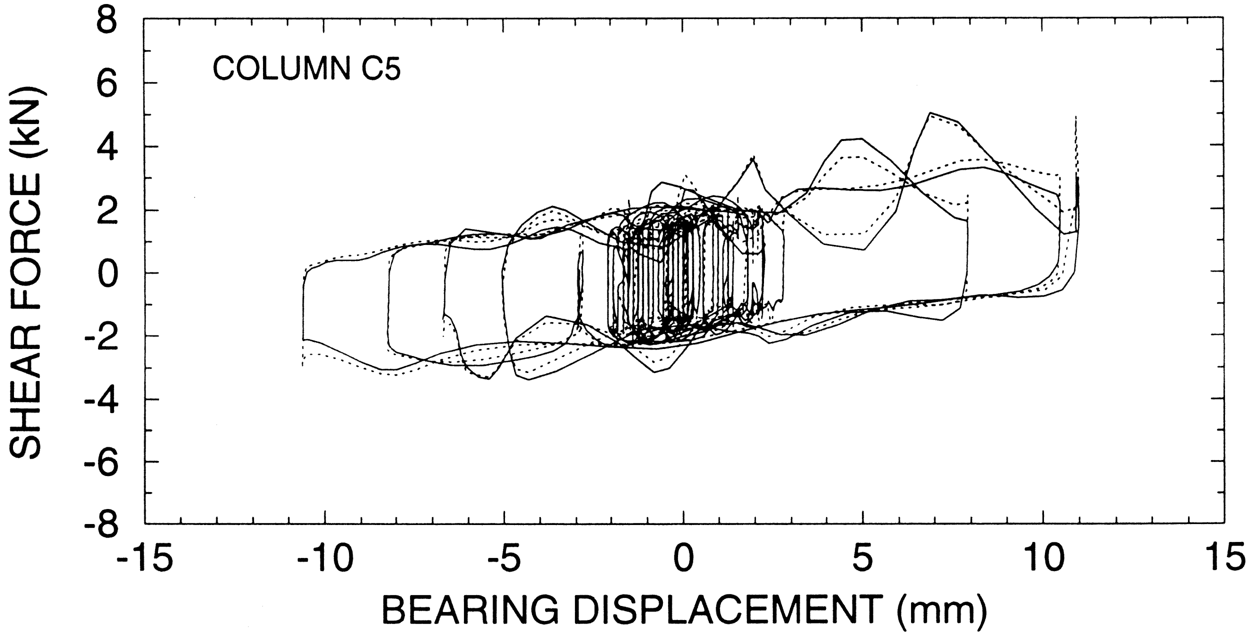


Figure 4-13 Recorded and Analytically Predicted Force-Displacements Loops of Exterior (C4) and Interior (C5) Bearings in El Centro S00E plus Vertical Test.

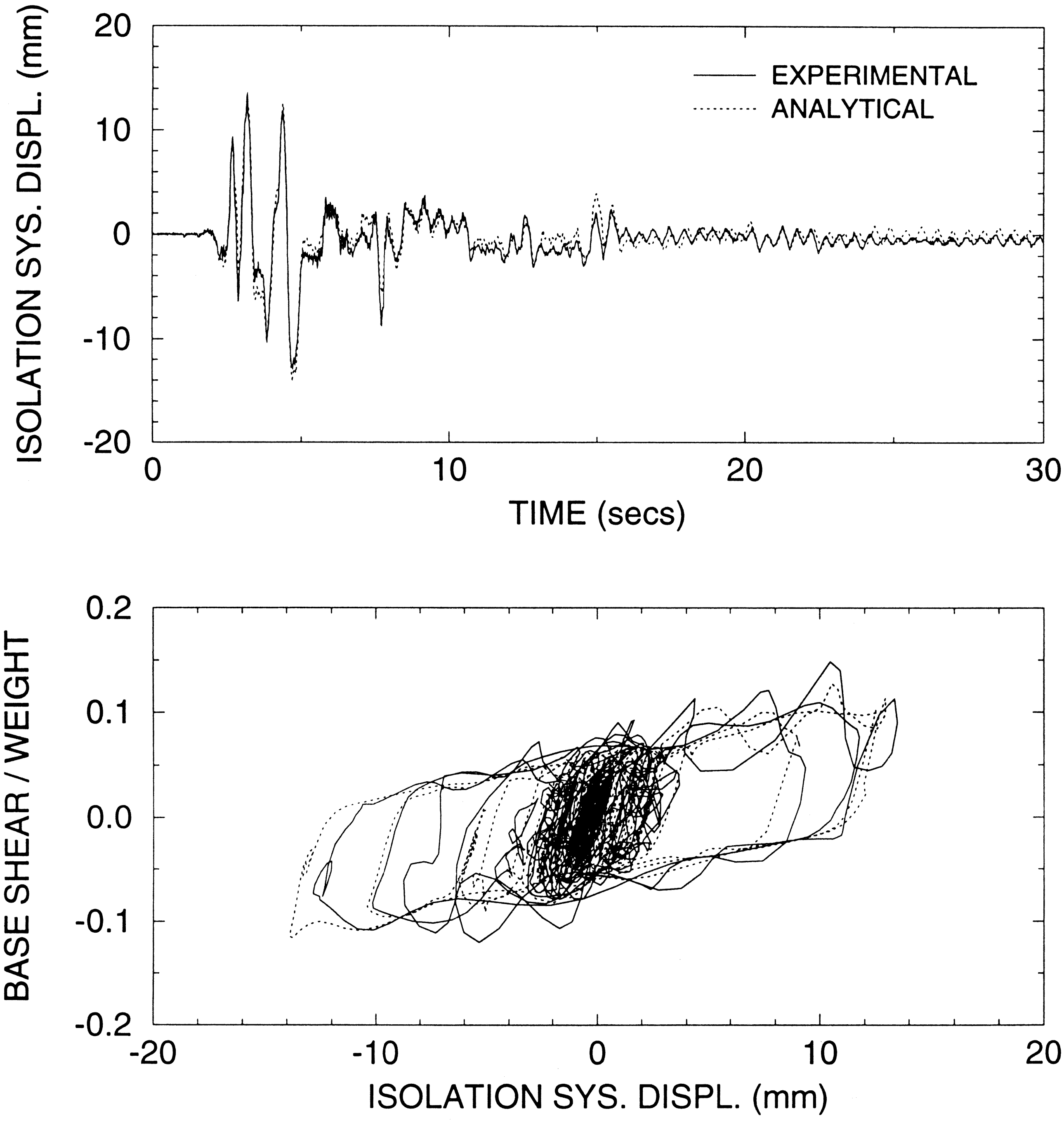


Figure 4-14 Comparison of Experimental and Analytical Response of Isolation System of Tested Model in El Centro S00E plus Vertical Input.

SECTION 5

EXAMPLES

5.1 Introduction

Examples are presented which demonstrate the modeling details of isolation devices and their implementation in program 3D-BASIS-ME. Detailed input and output from the program are presented for each case.

5.2 Isolated Structure

The isolated structure is a water tank as illustrated in Figure 5-1. Unit weights are : for water 62.75 lb/ft^3, for steel 490 lb/ft^3 and for concrete 150 lb/ft^3. The weights are : water (for full tank) 28387.4 kips, steel tank 646.5 kips, steel roof 477.3 kips and concrete basemat 2629.8 kips with a total isolated weight of 32141 kips.

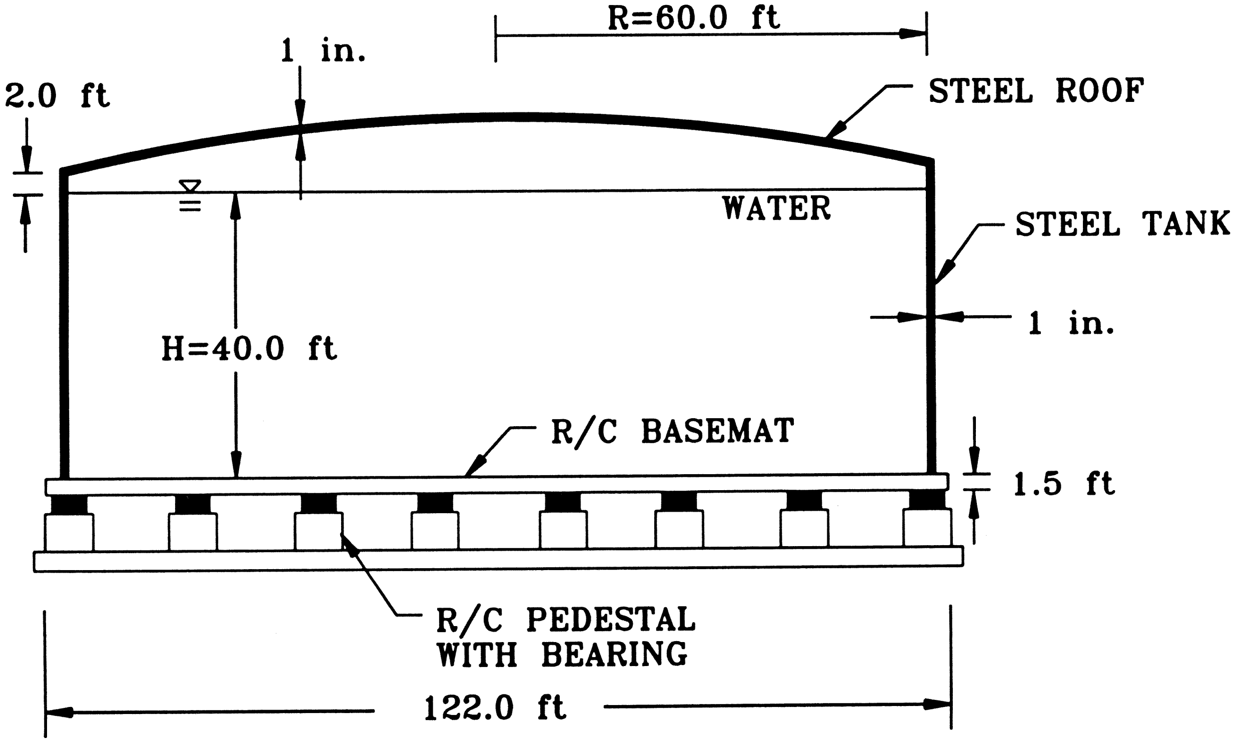


Figure 5-1 Geometry of Isolated Water Tank.

Four different isolated systems are considered. They are :

(a) High damping rubber bearings,

(b) Low damping rubber bearings with linear viscous fluid dampers,

(c) Low damping rubber bearings with non-linear viscous fluid dampers and

(d) FPS bearings.

Each isolation system consists of 52 bearings or 52 bearings plus 24 fluid dampers in the configurations shown in Figures 5-2 and 5-3.

5.3 Mathematical Model of Tank

The mathematical model of the tank is based on the mechanical analog of Haroun and Housner, 1981 which takes into account the deformability of the tank wall and sloshing of the fluid. In the mathematical model used in the present examples, only the fundamental sloshing and fundamental tank-fluid modes of vibration are considered. Based on the theory of Haroun and Housner, 1981, the following were determined:

Sloshing Mode : Sloshing weight 16317 kips, sloshing period 6.89 secs, damping ratio (assumed) 0.005.

Fluid-tank Mode: Weight 12000 kips, period 0.162 secs, damping ratio (assumed) 0.02.

The model of the tank is illustrated in Figure 5-4. It should be noted that the convective fluid is rigidly attached to the concrete basemat, raising its weight to 3824 kips.

5.4 Design of Isolation Systems

The design of the isolation systems does not follow a common design basis and their safety is not assessed. Rather, the design demonstrates the capabilities of the computer program rather than the capabilities of the isolation systems.

The properties of the isolation systems are determined in the stage of least stiffness and characteristic strength. That is, for rubber the properties under scragged and fresh conditions are used. Furthermore, all quantities, such as friction coefficient and shear modulus of rubber are obtained from

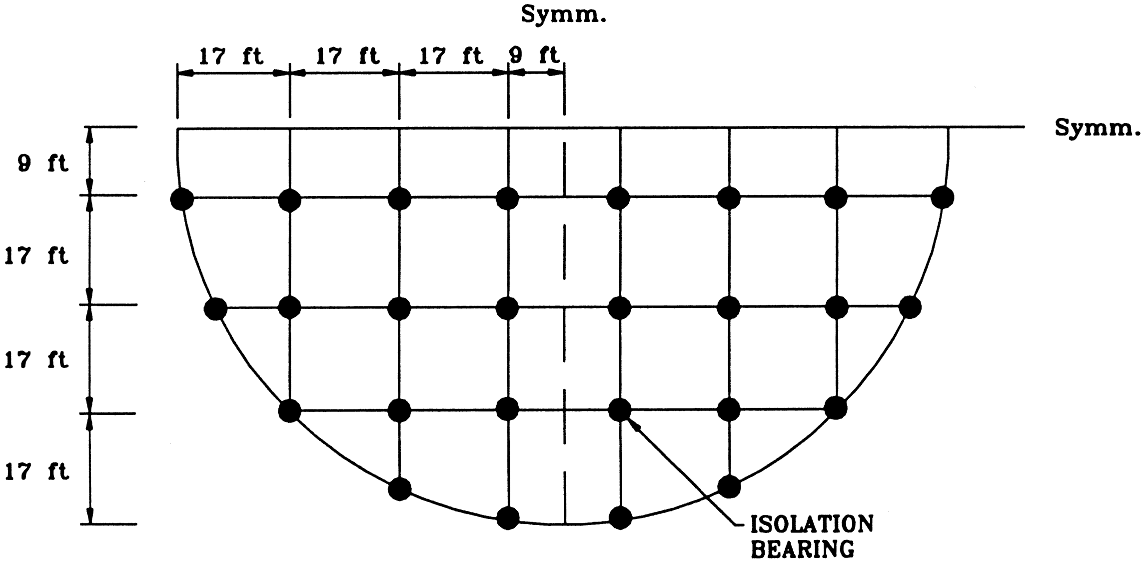


Figure 5-2 Configuration of Isolation System in High Damping Rubber Bearing and FPS System.

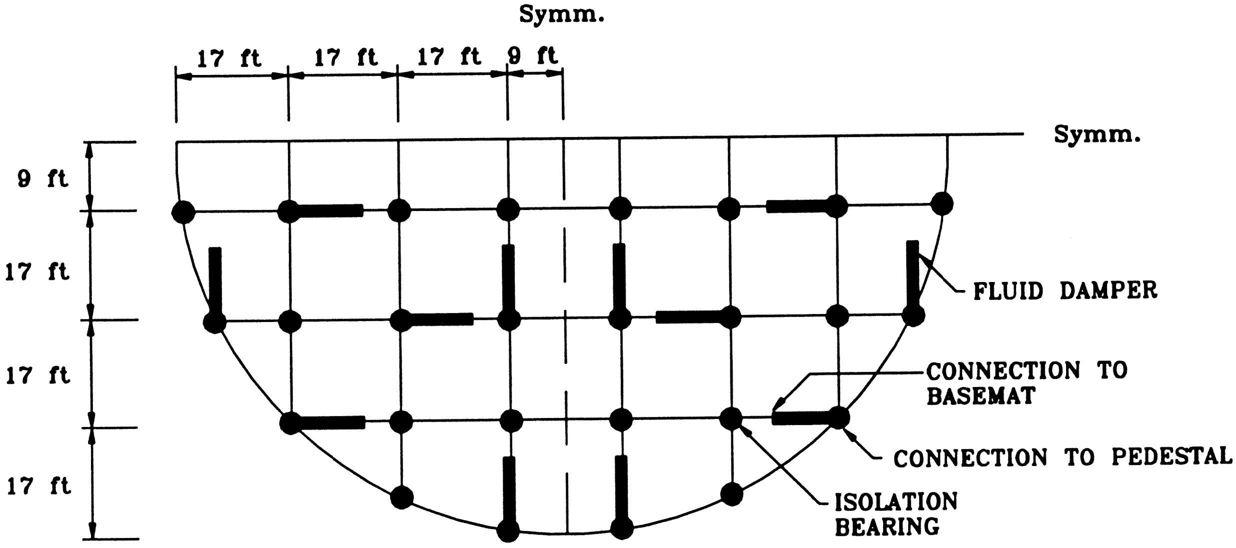


Figure 5-3 Configuration of Low Damping Rubber Bearing - Fluid Damper Isolation System.

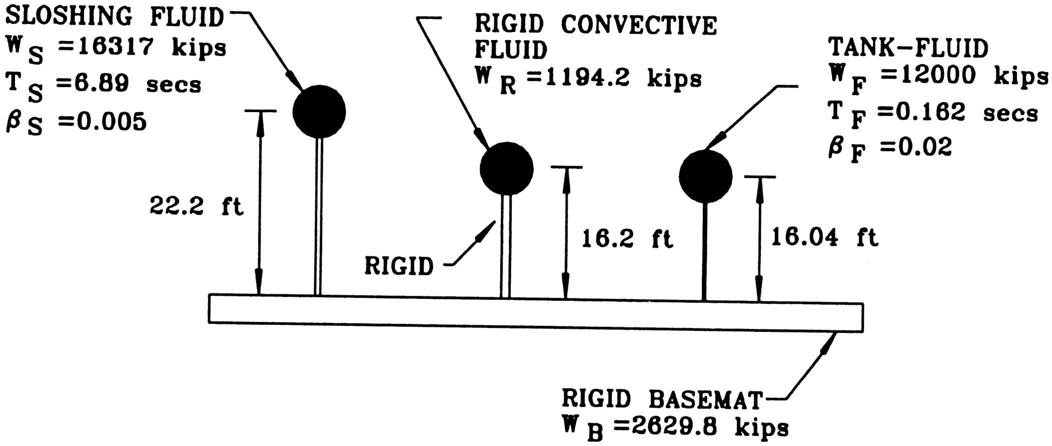


Figure 5-4 Mathematical Model of Fluid Tank.

representative mean values at normal temperatures and fresh conditions, with a further reduction for variability of properties. Thus, the analyzed stage is the one which results in the maximum response of the isolation system (i.e. bearing displacement). A complete analysis would require further analysis for a second stage of properties with the highest stiffness and characteristic strength. For this second stage it is necessary to consider the unscragged properties of rubber, aging and low temperature effects, and furthermore increase these properties for variability. This second stage results in the maximum response in the isolated superstructure.

5.4.1 High Damping Rubber Bearing System

The system consists of 52 bearings in the configuration of Figure 5-2. The bearing construction is shown in Figure 5-5. The bearings have stiffening hysteretic behavior as shown in Figure 4-2 with $K_2=2K_1$, $K_1=AG/T$ (Equation 4.7), $D_1=1.2T$, $D_2=1.25T$ and $Y=0.06T$, where A=bonded rubber area, T=total rubber thickness and G=115 psi. Furthermore, the characteristic strength Q is determined from Equation 4.8 and an assumed damping ratio $\beta=0.10$ at shear rubber strain of 1.0.

The properties for each bearing are

$K_1 = 7.45$ kip/in
$K_2 = 14.90$ kip/in
$Q = 13.19$ kips
$Y = 0.57$ in
$D_1 = 11.40$ in
$D_2 = 11.88$ in

5.4.2 Low Damping Rubber Bearing and Linear Viscous Fluid Damper System

The system consists of 52 bearings and 24 linear viscous fluid dampers in the configuration of Figure 5-3. The rubber bearing construction is shown in Figure 5-5. The behavior of the bearing is linear elastic and viscous with stiffness K=AG/T where G=96 psi. Thus, K=7.63 kip/in. The viscous behavior is accounted for by assuming a damping ratio in the isolation system equal to 0.03.

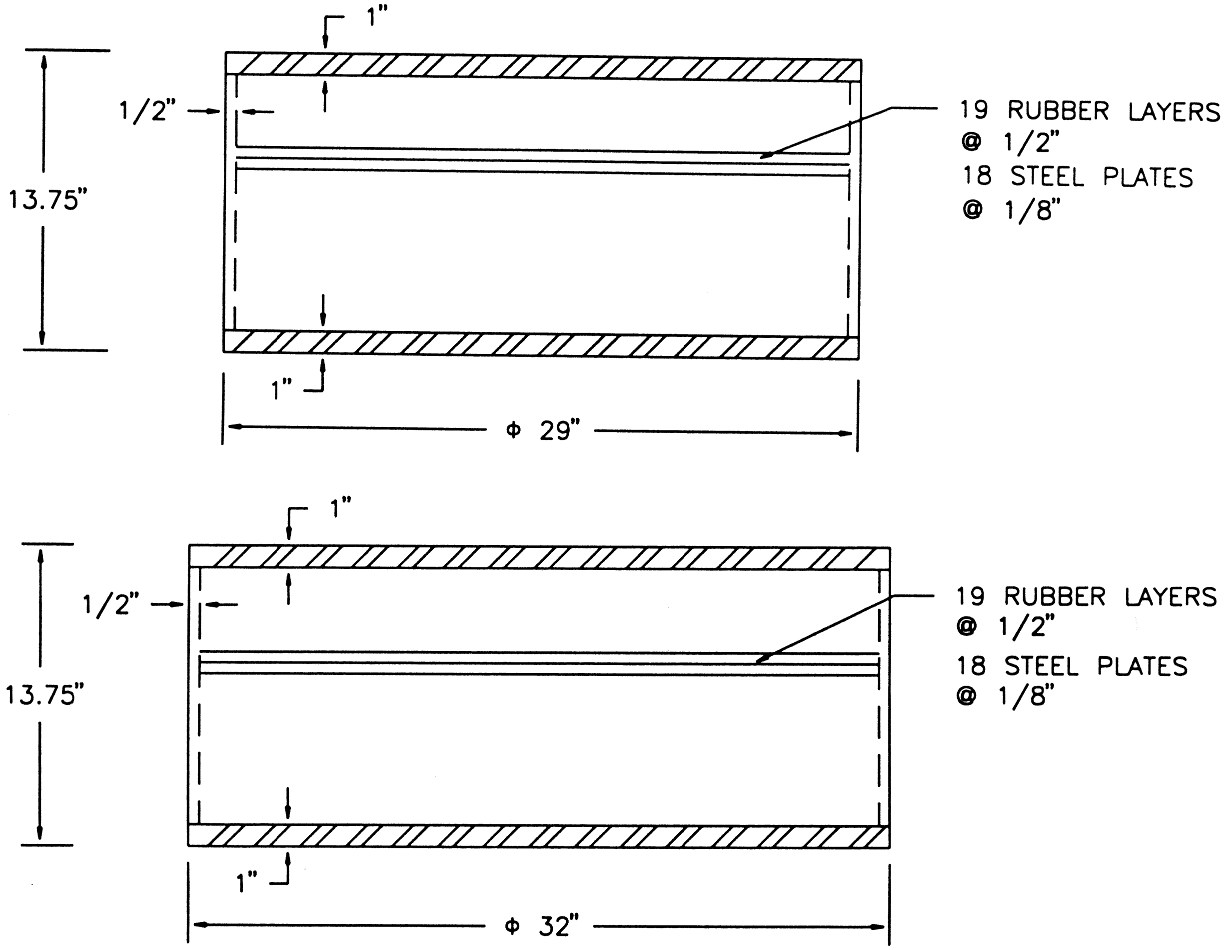


Figure 5-5 Construction of (a) High Damping Rubber Bearing, (b) Low Damping Rubber Bearing.

Each fluid damper has linear viscous behavior with force F_i proportional to velocity, $\dot{U}_i$ (i= X or Y, dampers are placed along principal directions):

$$F_i = C_L \dot{U}_i \tag{5.1}$$

where C_L= 3.61 kip-s/in. Approximate dimensions of a fluid damper with constant C_L= 3.61 kip-s/in, stroke of ±15 in., rated load of 200 kips and ultimate load of 500 kips are shown in Figure 5-6. It should be noted that for twelve dampers C_{TOTAL}=43.32 kip-s/in. Thus, for a SDOF system with K_{TOTAL}=52X7.63=396.76 kip/in and weight of 15824 kips (excluding the weight of the very flexible sloshing mode), the damping ratio is 0.17. This, together with 0.03 damping inherent in the rubber bearing, gives a total viscous damping of 0.20 of critical.

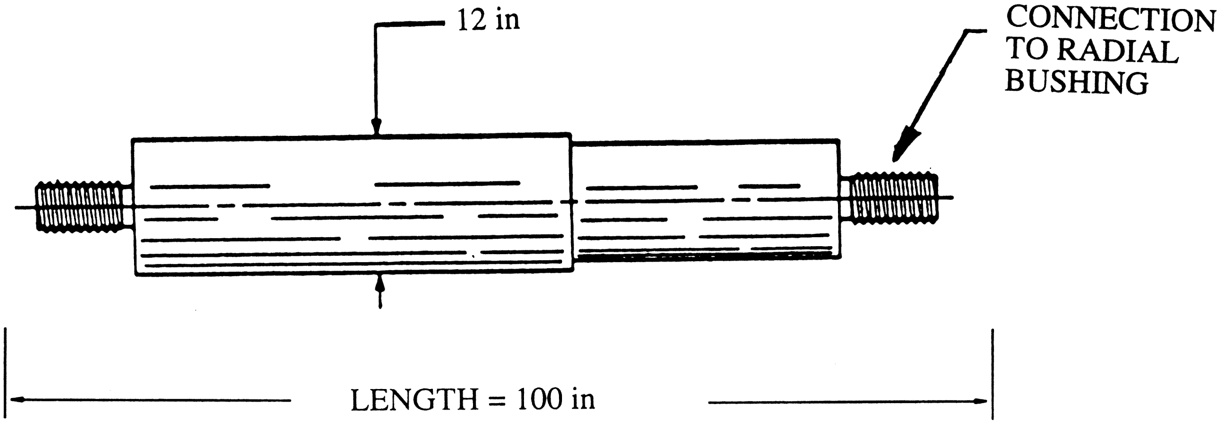


Figure 5-6 Approximate Dimensions of Fluid Damper with Stroke of ±15 in and Ultimate Load of 500 kips.

5.4.3 Low Damping Rubber Bearing and Nonlinear Viscous Fluid Damper System

The system consists of 52 bearings and 24 nonlinear viscous fluid dampers in the configuration of Figure 5-3. The bearing construction is that of Figure 5-5 with K=7.63 kip/in and viscous damping ratio of 0.03. Each fluid damper has force-velocity relation

$$F_i = C_N \mid U_i \mid^{\alpha} sgn(\dot{U}_i) \tag{5.2}$$

where α=0.5 and C_N=26.67 kip(s/in)$^{1/2}$. A damper with this damping constant, stroke of ±15 in. and ultimate load of 500 kips has approximately the same dimensions as the damper of Figure 5-6.

The difference between the nonlinear and linear viscous fluid dampers is illustrated in Figure 5-7. For this motion with peak velocity approximately equal to the one calculated in the analyses, the two dampers reach nearly the same peak force. However, the nonlinear damper dissipates more energy per cycle. This often desirable feature of nonlinear dampers has long being exploited in the shock isolation of military hardware. Furthermore, nonlinear dampers with α equal to approximately 0.5 are used together with rubber bearings in the seismic isolation system of the San Bernandino County Medical Center Replacement Project, of which construction is scheduled to start in late 1994.

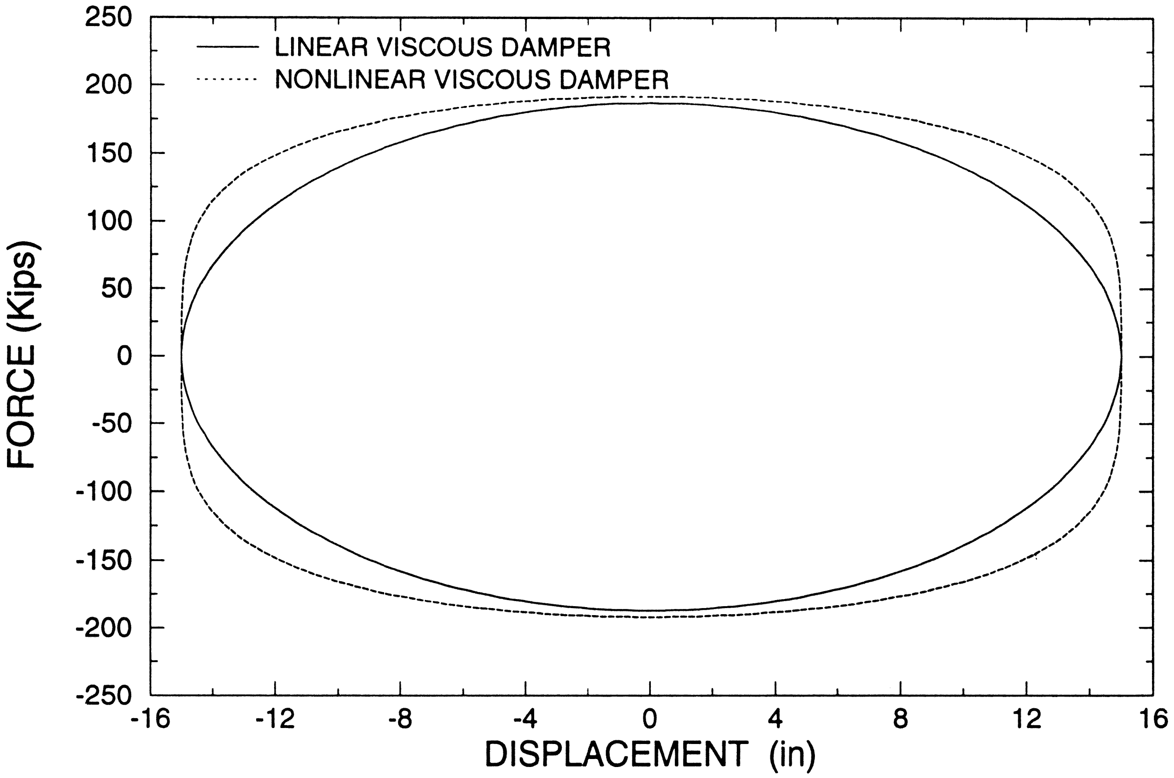


Figure 5-7 Comparison of Force-Displacement Loops of Linear and Nonlinear Viscous Fluid Dampers for Harmonic Motion of Frequency of 0.55 Hz and Amplitude of 15 in.

5.4.4 Friction Pendulum (or FPS) System

The system consists of 52 bearings in the configuration of Figure 5-2. The bearing construction is shown in Figure 5-8. The radius of curvature of the concave sliding surface is R=82.4 in. Average bearing pressure (for full tank) is 15 ksi. The coefficient of friction follows Equation 2.14 with $f_{min}=0.03$, $a=0.8$ sec/in and $f_{max}=0.045$ at pressure of 15 ksi. Parameter f_{max} is pressure dependent. Figure 5-9 depicts the variation of parameter f_{max} with bearing pressure.

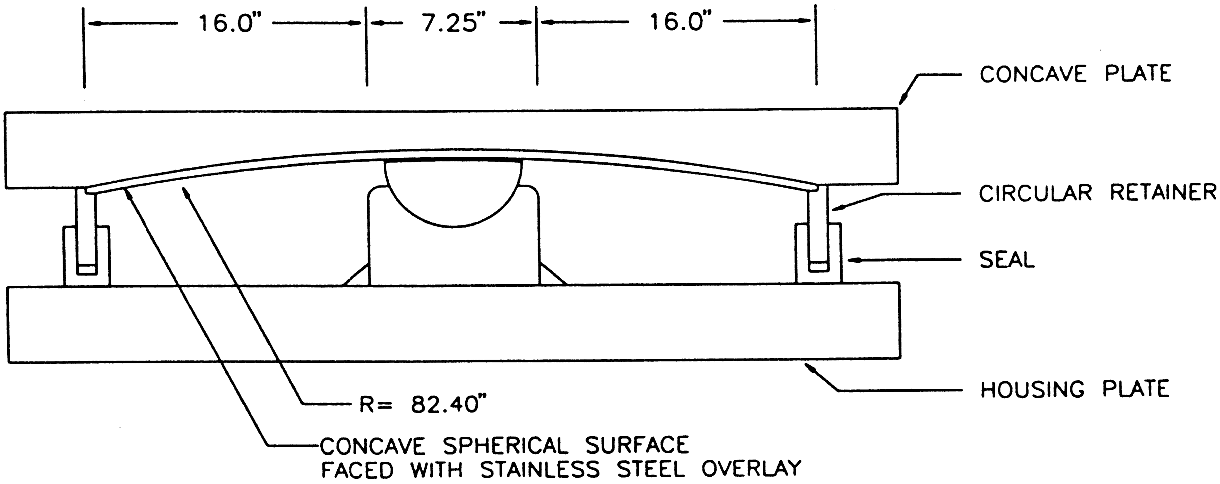


Figure 5-8 Construction of FPS Bearing.

5.5 Model of Isolated Tank in 3D-BASIS-ME

To reduce computational effort, the 52 isolation bearings are grouped into one cluster of 26 bearings at the center of the base and four clusters of 6.5 bearings each at a distance of 68.38 feet (820.56 in) from the center. In this way, the rotational stiffness of the five clusters of bearings is equal to that of the 52 bearings in the configuration of Figure 5-2. Furthermore, an eccentricity of 0.01 times the tank's plan dimension or 14.4 in. is induced in the X direction as illustrated in Figure 5-10.

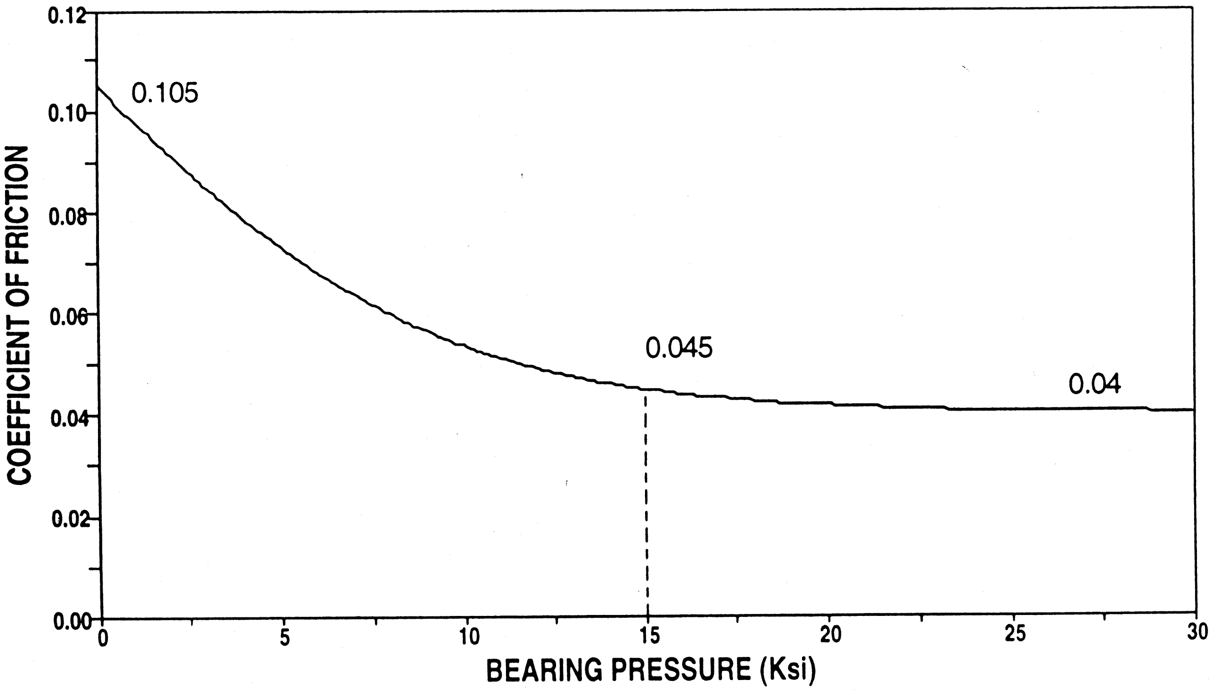


Figure 5-9 Dependency of Parameter f_{max} (coefficient of friction at high velocity of sliding) on Bearing Pressure of FPS Bearings.

The fluid dampers are also grouped into four clusters as shown in Figure 5-11. Each cluster consists of three fluid dampers placed in the X-direction and another three fluid dampers placed in the Y-direction. That is, the damping constants used for each cluster of dampers is $C_X=C_Y=10.83$ kip-s/in for the linear dampers and $C_X=C_Y=80.0$ kip(s/in)$^{1/2}$ for the nonlinear dampers.

In the analysis of the isolation systems with low damping rubber bearings, additional viscous damping of 0.03 of critical is used to account for the energy dissipation capability of the bearings. This is included in the analysis as a global linear viscous element (see Section 2.2.2) with $C_X=C_Y=7.65$ kip-s/in and $C_T=2374932$ kip-s-in.

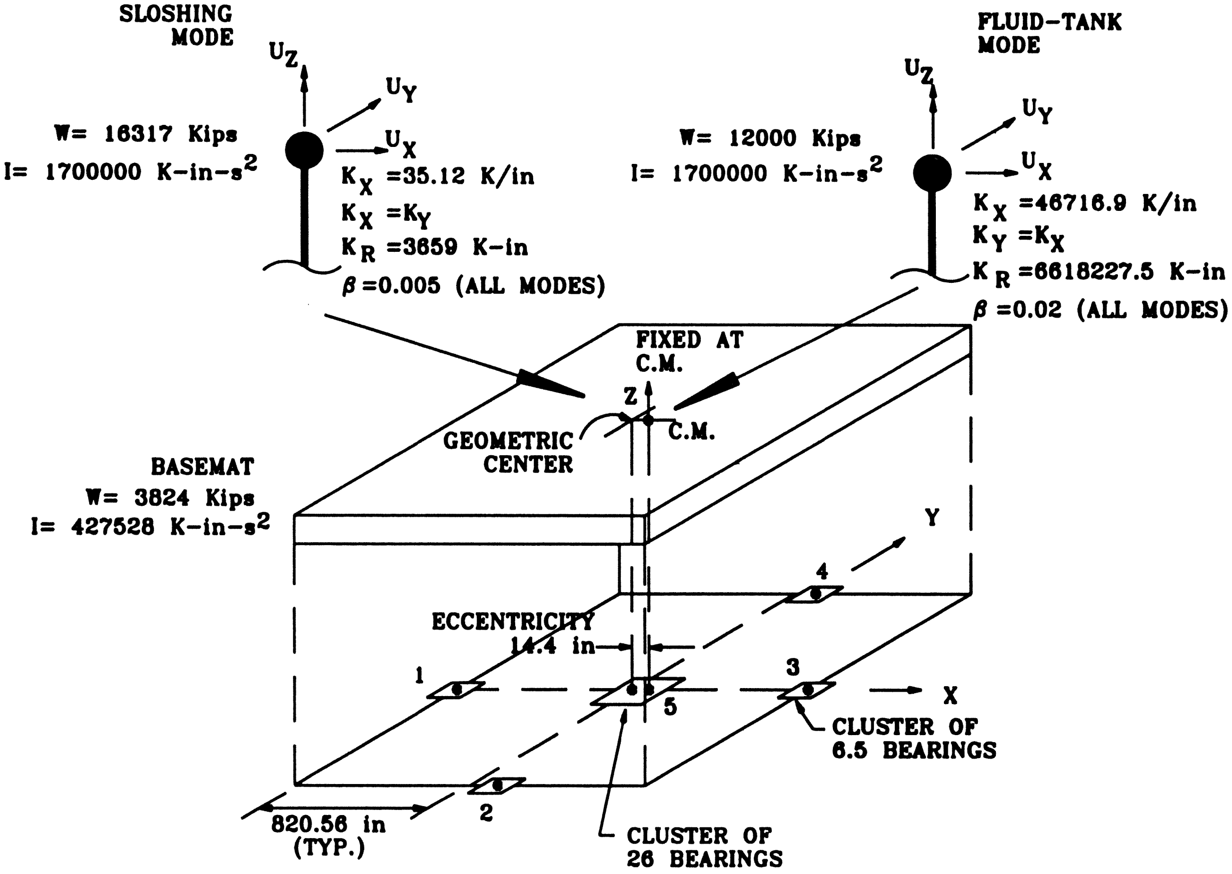


Figure 5-10 Model in 3D-BASIS-ME. Clusters of Bearings are used for Reducing the Computational Effort.

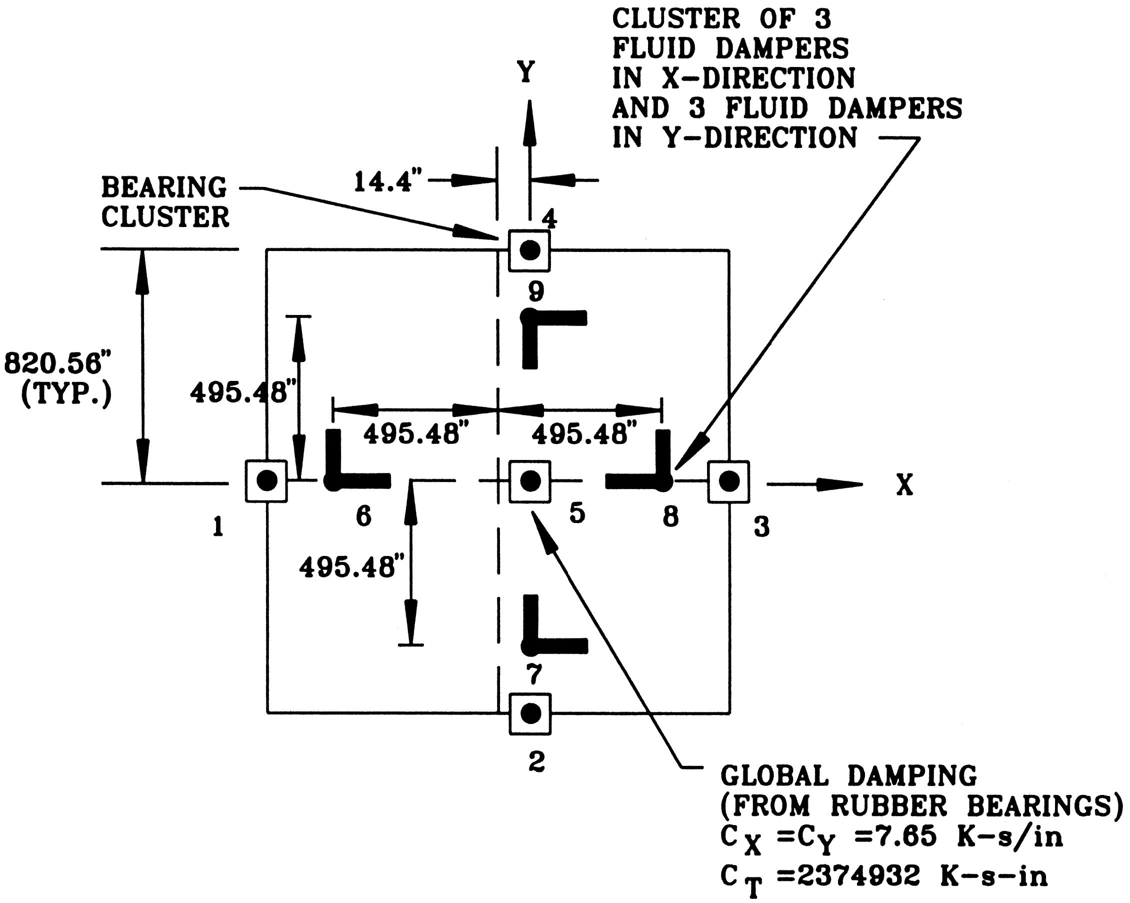


Figure 5-11 Clusters of Fluid Dampers in 3D-BASIS-ME. Model of Low Damping Rubber Bearing - Fluid Damper System. Rubber Bearings are Modeled as Linear Elements with Global Viscous Damping.

5.6 Seismic Excitation

Analyses are performed using the Pacoima Dam record from the 1971 San Fernando earthquake as input. Component S16E (PGA=1.17 g, PGV=44.58 in/s, PGD=14.83 in) is applied in the X direction and component S74W (PGA=1.08 g, PGV=22.73 in/s, PGD=4.26 in) is applied in the Y direction. The vertical component (PGA=0.71 g, PGV=22.95 in/s, PGD=7.60 in) is used only in the analysis of the FPS system. The very strong vertical component of this earthquake is known to influence the response of isolated structures with the FPS system. Specifically, Zayas et al. 1987 studied experimentally the response of three different isolated model structures with and without the vertical motion effects. Only the Pacoima Dam motion had some influence on the peak superstructure shear force, which amounted to an increase of about 20% over the case without vertical motion.

The vertical ground motion is included in the analysis of the FPS system because the effects of varying normal force on the FPS bearings is a well understood phenomenon (Al-Hussaini 1994, Constantinou 1993). Varying normal forces affect other types of isolation bearings. However, these effects are not well understood and have not been incorporated in computer program 3D-BASIS-ME. For such cases, a designer should bound the response by performing analyses which account for plausible variations in the characteristics of the isolation devices.

This seismic excitation is severe, even for an isolated structure. The use of this excitation illustrates the capabilities of program 3D-BASIS-ME in capturing the effects of strong vertical ground motion on the response of sliding systems and in capturing the effects of stiffening behavior at large strains of high damping rubber bearings. Furthermore, the nature of the motion, being a near-fault high velocity motion, demonstrates the usefulness of nonlinear viscous dampers.

5.7 Results of Dynamic Analysis

Dynamic analyses are performed for the five isolation systems under the following conditions:

(a) High damping rubber bearing system without the effect of vertical ground motion and overturning moments,

(b) Low damping rubber bearing system with linear fluid dampers without the effect of vertical ground motion and overturning moments,

(c) As (b) above but with the properties of bearings and fluid dampers represented by one global stiffness and one global damping element,

(d) Low damping rubber bearing system with nonlinear fluid dampers without the effect of vertical ground motion and overturning moments,

(e) FPS system without the effect of vertical ground motion and overturning moments,

(f) FPS system with the effect of vertical ground motion and overturning moments.

Detailed input and output of program 3D-BASIS-ME for each case is presented in Appendix B. A summary of the results is presented in Table 5-I. Figures 5-12 to 5-14 present representative force-displacement loops of the four systems. It should be observed that analysis of the low damping rubber bearing-linear viscous fluid damper system by explicit representation of the isolation devices or by global representation gives nearly identical results.

Table 5-I Summary of Dynamic Analysis Results

ISOLATION SYSTEM	TYPE OF ANALYSIS	RESULTANT CENTER BEARING DISPL. (in)	RESULTANT CORNER BEARING DISPL. (in)	RESULTANT ISOLATION SYSTEM SHEAR FORCE (kips)	RESULTANT SLOSHING FLUID SHEAR FORCE (kips)	RESULTANT FLUID-TANK SHEAR FORCE (kips)	SLOSHING DISPL. IN X / Y DIRECTIONS (in)	PEAK DAMPER VELOCITY AND FORCE[1] (in/s, kips)
High Damping Rubber Bearing	Without Vertical Motion and Overturning Moment Effects	19.32	19.49	11090.0	1423.0	8879.0	40.41 12.09	
Low Damping Rubber-Linear Fluid Damper	Without Vertical Motion and Overturning Moment Effects	12.60	12.73	5821.0	1337.0	5052.0	37.76 7.89	51.58 186.20
Low Damping Rubber-Linear Fluid Damper	Without Vertical Motion and Overturning Moment Effects, Global Representation of Isolation System	12.58[2]	12.78[2]	5792.0	1338.0	5045.0	37.79 7.87	51.08[2] 184.40[3]
Low Damping Rubber-Nonlinear Fluid Damper	Without Vertical Motion and Overturning Moment Effects	11.40	11.53	6029.0	1382.0	5245.0	39.03 5.93	47.57 183.90
FPS	Without Vertical Motion and Overturning Moment Effects	15.51	15.79	7352.0	1433.0	6287.0	40.53 9.82	
FPS	With Vertical Motion and Overturning Moment Effects	15.64	15.89	7909.0	1439.0	7228.0	40.72 9.97	

[1] Force of one damper, [2] At artificial (without stiffness) bearings, [3] Calculated from velocity

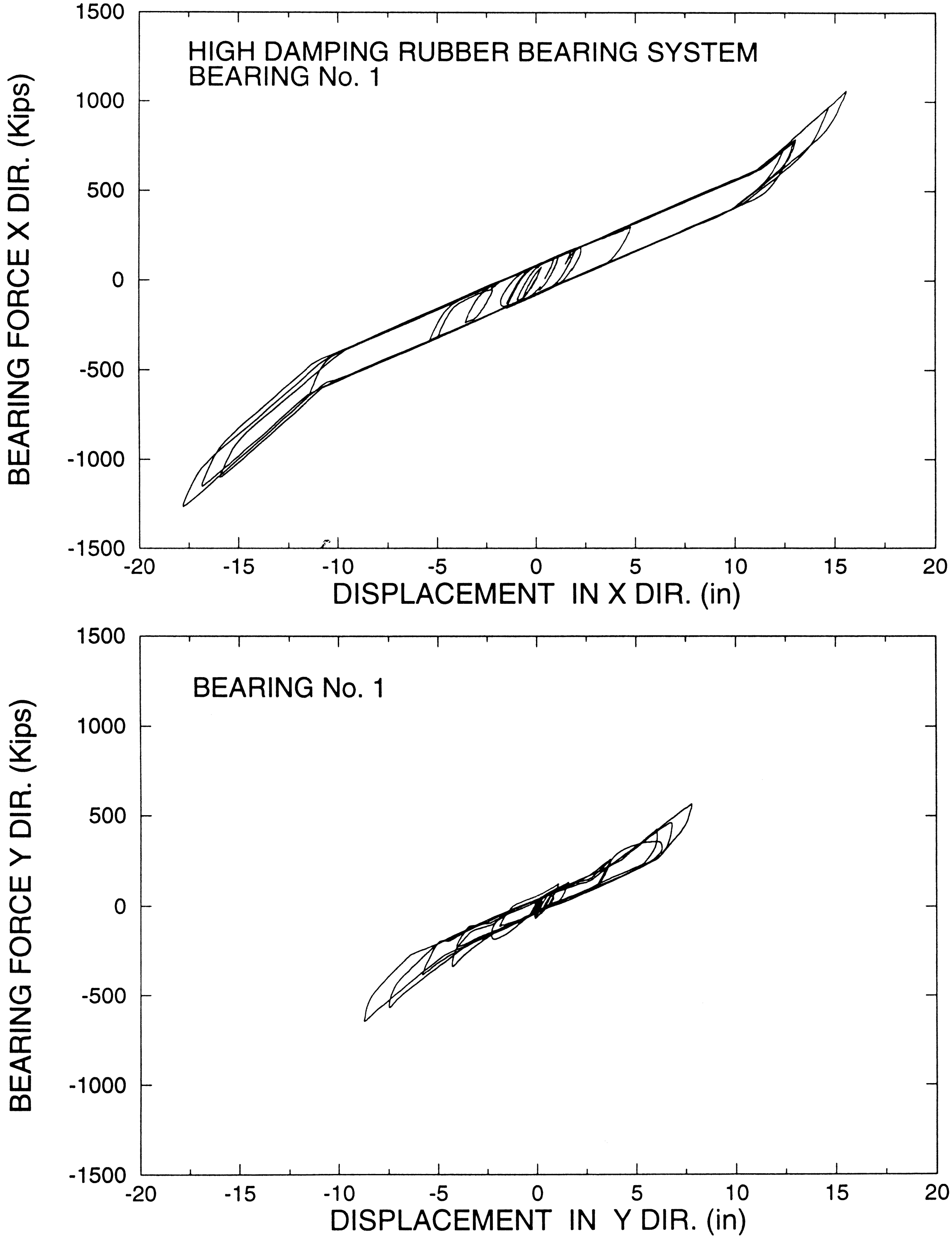


Figure 5-12 Force-Displacement Loops of High Damping Rubber Bearing System.

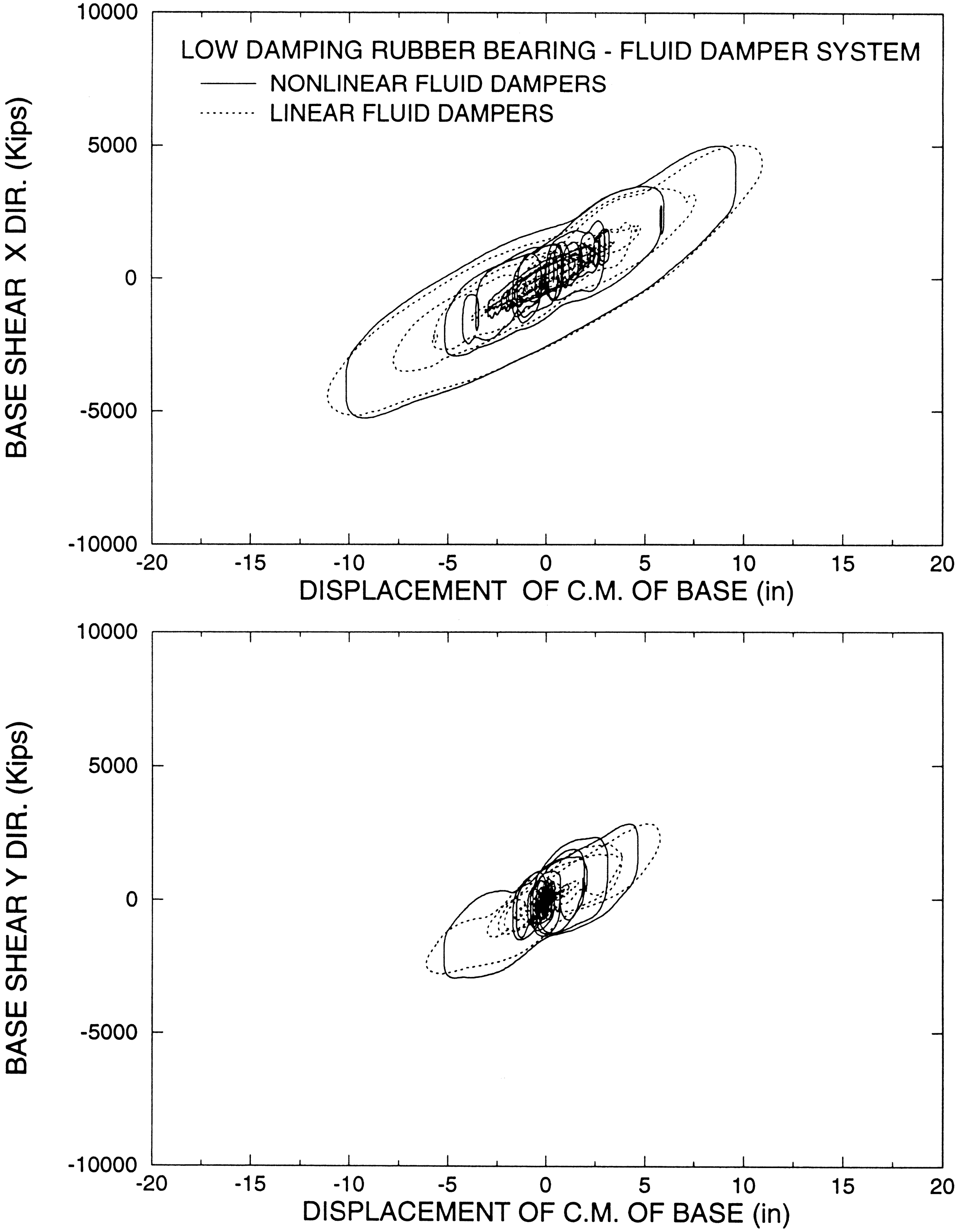


Figure 5-13 Base Shear Force-Isolation System Displacement Loops of Low Damping Rubber Bearing System with Fluid Dampers.

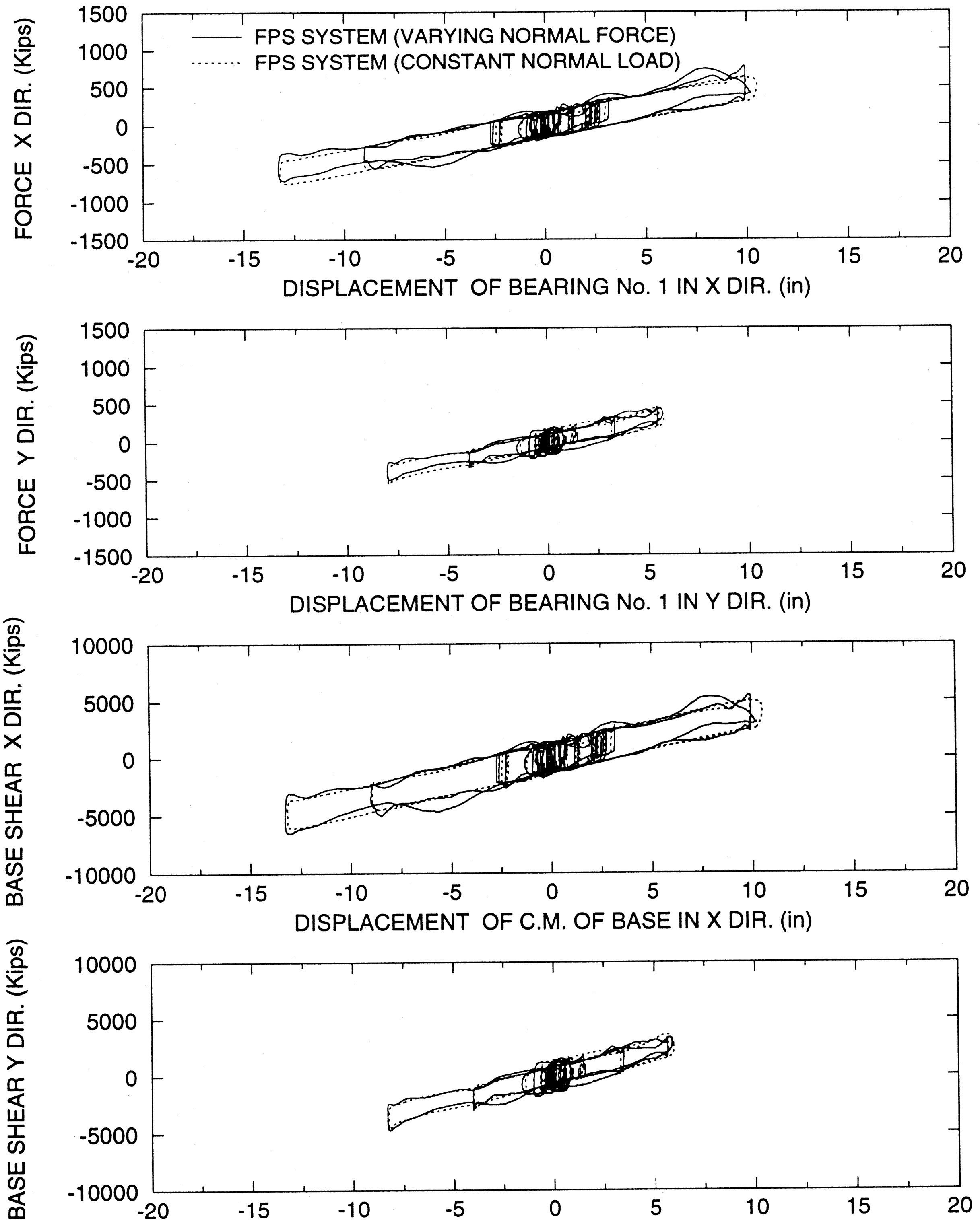


Figure 5-14 Force-Displacement Loops of FPS System With and Without the Effects of Vertical Ground Motion and Overturning Moments.

SECTION 6

SUMMARY

Program 3D-BASIS-ME is capable of analyzing single isolated structures, multiple building isolated structures on a common isolation basemat and isolated liquid storage tanks. New elements for modeling Friction Pendulum (FPS) bearings, high damping rubber bearings with stiffening behavior and nonlinear viscous dampers have been included in the program. Furthermore, program 3D-BASIS-ME accepts vertical ground motion and user supplied routines for describing the overturning moment effects on the axial bearing forces and for describing the dependency of the coefficient of friction on bearing pressure. This information is utilized by the program in modeling the behavior of sliding bearings.

The validity of the FPS bearing model in 3D-BASIS-ME has been established by comparisons of its predictions to experimental results under combined lateral displacement and varying normal load.

The capabilities of the program have been demonstrated through the analysis of an isolated liquid storage tank. The mathematical model included the effects of convective and impulsive modes of vibration.

SECTION 7

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

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

Input file name is 3DBME.DAT and the output file is 3DBME.OUT. Free format is used to read all input data. Earthquake records are to be given in files WAVEX.DAT and/or WAVEY.DAT and/or WAVEZ.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,G

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.

INP = Number of bearings at which output is desired.

G = Gravitational acceleration.

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, sliding bearings etc. .

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,LOR,XTH,ULF

INDGACC = Index for earthquake time history record.
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.
INDGACC = 3 for two independent earthquake records along the X and Z (vertical) axes. (X axes excitation at angle of incidence XTH.
INDGACC = 4 for three independent earthquake records along X, Y and Z (vertical) 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. Four 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 Centro 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.

c. INDGACC = 3 refers to two independent earthquake records input in the X and Z directions, e.g. El Centro N-S along the X direction and El Centro Vertical along the Z direction. Input two independent earthquake records in the X and Z directions (read through two files WAVEX.DAT and WAVEZ.DAT). Refer to D.2 and D.4 for wave input information.

d. INDGACC = 4 refers to three independent earthquake records input in the X, Y and Z directions, e.g. El Centro N-S along the X direction and El Centro E-W along the Y directionand El Centro Vertical along the Z direction. Input three independent earthquake records in the X, Y and Z directions (read through three files WAVEX.DAT, WAVEY.DAT and WAVEZ.DAT). Refer to D.2 to D.4 for wave input information.

2. The time step of earthquake record and the length of earthquake record has to be the same in X, Y and Z directions for INDGACC = 2 or 3 or 4.

3. Load factor is applied to the earthquake records in the X, Y and Z 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-ME 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

W(I) = Eigenvalue of Ith mode.

Note: 1. Input from the first mode to the NE mode.
2. Eigenvalues are frequencies squared (ω^2 in rad^2/s^2)

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

NE cards
(E(K,J),K=1,3*NF),J=1,NE

E(K,J)= Value corresponding to Kth floor of eigenvector of Jth mode.

Note: 1. Input from the first mode to the NE mode.
2. Eigenvectors must be normalized with respect to the mass matrix of superstructure ($\Phi^T M \Phi = \{1\}$).

B.4 Superstructure Mass Data

B.4.1 Translational Mass

NF Cards
CMX(I),I=1,NF

CMX(I)= 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

CMT(I)= Mass moment of inertia of floor I 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 θ 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).
2. See reports by Nagarajaiah et al. 1989 and 1991 for definitions.

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).
2. See reports by Nagarajaiah et al. 1989 and 1991 for definitions.

C.5 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.

Note: 1. If NP equals zero then skip Section C.5.

C.6 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,1),INELEM(K,2)

where K refers to the isolation element number (1 to NP), INELEM(K,1) denotes whether the element is uniaxial (unidirectional) or biaxial (bidirectional). INELEM(K,2) denotes the type of element :

INELEM(K,1)=1	for uniaxial element in the X direction
INELEM(K,1)=2	for uniaxial element in the Y direction
INELEM(K,1)=3	for biaxial element
INELEM(K,2)=1	for linear elastic element
INELEM(K,2)=2	for viscous element
INELEM(K,2)=3	for hysteretic element for elastomeric bearings/steel dampers
INELEM(K,2)=4	for hysteretic element for flat sliding bearings (friction force and f_{max} independent of instant changes in normal force)
INELEM(K,2)=5	for hysteretic element for flat sliding bearings (friction force and f_{max} depend on instant changes in normal force)
INELEM(K,2)=6	for FPS bearing element
INELEM(K,2)=7	for stiffening hysteretic element

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.

2. If NP equals zero then skip Section C.6.

C.6.1 Linear Elastic Element

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 1 (Refer to C.6 for further details).

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

PS(K,1)= 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).

PS(K,2)= 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.6.2 Viscous Element

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 2 (Refer to C.6 for further details).

One card
PC(K,1),PC(K,2),PC(K,3)

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).

PC(K,3)= Power that velocity is raised (α in the Equations 4.13 and 4.14). Usual values in the range of 0.5 to 1.2. If given value is 1.0 then the linear viscous element is recovered.

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

C.6.3 Hysteretic Element for Elastomeric Bearings/Steel Dampers

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 3 (Refer to C.6 for further details).

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

ALP(K,1)= Post-to-preyielding stiffness ratio (leave blank if the uniaxial element is in the Y direction only);

YF(K,1) = Yield force (leave blank if the uniaxial element is in the Y direction only);

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 (leave blank if the uniaxial element is in the X direction only);

YF(K,2) = Yield force (leave blank if the uniaxial element is in the X direction only);

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.6.4 Biaxial Hysteretic Element for Sliding Bearings (Friction Independent of Instant Change of Normal Load)

One card

INELEM(K,1),INELEM(K,2)

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 4 (Refer to C.6 for further details).

One card

(FMAX(K,I),I=1,2),(FMIN(K,I),I=1,2),(PA(K,I),I=1,2),(YD(K,I),I=1,2),FN(K)

FMAX(K,1)= Maximum coefficient of sliding friction (leave blank if the uniaxial element is in the Y direction only);

FMAX(K,2)= Maximum coefficient of sliding friction (leave blank if the uniaxial element is in the X direction only);

FMIN(K,1)= Minimum coefficient of sliding friction (leave blank if the uniaxial element is in the Y direction only);

FMIN(K,2)= Minimum coefficient of sliding friction (leave blank if the uniaxial element is in the X direction only);

PA(K,1) = Constant which controls the transition of coefficient of sliding friction from maximum to minimum value (leave blank if the uniaxial element is in the Y direction only);

PA(K,2) = Constant which controls the transition of coefficient of sliding friction from maximum to minimum value (leave blank if the uniaxial element is in the X direction only);

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);

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.6.5 New Biaxial Hysteretic Element for Sliding Bearings (Friction Depends on Instant Change of Normal Load)

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 5 (Refer to C.6 for further details).

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

FMAX(K,1)= Maximum coefficient of sliding friction at almost zero pressure (f_{max0} in Equation 4.16) (leave blank if the uniaxial element is in the Y direction only);

FMAX(K,2)= Maximum coefficient of sliding friction at almost zero pressure (f_{max0} in Equation 4.16) (leave blank if the uniaxial element is in the X direction only);

FMIN(K,1)= Minimum coefficient of sliding friction (independent of pressure) (leave blank if the uniaxial element is in the Y direction only);

FMIN(K,2)= Minimum coefficient of sliding friction (independent of pressure) (leave blank if the uniaxial element is in the X direction only);

PA(K,1) = Constant which controls the transition of coefficient of sliding friction from maximum (f_{max}) to minimum (f_{min})value (leave blank if the uniaxial element is in the Y direction only);

PA(K,2) = Constant which controls the transition of coefficient of sliding friction from maximum (f_{max}) to minimum (f_{min}) value (leave blank if the uniaxial element is in the X direction only);

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).

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 (static condition).

C.6.6 Element for Friction Pendulum Bearing (FPS)

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 6 (Refer to C.6 for further details).

One card
ALP(K,3),(FMAX(K,I),I=1,2),(FMIN(K,I),I=1,2),(PA(K,I),I=1,2),(YD(K,I),I=1, 2),FN(K)

ALP(K,3) = Radious of curvature of the concave surface of the bearing;

FMAX(K,1)= Maximum coefficient of sliding friction at almost zero pressure (f_{max0} in Equation 4.16) (leave blank if the uniaxial element is in the Y direction only);

FMAX(K,2)= Maximum coefficient of sliding friction at almost zero pressure (f_{max0} in Equation 4.16)(leave blank if the uniaxial element is in the X direction only).;

FMIN(K,1)= Minimum coefficient of sliding friction (independent of pressure)(leave blank if the uniaxial element is in the Y direction only);

FMIN(K,2)= Minimum coefficient of sliding friction (independent of pressure)(leave blank if the uniaxial element is in the X direction only).;

PA(K,1) = Constant which controls the transition of coefficient of sliding friction from maximum ($f_{\max}$) to minimum ($f_{\min}$) value (leave blank if the uniaxial element is in the Y direction only);

PA(K,2) = Constant which controls the transition of coefficient of sliding friction from maximum ($f_{\max}$) to minimum ($f_{\min}$) value (leave blank if the uniaxial element is in the X direction only).;

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);

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 (static condition).

C.6.7 Stiffening Biaxial Hysteretic Element

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

INELEM(K,1) = 1 or 2 or 3

INELEM(K,2) = 7 (Refer to C.6 for further details).

One card
ALP(K,3),ALP(K,4),ALP(K,5),ALP(K,6),ALP(K,7),YD(K,1)

ALP(K,3) = Characteristic strength (Q of Equation 4.6);

ALP(K,4) = Tangent stiffness K_1 (see Equation 4.1);

ALP(K,5) = Tangent stiffness K_2 (see Equation 4.1);

ALP(K,6) = Displacement limit D_1 (see Equation 4.1);

ALP(K,7) = Displacement limit D_2 (see Equation 4.1);

YD(K,1) = Yield displacement;

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 or 3, 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 or 4, 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 or 4)

LOR cards
Y(I,1),I=1,LOR

Y(I,1) = Acceleration component in the Y direction.

D.4 Earthquake Record in the Z (Vertical) Direction

File:WAVEZ.DAT (Input only if INDGACC = 3 or 4)

LOR cards
Y(I,2),I=1,LOR

Y(I,2) = Acceleration component in the Z 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.

Note: 1. If INP equals zero then skip Section E.3.

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

INPUT-OUTPUT OF 3D-BASIS-ME

HIGH DAMPING RUBBER BEARING SYSTEM

WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

INPUT

```
52  IMPROVED DAMPING RUBBER BEARINGS
 in                  Kips/in*sect2                  secs
1 2 5 5 386.22
1 3
1 3
0.005 10 1 500 1
0.5 0.25
2 0.02 2000 0 1
         35.12
         35.12
     3659.0059
0.0
0.0
      42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
      46716.90
      46716.90
    6618227.50
0.0
0.0
        31.07037
   1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
0 0 0 0 0
      9.90109
 427528.00000
0 0 0 0 0
-834.96    0.00
   0.00 -820.56
 806.16    0.00
   0.00  820.56
 -14.40    0.00
  3  7
85.735  48.425  96.85  11.40  11.88 0.57
  3  7
85.735  48.425  96.85  11.40  11.88 0.57
  3  7
85.735  48.425  96.85  11.40  11.88 0.57
  3  7
85.735  48.425  96.85  11.40  11.88 0.57
  3  7
342.94  193.7   387.4  11.40  11.88 0.57
0 2 1
1 2 3 4 5
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
    -0.30719E+01    -0.10240E+02    -0.48048E+01     0.10200E+02    -0.28356E+01
    -0.81918E+01     0.12051E+02    -0.10161E+02    -0.13430E+02     0.14611E+02
    -0.11618E+02    -0.13430E+02     0.14257E+02    -0.98065E+01    -0.72072E+01
     0.14532E+02     0.12248E+02    -0.56712E+01    -0.27962E+01     0.57500E+01
    -0.14178E+01     0.15753E+01     0.20755E+02     0.11027E+01    -0.28159E+02
     0.72072E+01     0.40526E+02     0.28317E+02     0.46866E+01    -0.10003E+02
    -0.23394E+02    -0.17053E+02     0.63014E+00     0.17014E+02     0.12997E+02
     0.90582E+00     0.94520E+00    -0.58681E+01    -0.23630E+01     0.88613E+01
     0.16108E+02    -0.15753E+01    -0.32058E+02    -0.88219E+01     0.91764E+01
     0.40959E+01     0.36666E+02     0.31389E+02    -0.16738E+02    -0.37139E+02
    -0.10318E+02     0.47654E+01     0.83493E+01     0.22764E+02     0.98459E+01
...........
...........
```

WAVEY.DAT

```
     0.12878E+02     0.22055E+01    -0.22842E+01    -0.16935E+01     0.88219E+01
     0.31507E+01    -0.20361E+02    -0.16502E+02     0.46079E+01     0.78767E+01
     0.36233E+01    -0.14572E+02    -0.10122E+02     0.16187E+02     0.19652E+02
    -0.66952E+00    -0.94914E+01    -0.26781E+01    -0.24418E+01    -0.13587E+02
    -0.14926E+02     0.12721E+02     0.29538E+02     0.83493E+01    -0.24851E+02
    -0.17526E+02     0.90582E+01     0.17368E+02    -0.60257E+01    -0.21779E+02
    -0.24378E+02    -0.10437E+02     0.26190E+02     0.50686E+02     0.10082E+02
    -0.44582E+02    -0.47772E+02    -0.19731E+02     0.87825E+01     0.41234E+02
     0.38753E+02    -0.40565E+01    -0.36745E+02    -0.37375E+02    -0.10673E+02
     0.21464E+02     0.27017E+02     0.39384E+01    -0.22527E+02    -0.35209E+02
    -0.29301E+02     0.67346E+01     0.46236E+02     0.47890E+02     0.44897E+01
...........
...........
```

OUTPUT

```
*******************************************************************

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


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


*******************************************************************'

            VERSION   3D-BASIS-ME,  JANUARY 1993

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


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


52  IMPROVED DAMPING RUBBER BEARINGS



UNITS
LENGTH :   in
MASS   :  Kips/in*sect2
TIME   :         secs



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



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



NO. OF BUILDINGS.......................=            2
NO. OF ISOLATORS.......................=            5
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=           1
```

```
   INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
   INDEX = 2 FOR FULL 3D REPRESENTATION
 NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=            5

 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.....=          500

 INDEX FOR GROUND MOTION INPUT...........=            2

   INDEX = 1 FOR X          DIR. INPUT
   INDEX = 2 FOR X & Y      DIR. INPUT
   INDEX = 3 FOR X & Z      DIR  INPUT
   INDEX = 4 FOR X , Y & Z  DIR. INPUT

 TIME STEP OF RECORD ....................=      0.02000
 LENGTH OF RECORD........................=         2000
 LOAD FACTOR.............................=      1.00000
 ANGLE OF EARTHQUAKE INCIDENCE...........=      0.00000




 ************* SUPERSTRUCTURE DATA ************



 SUPERSTRUCTURE  :  1


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

  STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
 LEVEL          STIFF  X          STIFF  Y          STIFF  R       ECCENT  X      ECCENT  Y

    1          35.12000          35.12000        3659.00590        0.00001        0.00000

 SUPERSTRUCTURE MASS..........
 LEVEL          TRANSL. MASS    ROTATIONAL MASS     ECCENT  X      ECCENT  Y

    1          42.24794        1700000.00000        0.00000        0.00000

 SUPERSTRUCTURE DAMPING.......
 MODE SHAPE     DAMPING RATIO

    1               0.00500
    2               0.00500
```

```
    3                 0.00500


HEIGHT.........
LEVEL         HEIGHT

    1        284.400
    0         18.000

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER      EIGENVALUE          PERIOD

      1        0.215236E-02   0.135432E+03
      2        0.831283E+00   0.689137E+01
      3        0.831283E+00   0.689137E+01


MODE SHAPES
LEVEL                1          2          3

    1  X   0.0000000 0.1538499 0.0000000

    1  Y   0.0000000 0.0000000 0.1538499

    1  R   0.0007670 0.0000000 0.0000000


SUPERSTRUCTURE  :  2


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y           STIFF  R      ECCENT  X      ECCENT  Y

    1        46716.90000        46716.90000      6618227.50000        0.00001        0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X      ECCENT  Y

    1             31.07037      1700000.00000           0.00000        0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE      DAMPING RATIO

    1                 0.02000
    2                 0.02000
    3                 0.02000


HEIGHT.........
LEVEL         HEIGHT

    1        210.480
    0         18.000
```

```
************* ISOLATION SYSTEM DATA ************


STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =                0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =                0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =                0.00000
ECCENT. IN  X  DIR. FROM CEN. OF MASS......=                0.00000
ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=                0.00000



MASS AT THE CENTER OF MASS OF THE BASE ....
            TRANSL. MASS   ROTATIONAL MASS

MASS               9.90109   427528.00000


GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                   X              Y               R               ECX              ECY

DAMPING          0.00000        0.00000         0.00000         0.00000          0.00000


ISOLATORS LOCATION INFORMATION.........
ISOLATOR     X          Y

    1     -834.9600     0.0000
    2        0.0000  -820.5600
    3      806.1600     0.0000
    4        0.0000   820.5600
    5      -14.4000     0.0000

......ELEMENT TYPE =


NONLINEAR ELEMENT FORCE-DISPLACEMENT LOOP PARAMETERS........
ISOLATOR   CHR. STRENGTH         K 1             K 2              D1              D2    YIELD DISPL.

    1           85.73500       48.42500        96.85000        11.40000        11.88000        0.57000
    2           85.73500       48.42500        96.85000        11.40000        11.88000        0.57000
    3           85.73500       48.42500        96.85000        11.40000        11.88000        0.57000
    4           85.73500       48.42500        96.85000        11.40000        11.88000        0.57000
    5          342.94000      193.70000       387.40000        11.40000        11.88000        0.57000

************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION ........................=            1

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT
```

```
NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED ..........................=               2
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=               1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                         1    2    3    4    5

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1        0.389307E+01   0.318444E+01
      2        0.150358E+04   0.162038E+00
      3        0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL                 1          2          3

    1  X    0.0000000 0.1794018 0.0000000

    1  Y    0.0000000 0.0000000 0.1794018

    1  R    0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                                 (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    9.315 0.4041E+02  4.735 -.1209E+02  3.925 0.2539E-03


SUPERSTRUCTURE :  2
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    5.550 -.1743E+00  3.900 -.9193E-01  4.710 -.3417E-03


MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION
 BASE  5.565 -.1780E+02  3.915 -.8949E+01  3.925 -.2539E-03


MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL     X                        MAX DISPL     Y                        MAX RES. DISPL. SQRT(DX↑2+DY↑2)
ISOLATOR   TIME   X  DIRECT  Y  DIRECT          TIME   X  DIRECT  Y  DIRECT         TIME  DISPLACEMENT
    1      5.565 -.1780E+02 -.7321E+01          3.915 -.1564E+02 -.8738E+01         5.570 0.1925E+02
    2      5.565 -.1798E+02 -.7502E+01          3.915 -.1585E+02 -.8949E+01         5.575 0.1949E+02
    3      5.565 -.1780E+02 -.7678E+01          3.915 -.1564E+02 -.9153E+01         5.575 0.1939E+02
    4      5.565 -.1762E+02 -.7502E+01          3.915 -.1544E+02 -.8949E+01         5.570 0.1916E+02
```

```
    5     5.565 -.1780E+02 -.7499E+01      3.915 -.1564E+02 -.8946E+01      5.575 0.1932E+02


MAXIMUM BEARING VELOCITIES

                MAX VELOCITY X                       MAX VELOCITY Y                         MAX RES. VELOCITY SQRT(VX↑2+VY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME   VELOCITY
    1     5.915 0.6571E+02 0.3482E+02      5.870 0.6351E+02 0.3884E+02      5.895 0.7519E+02
    2     5.920 0.6630E+02 0.3436E+02      5.870 0.6389E+02 0.3923E+02      5.900 0.7583E+02
    3     5.915 0.6571E+02 0.3599E+02      5.870 0.6351E+02 0.3961E+02      5.895 0.7566E+02
    4     5.915 0.6512E+02 0.3542E+02      5.870 0.6312E+02 0.3923E+02      5.895 0.7503E+02
    5     5.915 0.6571E+02 0.3541E+02      5.870 0.6351E+02 0.3923E+02      5.895 0.7543E+02


MAXIMUM BEARING FORCES

                MAX FORCE    X                       MAX FORCE    Y                         MAX RES. FORCE  SQRT(FX↑2+FY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME     FORCE
    1     5.555 -.1266E+04 -.5444E+03      3.895 -.1068E+04 -.6427E+03      5.565 0.1380E+04
    2     5.555 -.1283E+04 -.5598E+03      3.900 -.1080E+04 -.6615E+03      5.565 0.1403E+04
    3     5.555 -.1266E+04 -.5737E+03      3.910 -.1033E+04 -.6760E+03      5.565 0.1392E+04
    4     5.555 -.1248E+04 -.5589E+03      3.905 -.1023E+04 -.6576E+03      5.565 0.1369E+04
    5     5.555 -.5063E+04 -.2236E+04      3.900 -.4231E+04 -.2637E+04      5.565 0.5544E+04

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R

  1    9.300 -.3360E+02  4.725 0.1006E+02  3.675 -.9911E-06


SUPERSTRUCTURE :  2
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R

  1    5.545 0.2621E+03  3.900 0.1382E+03  4.690 0.1348E-02


MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R
 BASE  5.510 0.2590E+03  3.870 0.1358E+03  3.695 0.3119E-01




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


MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
TIME :  5.565

SUPERSTRUCTURE :  1
                X                       Y
```

```
LEVEL    DISP       ACCEL        DISP       ACCEL
  1      12.6955    -10.2606      5.3307     -4.4877
 BASE   -17.7974    252.2362     -7.5024    113.4474

SUPERSTRUCTURE :  2
                 X                         Y
LEVEL    DISP       ACCEL        DISP       ACCEL
  1      -0.1724    258.9142     -0.0774    116.5551
 BASE   -17.7974    252.2362     -7.5024    113.4474


MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
TIME :  3.915

SUPERSTRUCTURE :  1
                 X                         Y
LEVEL    DISP       ACCEL        DISP       ACCEL
  1      28.1312    -23.2372      7.6564     -6.2798
 BASE   -15.6448    210.4397     -8.9492    130.3809

SUPERSTRUCTURE :  2
                 X                         Y
LEVEL    DISP       ACCEL        DISP       ACCEL
  1      -0.1513    226.5920     -0.0909    136.4874
 BASE   -15.6448    210.4397     -8.9492    130.3809



 PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX ACCELERATION IN  X  DIRECTION
  TIME :  9.300


LEVEL    DISP       ACCEL        DISP       ACCEL
  1      40.3988    -33.5979      2.8356     -2.2247
 BASE    -7.7057    102.8309     -4.2112     43.0927


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  4.725


LEVEL    DISP       ACCEL        DISP       ACCEL
  1      -4.4987      3.7221    -12.0864     10.0587
 BASE    15.5430   -214.3719      7.9607   -123.5597


SUPERSTRUCTURE :  2


 MAX ACCELERATION IN  X  DIRECTION
```

```
  TIME :  5.545


LEVEL    DISP       ACCEL       DISP      ACCEL
  1      -0.1743   262.1055    -0.0747   112.6542
 BASE   -17.7337   244.8050    -7.3411   108.3166

 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  3.900


LEVEL    DISP       ACCEL       DISP      ACCEL
  1      -0.1579   236.9759    -0.0919   138.2470
 BASE   -15.8107   211.0198    -8.9285   126.1989




.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME   FORCE  X    TIME   FORCE  Y    TIME   Z  MOMENT
     1       9.300 -.1419E+04  4.725 0.4250E+03  3.675 -.1685E+01
     2       5.545 0.8144E+04  3.900 0.4295E+04  4.690 0.2291E+04




.MAXIMUM BASE SHEARS...........
 TIME   FORCE  X   TIME   FORCE  Y   TIME  Z  MOMENT   TIME  RES. SHEAR SQRT(FX↑2+FY↑2)
  5.555 -.1013E+05  3.900 -.5274E+04  3.910 -.1552E+05  5.565 0.1109E+05




.MAXIMUM STORY SHEARS.............


SUPERSTRUCTURE :   1
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1    9.300 -.1419E+04  4.725 0.4250E+03  3.675 -.1685E+01  9.295 0.1423E+04

SUPERSTRUCTURE :   2
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1    5.545 0.8144E+04  3.900 0.4295E+04  4.690 0.2291E+04  5.550 0.8879E+04
```

```
PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  9.300


LEVEL    DISP        ACCEL       DISP        ACCEL
  1      40.3988    -33.5979      2.8356     -2.2247
 BASE    -7.7057    102.8309     -4.2112     43.0927


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  4.725


LEVEL    DISP        ACCEL       DISP        ACCEL
  1      -4.4987      3.7221    -12.0864     10.0587
 BASE    15.5430   -214.3719      7.9607   -123.5597


SUPERSTRUCTURE :  2


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  5.545


LEVEL    DISP        ACCEL       DISP        ACCEL
  1      -0.1743    262.1055     -0.0747    112.6542
 BASE   -17.7337    244.8050     -7.3411    108.3166


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.900


LEVEL    DISP        ACCEL       DISP        ACCEL
  1      -0.1579    236.9759     -0.0919    138.2470
 BASE   -15.8107    211.0198     -8.9285    126.1989




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


MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  5.555

SUPERSTRUCTURE :  1
```

```
                X                             Y
  LEVEL     DISP        ACCEL        DISP       ACCEL
    1      13.0038    -10.5406      5.2631     -4.4421
   BASE   -17.7815    247.1465     -7.4272    110.0184

  SUPERSTRUCTURE :  2
                X                             Y
  LEVEL     DISP        ACCEL        DISP       ACCEL
    1      -0.1740    261.5005     -0.0763    114.9470
   BASE   -17.7815    247.1465     -7.4272    110.0184


  MAXIMUM BASE SHEAR IN  Y  DIRECTION
  TIME :  3.900

  SUPERSTRUCTURE :  1
                X                             Y
  LEVEL     DISP        ACCEL        DISP       ACCEL
    1      28.3480    -23.4494      7.7809     -6.4016
   BASE   -15.8107    211.0198     -8.9285    126.1989

  SUPERSTRUCTURE :  2
                X                             Y
  LEVEL     DISP        ACCEL        DISP       ACCEL
    1      -0.1579    236.9759     -0.0919    138.2470
   BASE   -15.8107    211.0198     -8.9285    126.1989


                          **************FORCE PROFILES***********

         MAX OVERTURNING MOMENT  X  DIRECTION                          MAX STRUCTURAL SHEAR X DIRECTION

SUPR/STURE  TIME    OVERTURNING MOMENT                              TIME    MAX STUCTURAL SHEAR
     1      9.300          -403689.7058                             9.300            -1419.4434


   FLOOR             INERTIA   FORCES                                       INERTIA  FORCES
     1                       -1419.4434                                              -1419.4434
   BASE                       1018.1382                                               1018.1382  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME    OVERTURNING MOMENT                              TIME    MAX STUCTURAL SHEAR
     2      5.545          1714089.1752                             5.545             8143.7152


   FLOOR             INERTIA   FORCES                                       INERTIA  FORCES
     1                        8143.7152                                               8143.7152
   BASE                       2423.8368                                               2423.8368  FORCE AT C.M. OF ENTIRE BASE


         MAX OVERTURNING MOMENT  Y  DIRECTION                          MAX STRUCTURAL SHEAR Y DIRECTION

SUPR/STURE  TIME    OVERTURNING MOMENT                              TIME    MAX STUCTURAL SHEAR
     1      4.725           120858.5028                             4.725              424.9596


   FLOOR             INERTIA   FORCES                                       INERTIA  FORCES
     1                         424.9596                                                424.9596
   BASE                      -1223.3757                                              -1223.3757  FORCE AT C.M. OF ENTIRE BASE
```

```
SUPR/STURE  TIME    OVERTURNING MOMENT                                      TIME   MAX STUCTURAL SHEAR
    2       3.900           904092.6905                                     3.900          4295.3853

   FLOOR              INERTIA   FORCES                                            INERTIA  FORCES
     1                          4295.3853                                                  4295.3853
   BASE                         1249.5070                                                  1249.5070  FORCE AT C.M. OF ENTIRE BASE



   .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


   SUPERSTRUCTURE :  1

   COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
   C/L : 1  X COOR :  -834.960
            Y COOR :     0.000

   COLUMN LINES
                   1
   LEVEL   TIME     X  DIR   TIME     Y  DIR    TIME     X  DIR   TIME     Y  DIR   TIME     X  DIR   TIME     Y  DIR
     1    9.315 0.1517E+00  4.735 0.4470E-01

   SUPERSTRUCTURE :  2

   COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
   C/L : 1  X COOR :   -14.400
            Y COOR :     0.000

   COLUMN LINES
                   1
   LEVEL   TIME     X  DIR   TIME     Y  DIR    TIME     X  DIR   TIME     Y  DIR   TIME     X  DIR   TIME     Y  DIR
     1    5.550 0.9058E-03  3.900 0.5024E-03
```

LOW DAMPING RUBBER BEARING - LINEAR VISCOUS FLUID DAMPER SYSTEM

WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

INPUT

```
52  LOW DAMPING RUBBER BEAR. + 24 LINEAR FLUID DAMPERS
 in                  Kips/in*sec↑2              secs
1 2 9 9 386.22
1 3
1 3
0.005 50 1 500 1
0.5 0.25
2 0.02 2000 0 1
         35.12
         35.12
     3659.0059
0.0
0.0
       42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
       46716.90
       46716.90
     6618227.50
0.0
0.0
          31.07037
    1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
0 0 0 0 0
        9.90109
 427528.00000
7.65, 7.65, 2374932, 0 0
-834.96    0.00
   0.00 -820.56
 806.16    0.00
   0.00  820.56
 -14.40    0.00
-509.88    0.00
   0.00 -495.48
 481.08    0.00
   0.00  495.48
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
198.38  198.38
  3  2
10.83 10.83 1.0
  3  2
10.83 10.83 1.0
  3  2
10.83 10.83 1.0
  3  2
10.83 10.83 1.0
0 2 1
1 2 3 4 5 6 7 8 9
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
    -0.30719E+01    -0.10240E+02    -0.48048E+01     0.10200E+02    -0.28356E+01
    -0.81918E+01     0.12051E+02    -0.10161E+02    -0.13430E+02     0.14611E+02
    -0.11618E+02    -0.13430E+02     0.14257E+02    -0.98065E+01    -0.72072E+01
     0.14532E+02     0.12248E+02    -0.56712E+01    -0.27962E+01     0.57500E+01
    -0.14178E+01     0.15753E+01     0.20755E+02     0.11027E+01    -0.28159E+02
     0.72072E+01     0.40526E+02     0.28317E+02     0.46866E+01    -0.10003E+02
    -0.23394E+02    -0.17053E+02     0.63014E+00     0.17014E+02     0.12997E+02
     0.90582E+00     0.94520E+00    -0.58681E+01    -0.23630E+01     0.88613E+01
     0.16108E+02    -0.15753E+01    -0.32058E+02    -0.88219E+01     0.91764E+01
     0.40959E+01     0.36666E+02     0.31389E+02    -0.16738E+02    -0.37139E+02
    -0.10318E+02     0.47654E+01     0.83493E+01     0.22764E+02     0.98459E+01
...........
...........
```

WAVEY.DAT

```
     0.12878E+02     0.22055E+01    -0.22842E+01    -0.16935E+01     0.88219E+01
     0.31507E+01    -0.20361E+02    -0.16502E+02     0.46079E+01     0.78767E+01
     0.36233E+01    -0.14572E+02    -0.10122E+02     0.16187E+02     0.19652E+02
    -0.66952E+00    -0.94914E+01    -0.26781E+01    -0.24418E+01    -0.13587E+02
    -0.14926E+02     0.12721E+02     0.29538E+02     0.83493E+01    -0.24851E+02
    -0.17526E+02     0.90582E+01     0.17368E+02    -0.60257E+01    -0.21779E+02
    -0.24378E+02    -0.10437E+02     0.26190E+02     0.50686E+02     0.10082E+02
    -0.44582E+02    -0.47772E+02    -0.19731E+02     0.87825E+01     0.41234E+02
     0.38753E+02    -0.40565E+01    -0.36745E+02    -0.37375E+02    -0.10673E+02
     0.21464E+02     0.27017E+02     0.39384E+01    -0.22527E+02    -0.35209E+02
    -0.29301E+02     0.67346E+01     0.46236E+02     0.47890E+02     0.44897E+01
...........
...........
```

OUTPUT

```
**********************************************************************

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


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


**********************************************************************'

            VERSION   3D-BASIS-ME,  JANUARY 1993

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

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


52  LOW DAMPING RUBBER BEAR. + 24 LINEAR FLUID DAMPERS



UNITS
LENGTH :  in
MASS   :  Kips/in*sec↑2
TIME   :         secs


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


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



NO. OF BUILDINGS.......................=           2
NO. OF ISOLATORS.......................=           9
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=           1
```

```
  INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
  INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=           9

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.........=    50.00000
REFERENCE MOMENT OF CONVERGENCE.........=     1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S.....=         500

INDEX FOR GROUND MOTION INPUT...........=           2

  INDEX = 1 FOR X          DIR. INPUT
  INDEX = 2 FOR X & Y      DIR. INPUT
  INDEX = 3 FOR X & Z      DIR  INPUT
  INDEX = 4 FOR X , Y & Z  DIR. INPUT

TIME STEP OF RECORD ....................=     0.02000
LENGTH OF RECORD........................=        2000
LOAD FACTOR.............................=     1.00000
ANGLE OF EARTHQUAKE INCIDENCE...........=     0.00000



************* SUPERSTRUCTURE DATA ************


SUPERSTRUCTURE  :  1


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y            STIFF  R       ECCENT  X       ECCENT  Y

    1            35.12000            35.12000         3659.00590         0.00001         0.00000

SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X       ECCENT  Y

    1            42.24794       1700000.00000            0.00000         0.00000

SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

    1                0.00500
    2                0.00500
```

```
   3              0.00500


HEIGHT.........
LEVEL        HEIGHT

   1        284.400
   0         18.000

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1        0.215236E-02   0.135432E+03
      2        0.831283E+00   0.689137E+01
      3        0.831283E+00   0.689137E+01


MODE SHAPES
LEVEL              1           2           3

   1  X   0.0000000 0.1538499 0.0000000

   1  Y   0.0000000 0.0000000 0.1538499

   1  R   0.0007670 0.0000000 0.0000000


SUPERSTRUCTURE  :  2


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y            STIFF  R      ECCENT  X      ECCENT  Y

   1        46716.90000         46716.90000       6618227.50000        0.00001        0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X      ECCENT  Y

   1             31.07037       1700000.00000          0.00000        0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

   1                0.02000
   2                0.02000
   3                0.02000

HEIGHT.........
LEVEL        HEIGHT

   1        210.480
   0         18.000
```

```
************* ISOLATION SYSTEM DATA ************


 STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

 STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =            0.00000
 STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =            0.00000
 STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =            0.00000
 ECCENT. IN  X  DIR. FROM CEN. OF MASS......=            0.00000
 ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=            0.00000



 MASS AT THE CENTER OF MASS OF THE BASE ....
             TRANSL. MASS   ROTATIONAL MASS

 MASS              9.90109   427528.00000


 GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                    X               Y              R              ECX              ECY

 DAMPING           7.65000        7.65000  2374932.00000        0.00000          0.00000


 ISOLATORS LOCATION INFORMATION.........
 ISOLATOR     X           Y

     1     -834.9600      0.0000
     2        0.0000   -820.5600
     3      806.1600      0.0000
     4        0.0000    820.5600
     5      -14.4000      0.0000
     6     -509.8800      0.0000
     7        0.0000   -495.4800
     8      481.0800      0.0000
     9        0.0000    495.4800

......ELEMENT TYPE =


 LINEAR ELASTIC ELEMENT PARAMETERS........
 ISOLATOR        STIFFNESS  X        STIFFNESS  Y
     1              49.59500            49.59500
     2              49.59500            49.59500
     3              49.59500            49.59500
     4              49.59500            49.59500
     5             198.38000           198.38000

......ELEMENT TYPE =


 VISCOUS ELEMENT PARAMETERS........
 ISOLATOR        DAMP-COEF  X        DAMP-COEF  Y   POWER OF VELOCITY
```

```
     6              10.83000            10.83000            1.00000
     7              10.83000            10.83000            1.00000
     8              10.83000            10.83000            1.00000
     9              10.83000            10.83000            1.00000

************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION ........................=           1

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT

NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED ..........................=           2
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=           1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                          1    2    3    4    5
                                          6    7    8    9

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1       0.389307E+01   0.318444E+01
      2       0.150358E+04   0.162038E+00
      3       0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL             1           2           3

    1  X    0.0000000 0.1794018 0.0000000

    1  Y    0.0000000 0.0000000 0.1794018

    1  R    0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                                 (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME   DISPL  X   TIME   DISPL  Y   TIME   ROTATION

  1    9.890 0.3776E+02  4.780 -.7885E+01  3.925 0.1870E-03


SUPERSTRUCTURE :  2
LEVEL  TIME   DISPL  X   TIME   DISPL  Y   TIME   ROTATION

  1    3.740 -.9760E-01  3.785 -.4893E-01  3.920 0.2575E-03
```

```
MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME    ROTATION
 BASE  3.850 -.1111E+02  3.905 -.6094E+01  3.925 -.1869E-03


MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL    X                       MAX DISPL    Y                       MAX RES. DISPL. SQRT(DXt2+DYt2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME  DISPLACEMENT
    1     3.850 -.1111E+02 -.5784E+01        3.905 -.1079E+02 -.5939E+01        3.860 0.1253E+02
    2     3.850 -.1125E+02 -.5932E+01        3.905 -.1094E+02 -.6094E+01        3.860 0.1273E+02
    3     3.850 -.1111E+02 -.6074E+01        3.905 -.1079E+02 -.6244E+01        3.860 0.1267E+02
    4     3.850 -.1096E+02 -.5932E+01        3.905 -.1064E+02 -.6094E+01        3.860 0.1247E+02
    5     3.850 -.1111E+02 -.5929E+01        3.905 -.1079E+02 -.6092E+01        3.860 0.1260E+02
    6     3.850 -.1111E+02 -.5841E+01        3.905 -.1079E+02 -.5999E+01        3.860 0.1256E+02
    7     3.850 -.1119E+02 -.5932E+01        3.905 -.1088E+02 -.6094E+01        3.860 0.1268E+02
    8     3.850 -.1111E+02 -.6017E+01        3.905 -.1079E+02 -.6184E+01        3.860 0.1265E+02
    9     3.850 -.1102E+02 -.5932E+01        3.905 -.1070E+02 -.6094E+01        3.860 0.1253E+02


MAXIMUM BEARING VELOCITIES

                MAX VELOCITY X                       MAX VELOCITY Y                       MAX RES. VELOCITY SQRT(VXt2+VYt2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME    VELOCITY
    1     3.465 -.5122E+02 -.1990E+02        3.595 -.4099E+02 -.2870E+02        3.450 0.5507E+02
    2     3.465 -.5182E+02 -.2050E+02        3.595 -.4166E+02 -.2938E+02        3.450 0.5588E+02
    3     3.465 -.5122E+02 -.2109E+02        3.595 -.4099E+02 -.3004E+02        3.445 0.5555E+02
    4     3.465 -.5063E+02 -.2050E+02        3.595 -.4032E+02 -.2938E+02        3.450 0.5475E+02
    5     3.465 -.5122E+02 -.2049E+02        3.595 -.4099E+02 -.2937E+02        3.450 0.5531E+02
    6     3.465 -.5122E+02 -.2013E+02        3.595 -.4099E+02 -.2897E+02        3.450 0.5517E+02
    7     3.465 -.5158E+02 -.2050E+02        3.595 -.4140E+02 -.2938E+02        3.450 0.5565E+02
    8     3.465 -.5122E+02 -.2085E+02        3.595 -.4099E+02 -.2977E+02        3.450 0.5545E+02
    9     3.465 -.5086E+02 -.2050E+02        3.595 -.4059E+02 -.2938E+02        3.450 0.5497E+02


MAXIMUM BEARING FORCES

                MAX FORCE    X                       MAX FORCE    Y                       MAX RES. FORCE  SQRT(FXt2+FYt2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME      FORCE
    1     3.850 -.5508E+03 -.2868E+03        3.905 -.5352E+03 -.2945E+03        3.860 0.6216E+03
    2     3.850 -.5580E+03 -.2942E+03        3.905 -.5428E+03 -.3022E+03        3.860 0.6315E+03
    3     3.850 -.5508E+03 -.3013E+03        3.905 -.5352E+03 -.3097E+03        3.860 0.6285E+03
    4     3.850 -.5436E+03 -.2942E+03        3.905 -.5276E+03 -.3022E+03        3.860 0.6187E+03
    5     3.850 -.2203E+04 -.1176E+04        3.905 -.2141E+04 -.1208E+04        3.860 0.2500E+04
    6     3.470 -.5547E+03 -.2166E+03        3.600 -.4401E+03 -.3136E+03        3.450 0.5974E+03
    7     3.470 -.5585E+03 -.2205E+03        3.600 -.4445E+03 -.3181E+03        3.450 0.6027E+03
    8     3.470 -.5547E+03 -.2243E+03        3.600 -.4401E+03 -.3224E+03        3.450 0.6006E+03
    9     3.470 -.5508E+03 -.2205E+03        3.600 -.4357E+03 -.3181E+03        3.450 0.5953E+03

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R
```

```
  1     9.880 -.3139E+02  4.765 0.6557E+01  3.170 0.5592E-06


SUPERSTRUCTURE :  2
LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R

  1    3.740 0.1468E+03  3.785 0.7357E+02  3.895 -.1006E-02


MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R
 BASE  3.720 0.1435E+03  3.825 0.7270E+02  8.525 -.1009E-01




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



MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
TIME :  3.850

SUPERSTRUCTURE :  1
                X                           Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      23.1487   -19.1878      5.1369    -4.2166
 BASE   -11.1062   126.9532     -5.9316    68.4944

SUPERSTRUCTURE :  2
                X                           Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0851   127.6845     -0.0463    69.5495
 BASE   -11.1062   126.9532     -5.9316    68.4944


MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
TIME :  3.905

SUPERSTRUCTURE :  1
                X                           Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      22.6028   -18.6650      4.7075    -3.8247
 BASE   -10.7910   110.4702     -6.0943    64.0398

SUPERSTRUCTURE :  2
                X                           Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0740   110.8643     -0.0421    63.0781
 BASE   -10.7910   110.4702     -6.0943    64.0398




 PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING
```

```
SUPERSTRUCTURE :  1


 MAX ACCELERATION IN  X  DIRECTION
  TIME :  9.880


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      37.7621   -31.3932    -4.7726     4.0137
 BASE     2.8223    -8.1532     0.1258    -7.7618


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  4.765


LEVEL    DISP       ACCEL       DISP       ACCEL
  1       3.5186    -2.9080    -7.8803     6.5571
 BASE     7.6046   -62.1106     3.8444   -48.8624

SUPERSTRUCTURE :  2


 MAX ACCELERATION IN  X  DIRECTION
  TIME :  3.740


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0976   146.7578    -0.0463    69.6603
 BASE    -9.7787   141.5995    -4.6387    71.8017


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  3.785


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0945   142.0019    -0.0489    73.5698
 BASE   -10.6610   140.6156    -5.3194    69.2991





.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME   FORCE  X    TIME   FORCE  Y    TIME   Z  MOMENT
     1       9.880 -.1326E+04  4.765 0.2770E+03  3.170 0.9507E+00
     2       3.740 0.4560E+04  3.785 0.2286E+04  3.895 -.1710E+04
```

```
.MAXIMUM BASE SHEARS...........
 TIME   FORCE  X   TIME   FORCE  Y   TIME  Z  MOMENT   TIME  RES. SHEAR SQRT(FX↑2+FY↑2)
  3.740 -.5154E+04  3.160 0.2824E+04  8.515 0.4941E+04  3.750 0.5821E+04



.MAXIMUM STORY SHEARS.............


SUPERSTRUCTURE :   1
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1    9.880 -.1326E+04  4.765 0.2770E+03  3.170 0.9507E+00  9.900 0.1337E+04

SUPERSTRUCTURE :   2
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1    3.740 0.4560E+04  3.785 0.2286E+04  3.895 -.1710E+04  3.750 0.5052E+04



PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  9.880


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      37.7621   -31.3932    -4.7726     4.0137
 BASE     2.8223    -8.1532     0.1258    -7.7618


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  4.765


LEVEL    DISP       ACCEL       DISP       ACCEL
  1       3.5186    -2.9080    -7.8803     6.5571
 BASE     7.6046   -62.1106     3.8444   -48.8624


SUPERSTRUCTURE :  2


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  3.740
```

```
LEVEL     DISP      ACCEL        DISP       ACCEL
  1      -0.0976   146.7578     -0.0463     69.6603
 BASE    -9.7787   141.5995     -4.6387     71.8017


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.785


LEVEL     DISP      ACCEL        DISP       ACCEL
  1      -0.0945   142.0019     -0.0489     73.5698
 BASE   -10.6610   140.6156     -5.3194     69.2991





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

MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  3.740

SUPERSTRUCTURE :  1
                 X                           Y
LEVEL     DISP      ACCEL        DISP       ACCEL
  1      22.8825   -19.1239      5.3280     -4.4510
 BASE    -9.7787   141.5995     -4.6387     71.8017

SUPERSTRUCTURE :  2
                 X                           Y
LEVEL     DISP      ACCEL        DISP       ACCEL
  1      -0.0976   146.7578     -0.0463     69.6603
 BASE    -9.7787   141.5995     -4.6387     71.8017

MAXIMUM BASE SHEAR IN  Y  DIRECTION
TIME :  3.160

SUPERSTRUCTURE :  1
                 X                           Y
LEVEL     DISP      ACCEL        DISP       ACCEL
  1      -0.4681     0.0192     -1.9595      1.5636
 BASE    10.9384  -103.9023      5.2116    -67.5392

SUPERSTRUCTURE :  2
                 X                           Y
LEVEL     DISP      ACCEL        DISP       ACCEL
  1       0.0697  -104.5141      0.0475    -71.4801
 BASE    10.9384  -103.9023      5.2116    -67.5392


                     **************FORCE PROFILES***********

   MAX OVERTURNING MOMENT  X  DIRECTION                          MAX STRUCTURAL SHEAR X DIRECTION
```

```
SUPR/STURE  TIME     OVERTURNING MOMENT                               TIME   MAX STUCTURAL SHEAR
    1       9.880          -377199.5405                               9.880            -1326.2994


  FLOOR              INERTIA   FORCES                                        INERTIA  FORCES
    1                       -1326.2994                                               -1326.2994
  BASE                        -80.7251                                                 -80.7251  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME     OVERTURNING MOMENT                               TIME   MAX STUCTURAL SHEAR
    2       3.740           959750.8119                               3.740             4559.8195


  FLOOR              INERTIA   FORCES                                        INERTIA  FORCES
    1                        4559.8195                                                4559.8195
  BASE                       1401.9893                                                1401.9893  FORCE AT C.M. OF ENTIRE BASE



        MAX OVERTURNING MOMENT  Y  DIRECTION                             MAX STRUCTURAL SHEAR Y DIRECTION

SUPR/STURE  TIME     OVERTURNING MOMENT                               TIME   MAX STUCTURAL SHEAR
    1       4.765            78786.0332                               4.765              277.0254


  FLOOR              INERTIA   FORCES                                        INERTIA  FORCES
    1                         277.0254                                                 277.0254
  BASE                       -483.7911                                                -483.7911  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME     OVERTURNING MOMENT                               TIME   MAX STUCTURAL SHEAR
    2       3.785           481124.0512                               3.785             2285.8421


  FLOOR              INERTIA   FORCES                                        INERTIA  FORCES
    1                        2285.8421                                                2285.8421
  BASE                        686.1370                                                 686.1370  FORCE AT C.M. OF ENTIRE BASE





   .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


   SUPERSTRUCTURE :  1

   COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
   C/L : 1  X COOR :  -834.960
            Y COOR :     0.000

   COLUMN LINES
                  1
   LEVEL   TIME     X  DIR   TIME      Y  DIR    TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
     1     9.890 0.1418E+00  4.775 0.2924E-01

   SUPERSTRUCTURE :  2

   COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
```

```
C/L : 1  X COOR :    -14.400
         Y COOR :      0.000

COLUMN LINES
                1
LEVEL   TIME     X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
  1    3.740 0.5071E-03  3.790 0.2706E-03
```

LOW DAMPING RUBBER BEARING - LINEAR VISCOUS FLUID DAMPER SYSTEM

GLOBAL REPRESENTATION OF ISOLATION SYSTEM

WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

```
SUPR/STURE  TIME     OVERTURNING MOMENT                              TIME    MAX STUCTURAL SHEAR
    2       3.847            868651.3953                             3.847              4127.0021

   FLOOR             INERTIA    FORCES                                   INERTIA  FORCES
     1                       4127.0021                                            4127.0021
   BASE                       882.9128                                             882.9128   FORCE AT C.M. OF ENTIRE BASE




    .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


    SUPERSTRUCTURE :   1

    COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
    C/L : 1  X COOR :   -834.960
             Y COOR :      0.000

    COLUMN LINES
                     1
    LEVEL   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
      1   10.042 0.1528E+00  4.754 0.3670E-01

    SUPERSTRUCTURE :  2

    COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
    C/L : 1  X COOR :    -14.400
             Y COOR :      0.000

    COLUMN LINES
                     1
    LEVEL   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
      1    3.837 0.6656E-03  3.848 0.4913E-03
```

INPUT

```
52  LOW DAMPING RUBBER BEAR. + 24 LINEAR FLUID DAMPERS - GLOBAL REPR.
 in                   Kips/in*sec↑2        secs
1 2 0 0 386.22
1 3
1 3
0.005 50 1 500 1
0.5 0.25
2 0.02 2000 0 1
         35.12
         35.12
     3659.0059
0.0
0.0
      42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
      46716.90
      46716.90
    6618227.50
0.0
0.0
        31.07037
   1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
396.76 396.76 123270280.0   14.4  0
      9.90109
 427528.00000
50.97 50.97 13010010.6 14.4  0.0
0 2 1
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
    -0.30719E+01   -0.10240E+02   -0.48048E+01    0.10200E+02   -0.28356E+01
    -0.81918E+01    0.12051E+02   -0.10161E+02   -0.13430E+02    0.14611E+02
    -0.11618E+02   -0.13430E+02    0.14257E+02   -0.98065E+01   -0.72072E+01
     0.14532E+02    0.12248E+02   -0.56712E+01   -0.27962E+01    0.57500E+01
    -0.14178E+01    0.15753E+01    0.20755E+02    0.11027E+01   -0.28159E+02
     0.72072E+01    0.40526E+02    0.28317E+02    0.46866E+01   -0.10003E+02
    -0.23394E+02   -0.17053E+02    0.63014E+00    0.17014E+02    0.12997E+02
     0.90582E+00    0.94520E+00   -0.58681E+01   -0.23630E+01    0.88613E+01
     0.16108E+02   -0.15753E+01   -0.32058E+02   -0.88219E+01    0.91764E+01
     0.40959E+01    0.36666E+02    0.31389E+02   -0.16738E+02   -0.37139E+02
    -0.10318E+02    0.47654E+01    0.83493E+01    0.22764E+02    0.98459E+01
...........
...........
```

WAVEY.DAT

```
     0.12878E+02    0.22055E+01   -0.22842E+01   -0.16935E+01    0.88219E+01
     0.31507E+01   -0.20361E+02   -0.16502E+02    0.46079E+01    0.78767E+01
     0.36233E+01   -0.14572E+02   -0.10122E+02    0.16187E+02    0.19652E+02
    -0.66952E+00   -0.94914E+01   -0.26781E+01   -0.24418E+01   -0.13587E+02
    -0.14926E+02    0.12721E+02    0.29538E+02    0.83493E+01   -0.24851E+02
    -0.17526E+02    0.90582E+01    0.17368E+02   -0.60257E+01   -0.21779E+02
    -0.24378E+02   -0.10437E+02    0.26190E+02    0.50686E+02    0.10082E+02
    -0.44582E+02   -0.47772E+02   -0.19731E+02    0.87825E+01    0.41234E+02
     0.38753E+02   -0.40565E+01   -0.36745E+02   -0.37375E+02   -0.10673E+02
     0.21464E+02    0.27017E+02    0.39384E+01   -0.22527E+02   -0.35209E+02
    -0.29301E+02    0.67346E+01    0.46236E+02    0.47890E+02    0.44897E+01
...........
...........
```

OUTPUT

```
****************************************************************

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


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


****************************************************************'

            VERSION   3D-BASIS-ME,  JANUARY 1993

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


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


52  LOW DAMPING RUBBER BEAR. + 24 LINEAR FLUID DAMPERS - GLOBAL REPR.



UNITS
LENGTH :  in
MASS   :  Kips/in*sec↑2
TIME   :  secs



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



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




NO. OF BUILDINGS......................=            2
NO. OF ISOLATORS......................=            0
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=          1
```

```
  INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
  INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=            0

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.........=     50.00000
REFERENCE MOMENT OF CONVERGENCE.........=      1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S.....=          500

INDEX FOR GROUND MOTION INPUT...........=            2

  INDEX = 1 FOR X         DIR. INPUT
  INDEX = 2 FOR X & Y     DIR. INPUT
  INDEX = 3 FOR X & Z     DIR  INPUT
  INDEX = 4 FOR X , Y & Z DIR. INPUT

TIME STEP OF RECORD ....................=      0.02000
LENGTH OF RECORD........................=         2000
LOAD FACTOR.............................=      1.00000
ANGLE OF EARTHQUAKE INCIDENCE...........=      0.00000




************* SUPERSTRUCTURE DATA ************



SUPERSTRUCTURE  :  1


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y            STIFF  R       ECCENT  X       ECCENT  Y

    1            35.12000            35.12000          3659.00590         0.00001         0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X       ECCENT  Y

    1            42.24794       1700000.00000           0.00000         0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

    1              0.00500
    2              0.00500
```

```
    3                 0.00500


HEIGHT.........
LEVEL         HEIGHT

    1       284.400
    0        18.000

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1       0.215236E-02   0.135432E+03
      2       0.831283E+00   0.689137E+01
      3       0.831283E+00   0.689137E+01


MODE SHAPES
LEVEL              1          2          3

    1  X   0.0000000 0.1538499 0.0000000

    1  Y   0.0000000 0.0000000 0.1538499

    1  R   0.0007670 0.0000000 0.0000000



SUPERSTRUCTURE  :  2


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y            STIFF  R      ECCENT  X      ECCENT  Y

    1        46716.90000         46716.90000       6618227.50000        0.00001        0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X      ECCENT  Y

    1             31.07037       1700000.00000           0.00000        0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

    1                0.02000
    2                0.02000
    3                0.02000


HEIGHT.........
LEVEL         HEIGHT

    1       210.480
    0        18.000
```

```
************* ISOLATION SYSTEM DATA ************


STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =             396.76000
STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =             396.76000
STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =       123270280.00000
ECCENT. IN  X  DIR. FROM CEN. OF MASS......=              14.40000
ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=               0.00000



MASS AT THE CENTER OF MASS OF THE BASE ....
            TRANSL. MASS   ROTATIONAL MASS

MASS              9.90109   427528.00000


GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                   X              Y              R             ECX            ECY

DAMPING         50.97000       50.97000 13010010.60000       14.40000        0.00000



************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION ........................=            1

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT

NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED ..........................=            2
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=            1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                       1

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER      EIGENVALUE          PERIOD

      1       0.389307E+01   0.318444E+01
      2       0.150358E+04   0.162038E+00
      3       0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL              1          2          3
```

```
     1  X    0.0000000 0.1794018 0.0000000

     1  Y    0.0000000 0.0000000 0.1794018

     1  R    0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                                   (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    9.890 0.3779E+02  4.780 -.7865E+01  3.885 -.2904E-03


SUPERSTRUCTURE :  2
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    3.735 -.9751E-01  3.780 -.4862E-01  3.875 -.3981E-03


MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME   DISPL  X    TIME   DISPL  Y    TIME   ROTATION
 BASE  3.850 -.1108E+02  3.905 -.6082E+01  3.885 0.2902E-03



MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL     X                          MAX DISPL     Y                          MAX RES. DISPL. SQRT(DX↑2+DY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME  DISPLACEMENT
    1     0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00



MAXIMUM BEARING VELOCITIES

                MAX VELOCITY X                           MAX VELOCITY Y                           MAX RES. VELOCITY SQRT(VX↑2+VY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME    VELOCITY
    1     0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00



MAXIMUM BEARING FORCES

                MAX FORCE     X                          MAX FORCE     Y                          MAX RES. FORCE  SQRT(FX↑2+FY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT        TIME   X  DIRECT  Y  DIRECT        TIME      FORCE
    1     0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00 0.0000E+00        0.000 0.0000E+00


MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME   ACCEL  X    TIME   ACCEL  Y    TIME   ACCEL  R

  1    9.880 -.3142E+02  4.770 0.6541E+01  3.660 0.9082E-06
```

```
SUPERSTRUCTURE :  2
LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R

  1    3.735 0.1466E+03  3.780 0.7311E+02  3.855 0.1555E-02


MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R
 BASE  3.770 0.1442E+03  3.815 0.7241E+02  8.520 0.1833E-01




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



MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
TIME :  3.850

SUPERSTRUCTURE :  1
                X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      23.1247    -19.1693     5.1287    -4.2100
 BASE   -11.0773    128.0581    -5.9176    67.4256

SUPERSTRUCTURE :  2
                X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0843    126.4401    -0.0461    69.3254
 BASE   -11.0773    128.0581    -5.9176    67.4256


MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
TIME :  3.905

SUPERSTRUCTURE :  1
                X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      22.5865    -18.6530     4.7008    -3.8195
 BASE   -10.7694    108.6323    -6.0816    63.5302

SUPERSTRUCTURE :  2
                X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0740    110.8292    -0.0418    62.7202
 BASE   -10.7694    108.6323    -6.0816    63.5302



PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING
```

```
SUPERSTRUCTURE :  1

 MAX ACCELERATION IN  X  DIRECTION
  TIME :  9.880

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      37.7935   -31.4193     -4.7617     4.0047
 BASE     2.7896    -3.7790      0.1157    -7.2207

 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  4.770

LEVEL    DISP       ACCEL       DISP       ACCEL
  1       3.5225    -2.9124     -7.8634     6.5410
 BASE     7.5914   -65.4995      3.8376   -48.1184

SUPERSTRUCTURE :  2

 MAX ACCELERATION IN  X  DIRECTION
  TIME :  3.735

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0975   146.6272     -0.0462    69.5194
 BASE    -9.6144   139.0588     -4.5405    70.9963

 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  3.780

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0938   140.9062     -0.0486    73.1071
 BASE   -10.5507   143.2994     -5.2394    68.9791



.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT
     1       9.880 -.1327E+04  4.770 0.2763E+03  3.660 0.1544E+01
     2       3.735 0.4556E+04  3.780 0.2271E+04  3.855 0.2644E+04



.MAXIMUM BASE SHEARS...........
```

```
 TIME    FORCE  X    TIME    FORCE  Y    TIME   Z  MOMENT    TIME   RES. SHEAR SQRT(FX↑2+FY↑2)
  3.735 -.5128E+04  3.155 0.2803E+04  8.525 -.7353E+04  3.745 0.5792E+04




.MAXIMUM STORY SHEARS.............


SUPERSTRUCTURE :    1
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT   TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1     9.880 -.1327E+04  4.770 0.2763E+03  3.660 0.1544E+01  9.905 0.1338E+04

SUPERSTRUCTURE :    2
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT   TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1     3.735 0.4556E+04  3.780 0.2271E+04  3.855 0.2644E+04  3.740 0.5045E+04




PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  9.880


LEVEL     DISP        ACCEL        DISP        ACCEL
  1      37.7935    -31.4193     -4.7617      4.0047
 BASE     2.7896     -3.7790      0.1157     -7.2207


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  4.770


LEVEL     DISP        ACCEL        DISP        ACCEL
  1       3.5225     -2.9124     -7.8634      6.5410
 BASE     7.5914    -65.4995      3.8376    -48.1184


SUPERSTRUCTURE :  2


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  3.735


LEVEL     DISP        ACCEL        DISP        ACCEL
```

```
  1      -0.0975   146.6272     -0.0462     69.5194
 BASE    -9.6144   139.0588     -4.5405     70.9963

 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.780

LEVEL     DISP       ACCEL        DISP        ACCEL
  1       -0.0938   140.9062     -0.0486     73.1071
 BASE   -10.5507   143.2994     -5.2394     68.9791




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


MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  3.735

SUPERSTRUCTURE :  1
                    X                        Y
LEVEL     DISP       ACCEL        DISP        ACCEL
  1       22.7904   -19.0552      5.3075     -4.4373
 BASE     -9.6144   139.0588     -4.5405     70.9963

SUPERSTRUCTURE :  2
                    X                        Y
LEVEL     DISP       ACCEL        DISP        ACCEL
  1       -0.0975   146.6272     -0.0462     69.5194
 BASE     -9.6144   139.0588     -4.5405     70.9963

MAXIMUM BASE SHEAR IN  Y  DIRECTION
TIME :  3.155

SUPERSTRUCTURE :  1
                    X                        Y
LEVEL     DISP       ACCEL        DISP        ACCEL
  1       -0.6457     0.1722     -1.9796      1.5830
 BASE     10.9257  -104.6614      5.1257    -70.5990

SUPERSTRUCTURE :  2
                    X                        Y
LEVEL     DISP       ACCEL        DISP        ACCEL
  1        0.0704  -105.4977      0.0465    -69.8758
 BASE     10.9257  -104.6614      5.1257    -70.5990


                      **************FORCE PROFILES***********

      MAX OVERTURNING MOMENT  X  DIRECTION                          MAX STRUCTURAL SHEAR X DIRECTION

SUPR/STURE  TIME    OVERTURNING MOMENT                            TIME   MAX STUCTURAL SHEAR
    1       9.880          -377512.6513                           9.880           -1327.4003
```

```
   FLOOR              INERTIA    FORCES
     1                         -1327.4003
   BASE                          -37.4167

 SUPR/STURE  TIME     OVERTURNING MOMENT
     2       3.735           958896.4609


   FLOOR              INERTIA    FORCES
     1                          4555.7605
   BASE                         1376.8334


        MAX OVERTURNING MOMENT  Y  DIRECTION

 SUPR/STURE  TIME     OVERTURNING MOMENT
     1       4.770            78592.7073


   FLOOR              INERTIA    FORCES
     1                           276.3457
   BASE                         -476.4251

 SUPR/STURE  TIME     OVERTURNING MOMENT
     2       3.780           478097.6979


   FLOOR              INERTIA    FORCES
     1                          2271.4638
   BASE                          682.9684
```

```
           INERTIA  FORCES
                  -1327.4003
                    -37.4167  FORCE AT C.M. OF ENTIRE BASE

 TIME   MAX STUCTURAL SHEAR
 3.735            4555.7605


           INERTIA  FORCES
                   4555.7605
                   1376.8334  FORCE AT C.M. OF ENTIRE BASE


     MAX STRUCTURAL SHEAR Y DIRECTION

 TIME   MAX STUCTURAL SHEAR
 4.770             276.3457


           INERTIA  FORCES
                    276.3457
                   -476.4251  FORCE AT C.M. OF ENTIRE BASE

 TIME   MAX STUCTURAL SHEAR
 3.780            2271.4638


           INERTIA  FORCES
                   2271.4638
                    682.9684  FORCE AT C.M. OF ENTIRE BASE
```

```
 .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


 SUPERSTRUCTURE :  1

 COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
 C/L : 1  X COOR :   -834.960
          Y COOR :      0.000

 COLUMN LINES
                1
 LEVEL   TIME     X DIR    TIME      Y DIR   TIME     X DIR   TIME     Y DIR   TIME     X DIR   TIME     Y DIR
   1    9.890 0.1419E+00  4.780 0.3007E-01

 SUPERSTRUCTURE :  2

 COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
 C/L : 1  X COOR :    -14.400
          Y COOR :      0.000
```

```
COLUMN LINES
                1
LEVEL   TIME     X  DIR    TIME      Y  DIR    TIME      X  DIR    TIME      Y  DIR    TIME      X  DIR    TIME      Y  DIR
  1    3.735 0.5066E-03  3.780 0.2252E-03
```

LOW DAMPING RUBBER BEARING - NONLINEAR VISCOUS FLUID DAMPER SYSTEM

WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

INPUT

```
2  LOW DAMPING RUBBER BEAR. + 24 NON-LINEAR DAMPERS
 in                     Kips/in*sec↑2           secs
1 2 9 9 386.22
1 3
1 3
.0002 10 100 500 1
.5 0.25
2 0.02 2000 0 1
          35.12
          35.12
     3659.0059
0.0
0.0
       42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
       46716.90
       46716.90
    6618227.50
0.0
0.0
          31.07037
   1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
0.0, 0.0, 0.0, 0.0, 0.0
       9.90109
 427528.00000
7.65 7.65 2374932. 0 0
-834.96    0.00
   0.00 -820.56
 806.16    0.00
   0.00  820.56
 -14.40    0.00
-509.88    0.00
   0.00 -495.48
 481.08    0.00
   0.00  495.48
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
49.595  49.595
  3  1
198.38  198.38
  3  2
80 80 0.5
  3  2
80 80 0.5
  3  2
80 80 0.5
  3  2
80 80 0.5
0 50 1
1 2 3 4 5 6 7 8 9
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
    -0.30719E+01   -0.10240E+02   -0.48048E+01    0.10200E+02   -0.28356E+01
    -0.81918E+01    0.12051E+02   -0.10161E+02   -0.13430E+02    0.14611E+02
    -0.11618E+02   -0.13430E+02    0.14257E+02   -0.98065E+01   -0.72072E+01
     0.14532E+02    0.12248E+02   -0.56712E+01   -0.27962E+01    0.57500E+01
    -0.14178E+01    0.15753E+01    0.20755E+02    0.11027E+01   -0.28159E+02
     0.72072E+01    0.40526E+02    0.28317E+02    0.46866E+01   -0.10003E+02
    -0.23394E+02   -0.17053E+02    0.63014E+00    0.17014E+02    0.12997E+02
     0.90582E+00    0.94520E+00   -0.58681E+01   -0.23630E+01    0.88613E+01
     0.16108E+02   -0.15753E+01   -0.32058E+02   -0.88219E+01    0.91764E+01
     0.40959E+01    0.36666E+02    0.31389E+02   -0.16738E+02   -0.37139E+02
    -0.10318E+02    0.47654E+01    0.83493E+01    0.22764E+02    0.98459E+01
...........
...........
```

WAVEY.DAT

```
     0.12878E+02    0.22055E+01   -0.22842E+01   -0.16935E+01    0.88219E+01
     0.31507E+01   -0.20361E+02   -0.16502E+02    0.46079E+01    0.78767E+01
     0.36233E+01   -0.14572E+02   -0.10122E+02    0.16187E+02    0.19652E+02
    -0.66952E+00   -0.94914E+01   -0.26781E+01   -0.24418E+01   -0.13587E+02
    -0.14926E+02    0.12721E+02    0.29538E+02    0.83493E+01   -0.24851E+02
    -0.17526E+02    0.90582E+01    0.17368E+02   -0.60257E+01   -0.21779E+02
    -0.24378E+02   -0.10437E+02    0.26190E+02    0.50686E+02    0.10082E+02
    -0.44582E+02   -0.47772E+02   -0.19731E+02    0.87825E+01    0.41234E+02
     0.38753E+02   -0.40565E+01   -0.36745E+02   -0.37375E+02   -0.10673E+02
     0.21464E+02    0.27017E+02    0.39384E+01   -0.22527E+02   -0.35209E+02
    -0.29301E+02    0.67346E+01    0.46236E+02    0.47890E+02    0.44897E+01
...........
...........
```

OUTPUT

```
*******************************************************************

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


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

*******************************************************************'

            VERSION   3D-BASIS-ME,  JANUARY 1993

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

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


52  LOW DAMPING RUBBER BEAR. + 24 NON-LINEAR DAMPERS



UNITS
LENGTH :  in
MASS   :  Kips/in*sec↑2
TIME   :    secs


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


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



NO. OF BUILDINGS........................=            2
NO. OF ISOLATORS........................=            9
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=            1
```

```
  INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
  INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=             9

TIME STEP OF INTEGRATION (NEWMARK)......=       0.00020
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.........=     100.00000
MAX NUMBER OF ITERATIONS WITHIN T.S.....=           500

INDEX FOR GROUND MOTION INPUT...........=             2

  INDEX = 1 FOR X          DIR. INPUT
  INDEX = 2 FOR X & Y      DIR. INPUT
  INDEX = 3 FOR X & Z      DIR  INPUT
  INDEX = 4 FOR X , Y & Z  DIR. INPUT

TIME STEP OF RECORD ....................=       0.02000
LENGTH OF RECORD........................=          2000
LOAD FACTOR.............................=       1.00000
ANGLE OF EARTHQUAKE INCIDENCE...........=       0.00000




************* SUPERSTRUCTURE DATA ************



SUPERSTRUCTURE  :  1


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X            STIFF  Y            STIFF  R       ECCENT  X      ECCENT  Y

    1            35.12000            35.12000          3659.00590        0.00001        0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X      ECCENT  Y

    1            42.24794       1700000.00000            0.00000        0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

    1               0.00500
    2               0.00500
```

```
   3                0.00500


HEIGHT.........
LEVEL        HEIGHT

   1       284.400
   0        18.000

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE        PERIOD

      1        0.215236E-02   0.135432E+03
      2        0.831283E+00   0.689137E+01
      3        0.831283E+00   0.689137E+01


MODE SHAPES
LEVEL              1           2          3

   1  X   0.0000000 0.1538499 0.0000000

   1  Y   0.0000000 0.0000000 0.1538499

   1  R   0.0007670 0.0000000 0.0000000


SUPERSTRUCTURE  :  2


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL            STIFF  X             STIFF  Y             STIFF  R       ECCENT  X       ECCENT  Y

   1        46716.90000         46716.90000        6618227.50000         0.00001         0.00000


SUPERSTRUCTURE MASS..........
LEVEL            TRANSL. MASS     ROTATIONAL MASS         ECCENT  X       ECCENT  Y

   1             31.07037       1700000.00000            0.00000         0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

   1                0.02000
   2                0.02000
   3                0.02000


HEIGHT.........
LEVEL        HEIGHT

   1       210.480
   0        18.000
```

```
************* ISOLATION SYSTEM DATA ************

STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =               0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =               0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =               0.00000
ECCENT. IN  X  DIR. FROM CEN. OF MASS......=               0.00000
ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=               0.00000



MASS AT THE CENTER OF MASS OF THE BASE ....
             TRANSL. MASS   ROTATIONAL MASS

MASS              9.90109   427528.00000


GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                    X              Y              R              ECX            ECY

DAMPING           7.65000        7.65000  2374932.00000        0.00000        0.00000


ISOLATORS LOCATION INFORMATION.........
ISOLATOR     X           Y

    1     -834.9600     0.0000
    2        0.0000  -820.5600
    3      806.1600     0.0000
    4        0.0000   820.5600
    5      -14.4000     0.0000
    6     -509.8800     0.0000
    7        0.0000  -495.4800
    8      481.0800     0.0000
    9        0.0000   495.4800

......ELEMENT TYPE =


LINEAR ELASTIC ELEMENT PARAMETERS........
ISOLATOR        STIFFNESS  X        STIFFNESS  Y
    1               49.59500            49.59500
    2               49.59500            49.59500
    3               49.59500            49.59500
    4               49.59500            49.59500
    5              198.38000           198.38000

......ELEMENT TYPE =


VISCOUS ELEMENT PARAMETERS........
ISOLATOR        DAMP-COEF  X        DAMP-COEF  Y   POWER OF VELOCITY
```

```
     6              80.00000           80.00000            0.50000
     7              80.00000           80.00000            0.50000
     8              80.00000           80.00000            0.50000
     9              80.00000           80.00000            0.50000


************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION ........................=            1

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT

NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED ..........................=           50
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=            1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                         1    2    3    4    5
                                         6    7    8    9

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE        PERIOD

     1        0.389307E+01   0.318444E+01
     2        0.150358E+04   0.162038E+00
     3        0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL              1          2          3

    1  X    0.0000000 0.1794018 0.0000000

    1  Y    0.0000000 0.0000000 0.1794018

    1  R    0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                               (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME    DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    10.022 0.3903E+02 11.018 -.5926E+01  3.825 0.1868E-03


SUPERSTRUCTURE :  2
LEVEL  TIME    DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1     3.736 -.9993E-01  3.645 -.5174E-01  3.807 0.2545E-03
```

```
MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME    DISPL  X    TIME    DISPL  Y    TIME   ROTATION
 BASE  3.824 -.1015E+02  3.843 -.5202E+01  3.825 -.1867E-03


MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL    X                        MAX DISPL    Y                        MAX RES. DISPL. SQRT(DX↑2+DY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME  DISPLACEMENT
    1     3.824 -.1015E+02 -.5029E+01      3.844 -.1012E+02 -.5046E+01      3.829 0.1133E+02
    2     3.824 -.1030E+02 -.5185E+01      3.843 -.1027E+02 -.5202E+01      3.829 0.1153E+02
    3     3.824 -.1015E+02 -.5335E+01      3.843 -.1012E+02 -.5352E+01      3.829 0.1147E+02
    4     3.824 -.9995E+01 -.5185E+01      3.843 -.9966E+01 -.5202E+01      3.829 0.1126E+02
    5     3.824 -.1015E+02 -.5182E+01      3.843 -.1012E+02 -.5199E+01      3.829 0.1140E+02
    6     3.824 -.1015E+02 -.5090E+01      3.843 -.1012E+02 -.5107E+01      3.829 0.1135E+02
    7     3.824 -.1024E+02 -.5185E+01      3.843 -.1021E+02 -.5202E+01      3.829 0.1148E+02
    8     3.824 -.1015E+02 -.5275E+01      3.843 -.1012E+02 -.5291E+01      3.829 0.1144E+02
    9     3.824 -.1006E+02 -.5185E+01      3.843 -.1003E+02 -.5202E+01      3.829 0.1132E+02


MAXIMUM BEARING VELOCITIES

                MAX VELOCITY X                        MAX VELOCITY Y                        MAX RES. VELOCITY SQRT(VX↑2+VY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME   VELOCITY
    1     3.454 -.4717E+02 -.1832E+02      3.591 -.3666E+02 -.2381E+02      3.418 0.5119E+02
    2     3.451 -.4783E+02 -.1930E+02      3.592 -.3707E+02 -.2432E+02      3.417 0.5221E+02
    3     3.454 -.4717E+02 -.1961E+02      3.592 -.3651E+02 -.2482E+02      3.417 0.5185E+02
    4     3.459 -.4653E+02 -.1853E+02      3.592 -.3606E+02 -.2432E+02      3.418 0.5083E+02
    5     3.454 -.4717E+02 -.1896E+02      3.592 -.3657E+02 -.2431E+02      3.417 0.5151E+02
    6     3.454 -.4717E+02 -.1857E+02      3.591 -.3663E+02 -.2401E+02      3.418 0.5132E+02
    7     3.452 -.4757E+02 -.1918E+02      3.592 -.3687E+02 -.2432E+02      3.417 0.5194E+02
    8     3.454 -.4717E+02 -.1935E+02      3.592 -.3654E+02 -.2462E+02      3.417 0.5172E+02
    9     3.457 -.4678E+02 -.1873E+02      3.592 -.3626E+02 -.2432E+02      3.418 0.5110E+02


MAXIMUM BEARING FORCES

                MAX FORCE    X                        MAX FORCE    Y                        MAX RES. FORCE  SQRT(FX↑2+FY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME      FORCE
    1     3.824 -.5033E+03 -.2494E+03      3.844 -.5018E+03 -.2503E+03      3.829 0.5618E+03
    2     3.824 -.5109E+03 -.2571E+03      3.843 -.5094E+03 -.2580E+03      3.829 0.5721E+03
    3     3.824 -.5033E+03 -.2646E+03      3.843 -.5019E+03 -.2654E+03      3.829 0.5687E+03
    4     3.824 -.4957E+03 -.2571E+03      3.843 -.4943E+03 -.2580E+03      3.829 0.5585E+03
    5     3.824 -.2013E+04 -.1028E+04      3.843 -.2007E+04 -.1031E+04      3.829 0.2261E+04
    6     3.455 -.5495E+03 -.3447E+03      3.591 -.4841E+03 -.3920E+03      3.407 0.6618E+03
    7     3.453 -.5517E+03 -.3502E+03      3.592 -.4859E+03 -.3945E+03      3.407 0.6665E+03
    8     3.455 -.5495E+03 -.3519E+03      3.592 -.4835E+03 -.3969E+03      3.407 0.6664E+03
    9     3.457 -.5472E+03 -.3462E+03      3.592 -.4818E+03 -.3945E+03      3.407 0.6619E+03

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R
```

```
  1   10.011 -.3244E+02 11.009 0.4927E+01  3.663 -.5861E-06


 SUPERSTRUCTURE :  2
 LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R

   1    3.735 0.1503E+03  3.644 0.7780E+02  3.787 -.9945E-03


 MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
 LEVEL  TIME   ACCEL  X   TIME   ACCEL  Y   TIME   ACCEL  R
  BASE  3.699 0.1481E+03  3.679 0.8192E+02  6.081 0.6538E-01




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


 MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
 TIME :  3.824

 SUPERSTRUCTURE :  1
                  X                        Y
 LEVEL    DISP        ACCEL        DISP        ACCEL
   1      22.4005    -18.5478      4.7462      -3.8455
  BASE   -10.1484     96.9077     -5.1848      64.8046

 SUPERSTRUCTURE :  2
                  X                        Y
 LEVEL    DISP        ACCEL        DISP        ACCEL
   1      -0.0843    126.0661     -0.0437      65.3455
  BASE   -10.1484     96.9077     -5.1848      64.8046


 MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
 TIME :  3.843

 SUPERSTRUCTURE :  1
                  X                        Y
 LEVEL    DISP        ACCEL        DISP        ACCEL
   1      22.2317    -18.3897      4.5285      -3.6537
  BASE   -10.1186    105.5173     -5.2017      41.5514

 SUPERSTRUCTURE :  2
                  X                        Y
 LEVEL    DISP        ACCEL        DISP        ACCEL
   1      -0.0685    101.3220     -0.0395      58.9043
  BASE   -10.1186    105.5173     -5.2017      41.5514




  PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING
```

```
SUPERSTRUCTURE :  1


 MAX ACCELERATION IN  X  DIRECTION
  TIME : 10.011


LEVEL     DISP        ACCEL        DISP        ACCEL
  1      39.0252    -32.4439     -4.9032      4.0881
 BASE     2.4990     -4.3183      0.1289    -11.0347


 MAX ACCELERATION IN  Y  DIRECTION
  TIME : 11.009


LEVEL     DISP        ACCEL        DISP        ACCEL
  1      23.3868    -19.1713     -5.9254      4.9270
 BASE     2.6353    -10.5967     -0.5949     -7.9287

SUPERSTRUCTURE :  2


 MAX ACCELERATION IN  X  DIRECTION
  TIME :   3.735


LEVEL     DISP        ACCEL        DISP        ACCEL
  1      -0.0999    150.2559     -0.0511     76.8194
 BASE    -9.2473    140.0605     -4.6020     75.2855


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :   3.644


LEVEL     DISP        ACCEL        DISP        ACCEL
  1      -0.0893    134.6504     -0.0517     77.8041
 BASE    -6.8886    129.1985     -3.2762     66.4948






.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT
     1      10.011 -.1371E+04 11.009 0.2082E+03  3.663 -.9963E+00
     2       3.735 0.4669E+04  3.644 0.2417E+04  3.787 -.1691E+04
```

```
.MAXIMUM BASE SHEARS...........
 TIME    FORCE  X    TIME    FORCE  Y    TIME  Z  MOMENT    TIME  RES. SHEAR SQRT(FX↑2+FY↑2)
  3.732 -.5263E+04  3.741 -.2945E+04  6.081 -.2907E+05  3.734 0.6029E+04




.MAXIMUM STORY SHEARS.............

SUPERSTRUCTURE :   1
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT  TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1    10.011 -.1371E+04 11.009 0.2082E+03  3.663 -.9963E+00 10.016 0.1382E+04

SUPERSTRUCTURE :   2
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT  TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1     3.735 0.4669E+04  3.644 0.2417E+04  3.787 -.1691E+04  3.732 0.5245E+04



PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING

SUPERSTRUCTURE :  1

 MAX STRUC SHEAR IN  X  DIRECTION
  TIME : 10.011

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      39.0252   -32.4439    -4.9032     4.0881
 BASE     2.4990    -4.3183     0.1289   -11.0347

 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME : 11.009

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      23.3868   -19.1713    -5.9254     4.9270
 BASE     2.6353   -10.5967    -0.5949    -7.9287

SUPERSTRUCTURE :  2

 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  3.735
```

```
LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.0999    150.2559     -0.0511    76.8194
 BASE     -9.2473    140.0605     -4.6020    75.2855

 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.644

LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.0893    134.6504     -0.0517    77.8041
 BASE     -6.8886    129.1985     -3.2762    66.4948




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

MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  3.732

SUPERSTRUCTURE :  1
                 X                          Y
LEVEL     DISP       ACCEL        DISP       ACCEL
  1       22.5072    -18.7662      5.4449    -4.4900
 BASE     -9.2024    140.1913     -4.5787    74.7148

SUPERSTRUCTURE :  2
                 X                          Y
LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.0999    150.2219     -0.0512    76.9759
 BASE     -9.2024    140.1913     -4.5787    74.7148

MAXIMUM BASE SHEAR IN  Y  DIRECTION
TIME :  3.741

SUPERSTRUCTURE :  1
                 X                          Y
LEVEL     DISP       ACCEL        DISP       ACCEL
  1       22.5554    -18.7936      5.4068    -4.4519
 BASE     -9.3761    140.3449     -4.6699    76.9049

SUPERSTRUCTURE :  2
                 X                          Y
LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.0998    149.9164     -0.0508    76.3190
 BASE     -9.3761    140.3449     -4.6699    76.9049


                      **************FORCE PROFILES***********

   MAX OVERTURNING MOMENT  X  DIRECTION                        MAX STRUCTURAL SHEAR X DIRECTION
```

```
SUPR/STURE  TIME    OVERTURNING MOMENT                          TIME   MAX STUCTURAL SHEAR
    1      10.011          -389823.1014                        10.011          -1370.6860


   FLOOR             INERTIA   FORCES                                   INERTIA  FORCES
    1                        -1370.6860                                        -1370.6860
   BASE                        -42.7563                                          -42.7563  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME    OVERTURNING MOMENT                          TIME   MAX STUCTURAL SHEAR
    2       3.735           982627.0317                         3.735           4668.5055


   FLOOR             INERTIA   FORCES                                   INERTIA  FORCES
    1                         4668.5055                                          4668.5055
   BASE                       1386.7519                                          1386.7519  FORCE AT C.M. OF ENTIRE BASE


         MAX OVERTURNING MOMENT  Y  DIRECTION                        MAX STRUCTURAL SHEAR Y DIRECTION

SUPR/STURE  TIME    OVERTURNING MOMENT                          TIME   MAX STUCTURAL SHEAR
    1      11.009            59198.9824                        11.009            208.1539


   FLOOR             INERTIA   FORCES                                   INERTIA  FORCES
    1                          208.1539                                            208.1539
   BASE                        -78.5025                                            -78.5025  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME    OVERTURNING MOMENT                          TIME   MAX STUCTURAL SHEAR
    2       3.644           508814.5347                         3.644           2417.4009


   FLOOR             INERTIA   FORCES                                   INERTIA  FORCES
    1                         2417.4009                                          2417.4009
   BASE                        658.3715                                           658.3715  FORCE AT C.M. OF ENTIRE BASE




      .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


      SUPERSTRUCTURE :  1

      COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
      C/L : 1  X COOR :  -834.960
               Y COOR :     0.000

      COLUMN LINES
                   1
      LEVEL   TIME     X  DIR   TIME     Y  DIR   TIME     X  DIR   TIME     Y  DIR   TIME     X  DIR   TIME     Y  DIR
        1   10.022 0.1465E+00 11.008 0.2232E-01

      SUPERSTRUCTURE :  2

      COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
```

```
C/L : 1  X COOR :    -14.400
         Y COOR :      0.000

COLUMN LINES
                1
LEVEL   TIME     X  DIR   TIME      Y  DIR    TIME      X  DIR    TIME      Y  DIR    TIME      X  DIR    TIME      Y  DIR
  1    3.736 0.5192E-03  3.722 0.2854E-03
```

FPS SYSTEM

WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

INPUT

```
52  FPS BEARINGS - CONSTANT NORMAL LOAD
 in                  Kips/in*sec↑2               secs
1 2 5 5 386.22
1 3
1 3
0.001 50 1 500 1
0.5 0.25
2 0.02 2000 0 1
         35.12
         35.12
     3659.0059
0.0
0.0
      42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
      46716.90
      46716.90
    6618227.50
0.0
0.0
        31.07037
   1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
390.06, 390.06, 121188853.0, -14.40,  0.00
      9.90109
 427528.00000
0 0 0 0 0
-834.96    0.00
   0.00 -820.56
 806.16    0.00
   0.00  820.56
 -14.40    0.00
  3  4
 0.045 0.045  0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  4
 0.045 0.045  0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  4
 0.045 0.045  0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  4
 0.045 0.045  0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  4
 0.045 0.045  0.03 0.03 0.8 0.8 0.02 0.02 16070.5
0 10 1
1 2 3 4 5
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
    -0.30719E+01    -0.10240E+02    -0.48048E+01     0.10200E+02    -0.28356E+01
    -0.81918E+01     0.12051E+02    -0.10161E+02    -0.13430E+02     0.14611E+02
    -0.11618E+02    -0.13430E+02     0.14257E+02    -0.98065E+01    -0.72072E+01
     0.14532E+02     0.12248E+02    -0.56712E+01    -0.27962E+01     0.57500E+01
    -0.14178E+01     0.15753E+01     0.20755E+02     0.11027E+01    -0.28159E+02
     0.72072E+01     0.40526E+02     0.28317E+02     0.46866E+01    -0.10003E+02
    -0.23394E+02    -0.17053E+02     0.63014E+00     0.17014E+02     0.12997E+02
     0.90582E+00     0.94520E+00    -0.58681E+01    -0.23630E+01     0.88613E+01
     0.16108E+02    -0.15753E+01    -0.32058E+02    -0.88219E+01     0.91764E+01
     0.40959E+01     0.36666E+02     0.31389E+02    -0.16738E+02    -0.37139E+02
    -0.10318E+02     0.47654E+01     0.83493E+01     0.22764E+02     0.98459E+01
...........
...........
```

WAVEY.DAT

```
     0.12878E+02     0.22055E+01    -0.22842E+01    -0.16935E+01     0.88219E+01
     0.31507E+01    -0.20361E+02    -0.16502E+02     0.46079E+01     0.78767E+01
     0.36233E+01    -0.14572E+02    -0.10122E+02     0.16187E+02     0.19652E+02
    -0.66952E+00    -0.94914E+01    -0.26781E+01    -0.24418E+01    -0.13587E+02
    -0.14926E+02     0.12721E+02     0.29538E+02     0.83493E+01    -0.24851E+02
    -0.17526E+02     0.90582E+01     0.17368E+02    -0.60257E+01    -0.21779E+02
    -0.24378E+02    -0.10437E+02     0.26190E+02     0.50686E+02     0.10082E+02
    -0.44582E+02    -0.47772E+02    -0.19731E+02     0.87825E+01     0.41234E+02
     0.38753E+02    -0.40565E+01    -0.36745E+02    -0.37375E+02    -0.10673E+02
     0.21464E+02     0.27017E+02     0.39384E+01    -0.22527E+02    -0.35209E+02
    -0.29301E+02     0.67346E+01     0.46236E+02     0.47890E+02     0.44897E+01
...........
...........
```

OUTPUT

```
*******************************************************************

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


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

*******************************************************************'

           VERSION   3D-BASIS-ME,  JANUARY 1993

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

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


52  FPS BEARINGS - CONSTANT NORMAL LOAD



UNITS
LENGTH :  in
MASS   :  Kips/in*sec↑2
TIME   :         secs



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



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




NO. OF BUILDINGS.......................=           2
NO. OF ISOLATORS.......................=           5
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=           1
```

```
  INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
  INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=            5

TIME STEP OF INTEGRATION (NEWMARK)......=      0.00100
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.........=     50.00000
REFERENCE MOMENT OF CONVERGENCE.........=      1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S.....=          500

INDEX FOR GROUND MOTION INPUT...........=            2

  INDEX = 1 FOR X         DIR. INPUT
  INDEX = 2 FOR X & Y     DIR. INPUT
  INDEX = 3 FOR X & Z     DIR  INPUT
  INDEX = 4 FOR X , Y & Z DIR. INPUT

TIME STEP OF RECORD ....................=      0.02000
LENGTH OF RECORD........................=         2000
LOAD FACTOR.............................=      1.00000
ANGLE OF EARTHQUAKE INCIDENCE...........=      0.00000




************* SUPERSTRUCTURE DATA ************


SUPERSTRUCTURE  :  1


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL          STIFF  X          STIFF  Y          STIFF  R      ECCENT  X      ECCENT  Y

   1           35.12000          35.12000        3659.00590        0.00001        0.00000

SUPERSTRUCTURE MASS..........
LEVEL          TRANSL. MASS    ROTATIONAL MASS      ECCENT  X      ECCENT  Y

   1           42.24794       1700000.00000         0.00000        0.00000

SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

   1               0.00500
   2               0.00500
```

```
    3                0.00500


HEIGHT.........
LEVEL        HEIGHT

    1       284.400
    0        18.000

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER      EIGENVALUE         PERIOD

      1        0.215236E-02   0.135432E+03
      2        0.831283E+00   0.689137E+01
      3        0.831283E+00   0.689137E+01


MODE SHAPES
LEVEL                 1            2            3

    1   X    0.0000000 0.1538499 0.0000000

    1   Y    0.0000000 0.0000000 0.1538499

    1   R    0.0007670 0.0000000 0.0000000


SUPERSTRUCTURE   :  2


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL              STIFF  X              STIFF  Y              STIFF  R        ECCENT  X        ECCENT  Y

    1          46716.90000          46716.90000          6618227.50000          0.00001          0.00000


SUPERSTRUCTURE MASS..........
LEVEL              TRANSL. MASS      ROTATIONAL MASS          ECCENT  X        ECCENT  Y

    1                31.07037      1700000.00000              0.00000          0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE       DAMPING RATIO

    1                  0.02000
    2                  0.02000
    3                  0.02000


HEIGHT.........
LEVEL         HEIGHT

    1       210.480
    0        18.000
```

```
************* ISOLATION SYSTEM DATA ************


STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =            390.06000
STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =            390.06000
STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =      121188853.00000
ECCENT. IN  X  DIR. FROM CEN. OF MASS......=            -14.40000
ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=              0.00000



MASS AT THE CENTER OF MASS OF THE BASE ....
            TRANSL. MASS   ROTATIONAL MASS

MASS                9.90109   427528.00000


GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                    X              Y              R              ECX            ECY

DAMPING             0.00000        0.00000        0.00000        0.00000        0.00000



ISOLATORS LOCATION INFORMATION.........
ISOLATOR      X          Y

    1     -834.9600     0.0000
    2        0.0000  -820.5600
    3      806.1600     0.0000
    4        0.0000   820.5600
    5      -14.4000     0.0000

......ELEMENT TYPE =


SLIDING BEARING PARAMETERS..(CONSTANT NORMAL FORCE & FMAX)...........
ISOLATOR   FMAX  X   FMAX  Y   FMIN  X   FMIN  Y      PA X      PA Y  YIELD DISPL. X  YIELD DISPL. Y   NORMAL FORCE

    1     0.04500   0.04500   0.03000   0.03000     0.800     0.800      0.02000         0.02000      4017.62500
    2     0.04500   0.04500   0.03000   0.03000     0.800     0.800      0.02000         0.02000      4017.62500
    3     0.04500   0.04500   0.03000   0.03000     0.800     0.800      0.02000         0.02000      4017.62500
    4     0.04500   0.04500   0.03000   0.03000     0.800     0.800      0.02000         0.02000      4017.62500
    5     0.04500   0.04500   0.03000   0.03000     0.800     0.800      0.02000         0.02000     16070.50000

************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION .......................=            0

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT
```

```
NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED .........................=            10
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=            1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                             1    2    3    4    5

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1       0.389307E+01   0.318444E+01
      2       0.150358E+04   0.162038E+00
      3       0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL              1            2            3

    1  X    0.0000000 0.1794018 0.0000000

    1  Y    0.0000000 0.0000000 0.1794018

    1  R    0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                                   (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME    DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1   10.044 0.4053E+02  4.753 -.9815E+01  3.887 0.3999E-03


SUPERSTRUCTURE :  2
LEVEL  TIME    DISPL  X    TIME   DISPL  Y    TIME   ROTATION

  1    3.809 -.1136E+00  3.872 -.8195E-01  4.755 -.5577E-03


MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME    DISPL  X    TIME   DISPL  Y    TIME   ROTATION
 BASE  3.857 -.1317E+02  3.896 -.8243E+01  3.887 -.3998E-03


MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL    X                          MAX DISPL    Y                         MAX RES. DISPL. SQRT(DX↑2+DY↑2)
ISOLATOR  TIME    X  DIRECT  Y  DIRECT       TIME    X  DIRECT  Y  DIRECT       TIME  DISPLACEMENT
    1     3.857 -.1317E+02 -.7837E+01       3.897 -.1303E+02 -.7909E+01       3.866 0.1534E+02
    2     3.857 -.1350E+02 -.8168E+01       3.896 -.1336E+02 -.8243E+01       3.866 0.1579E+02
    3     3.857 -.1317E+02 -.8488E+01       3.896 -.1303E+02 -.8565E+01       3.867 0.1568E+02
    4     3.856 -.1285E+02 -.8164E+01       3.896 -.1271E+02 -.8243E+01       3.866 0.1523E+02
```

```
    5     3.857 -.1317E+02 -.8162E+01      3.896 -.1303E+02 -.8237E+01      3.866 0.1551E+02


MAXIMUM BEARING VELOCITIES

                MAX VELOCITY X                      MAX VELOCITY Y                      MAX RES. VELOCITY SQRT(VX↑2+VY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME   VELOCITY
    1     3.475 -.5359E+02 -.2342E+02      3.594 -.4573E+02 -.3295E+02      3.554 0.5902E+02
    2     3.474 -.5468E+02 -.2456E+02      3.595 -.4655E+02 -.3393E+02      3.554 0.6014E+02
    3     3.475 -.5359E+02 -.2559E+02      3.597 -.4533E+02 -.3487E+02      3.555 0.5986E+02
    4     3.477 -.5251E+02 -.2445E+02      3.595 -.4464E+02 -.3393E+02      3.554 0.5875E+02
    5     3.475 -.5359E+02 -.2451E+02      3.595 -.4559E+02 -.3391E+02      3.554 0.5944E+02


MAXIMUM BEARING FORCES

                MAX FORCE    X                      MAX FORCE    Y                      MAX RES. FORCE  SQRT(FX↑2+FY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME     FORCE
    1     3.213 -.1808E+03 -.2562E+01      3.149 -.3453E+01 0.1808E+03      3.149 0.1808E+03
    2     2.593 0.1808E+03 0.1507E+01      9.167 0.6027E+00 0.1808E+03      2.593 0.1808E+03
    3     6.024 0.1808E+03 -.1410E+00      9.172 0.1792E+01 0.1808E+03      9.172 0.1808E+03
    4     2.593 0.1808E+03 0.1513E+01      3.146 -.2252E+01 0.1808E+03      3.146 0.1808E+03
    5     2.593 0.7232E+03 0.6053E+01      9.172 0.6640E+01 0.7231E+03      2.593 0.7232E+03

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME    ACCEL  X    TIME   ACCEL  Y    TIME   ACCEL  R

  1   10.033 -.3370E+02  4.742 0.8163E+01  3.706 -.1224E-05


SUPERSTRUCTURE :  2
LEVEL  TIME    ACCEL  X    TIME   ACCEL  Y    TIME   ACCEL  R

  1    3.808 0.1707E+03  3.871 0.1232E+03  4.739 0.2174E-02


MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
LEVEL  TIME    ACCEL  X    TIME   ACCEL  Y    TIME   ACCEL  R
 BASE  7.398 -.2271E+03  6.247 -.1482E+03  6.155 0.2386E-01




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


MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
TIME :  3.857

SUPERSTRUCTURE :  1
                X                      Y
```

```
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      25.8562   -21.4382      7.7007    -6.3355
 BASE   -13.1743   126.2531     -8.1682   117.3894

SUPERSTRUCTURE :  2
                 X                         Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.1074   160.7382     -0.0790   119.2784
 BASE   -13.1743   126.2531     -8.1682   117.3894


MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
TIME :  3.896

SUPERSTRUCTURE :  1
                 X                         Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      25.5221   -21.1124      7.3476    -6.0140
 BASE   -13.0336   177.4479     -8.2425    63.7978

SUPERSTRUCTURE :  2
                 X                         Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0606    89.4051     -0.0644    94.5614
 BASE   -13.0336   177.4479     -8.2425    63.7978



 PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX ACCELERATION IN  X  DIRECTION
  TIME : 10.033


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      40.5288   -33.6970     -4.5752     3.7966
 BASE     1.9910    25.5478      0.5174    13.2791


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  4.742


LEVEL    DISP       ACCEL       DISP       ACCEL
  1       0.8322    -0.6490     -9.8099     8.1633
 BASE     9.8686  -113.8913      5.6894   -80.1861


SUPERSTRUCTURE :  2


 MAX ACCELERATION IN  X  DIRECTION
```

```
  TIME :  3.808


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.1136   170.7426    -0.0697   104.9407
 BASE   -12.8939   168.8793    -7.7689   106.5026

 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  3.871

LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0965   143.3974    -0.0819   123.2494
 BASE   -13.1541    87.5046    -8.2144    87.1164




.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME   FORCE  X    TIME   FORCE  Y    TIME   Z  MOMENT
     1      10.033 -.1424E+04  4.742 0.3449E+03  3.706 -.2080E+01
     2       3.808 0.5305E+04  3.871 0.3829E+04  4.739 0.3697E+04




.MAXIMUM BASE SHEARS...........
 TIME   FORCE  X   TIME   FORCE  Y    TIME  Z  MOMENT   TIME  RES. SHEAR SQRT(FX↑2+FY↑2)
  3.808 -.6065E+04  3.861 -.4609E+04  6.155 -.1117E+05  3.830 0.7352E+04




.MAXIMUM STORY SHEARS.............


SUPERSTRUCTURE :    1
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1   10.033 -.1424E+04  4.742 0.3449E+03  3.706 -.2080E+01 10.032 0.1433E+04

SUPERSTRUCTURE :    2
LEVEL  TIME   FORCE  X   TIME   FORCE  Y   TIME   Z  MOMENT  TIME  RES. SHEAR SQRT(FX↑2+FY↑2)

  1    3.808 0.5305E+04  3.871 0.3829E+04  4.739 0.3697E+04  3.841 0.6287E+04
```

```
PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME : 10.033


LEVEL    DISP        ACCEL        DISP       ACCEL
  1      40.5288    -33.6970     -4.5752     3.7966
 BASE     1.9910     25.5478      0.5174    13.2791


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  4.742


LEVEL    DISP        ACCEL        DISP       ACCEL
  1       0.8322     -0.6490     -9.8099     8.1633
 BASE     9.8686   -113.8913      5.6894   -80.1861


SUPERSTRUCTURE :  2


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  3.808


LEVEL    DISP        ACCEL        DISP       ACCEL
  1      -0.1136    170.7426     -0.0697   104.9407
 BASE   -12.8939    168.8793     -7.7689   106.5026


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.871


LEVEL    DISP        ACCEL        DISP       ACCEL
  1      -0.0965    143.3974     -0.0819   123.2494
 BASE   -13.1541     87.5046     -8.2144    87.1164




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


MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  3.808

SUPERSTRUCTURE :  1
```

```
                  X                          Y
LEVEL     DISP         ACCEL        DISP         ACCEL
  1       25.9461    -21.5934       7.9075      -6.5616
 BASE    -12.8939    168.8793      -7.7689     106.5026

SUPERSTRUCTURE :  2
                  X                          Y
LEVEL     DISP         ACCEL        DISP         ACCEL
  1       -0.1136    170.7426      -0.0697     104.9407
 BASE    -12.8939    168.8793      -7.7689     106.5026


MAXIMUM BASE SHEAR IN  Y  DIRECTION
TIME :  3.861

SUPERSTRUCTURE :  1
                  X                          Y
LEVEL     DISP         ACCEL        DISP         ACCEL
  1       25.8306    -21.4117       7.6708      -6.3062
 BASE    -13.1722    114.8752      -8.1843     113.1370

SUPERSTRUCTURE :  2
                  X                          Y
LEVEL     DISP         ACCEL        DISP         ACCEL
  1       -0.1052    157.2186      -0.0801     120.8517
 BASE    -13.1722    114.8752      -8.1843     113.1370


                        **************FORCE PROFILES***********

        MAX OVERTURNING MOMENT  X  DIRECTION

SUPR/STURE  TIME     OVERTURNING MOMENT
    1      10.033          -404880.0690


   FLOOR             INERTIA   FORCES
     1                       -1423.6289
   BASE                        252.9515

SUPR/STURE  TIME     OVERTURNING MOMENT
    2       3.808          1116603.7337


   FLOOR             INERTIA   FORCES
     1                        5305.0348
   BASE                       1672.0887


        MAX OVERTURNING MOMENT  Y  DIRECTION

SUPR/STURE  TIME     OVERTURNING MOMENT
    1       4.742            98084.1321


   FLOOR             INERTIA   FORCES
     1                          344.8809
   BASE                        -793.9299
```

```
      MAX STRUCTURAL SHEAR X DIRECTION

TIME    MAX STUCTURAL SHEAR
10.033           -1423.6289


         INERTIA  FORCES
                 -1423.6289
                   252.9515  FORCE AT C.M. OF ENTIRE BASE

TIME    MAX STUCTURAL SHEAR
3.808             5305.0348


         INERTIA  FORCES
                  5305.0348
                  1672.0887  FORCE AT C.M. OF ENTIRE BASE


      MAX STRUCTURAL SHEAR Y DIRECTION

TIME    MAX STUCTURAL SHEAR
4.742              344.8809


         INERTIA  FORCES
                   344.8809
                  -793.9299  FORCE AT C.M. OF ENTIRE BASE
```

```
SUPR/STURE  TIME    OVERTURNING MOMENT                                  TIME   MAX STUCTURAL SHEAR
    2      3.871            806013.2396                                 3.871              3829.4054


   FLOOR            INERTIA   FORCES                                          INERTIA  FORCES
    1                      3829.4054                                                3829.4054
   BASE                     862.5474                                                 862.5474  FORCE AT C.M. OF ENTIRE BASE




     .MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE


     SUPERSTRUCTURE :  1

     COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
     C/L : 1  X COOR :  -834.960
              Y COOR :     0.000

     COLUMN LINES
                    1
     LEVEL   TIME     X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
       1   10.044 0.1521E+00  4.752 0.3598E-01

     SUPERSTRUCTURE :  2

     COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE
     C/L : 1  X COOR :   -14.400
              Y COOR :     0.000

     COLUMN LINES
                    1
     LEVEL   TIME     X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR   TIME      X  DIR   TIME      Y  DIR
       1    3.809 0.5900E-03  3.872 0.4664E-03
```

FPS SYSTEM

WITH EFFECT OF VERTICAL GROUND MOTION AND OVERTURNING MOMENTS

INPUT

```
52  FPS BEARINGS - VARIABLE NORMAL LOAD
 in                    Kips/in*sec↑2                  secs
1 2 5 5 386.22
1 3
1 3
0.001 50 1 500 1
0.5 0.25
4 0.02 2000 0 1
         35.12
         35.12
     3659.0059
0.0
0.0
      42.24794
 1700000.00000
 0.005 0.005 0.005
0.0
0.0
284.40, 18.00
      46716.90
      46716.90
    6618227.50
0.0
0.0
        31.07037
   1700000.00000
 0.02 0.02 0.02
0.0
0.0
210.48, 18.00
0 0 0 0 0

      9.90109
 427528.00000
0 0 0 0 0
-834.96    0.00
   0.00 -820.56
 806.16    0.00
   0.00  820.56
 -14.40    0.00
  3  6
82.4  0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  6
82.4  0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  6
82.4  0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  6
82.4  0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625
  3  6
82.4  0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 16070.5
0 10 1
1 2 3 4 5
1
-834.96    0.00
1
 -14.40    0.00
```

WAVEX.DAT

```
 -0.30719E+01   -0.10240E+02   -0.48048E+01    0.10200E+02   -0.28356E+01
 -0.81918E+01    0.12051E+02   -0.10161E+02   -0.13430E+02    0.14611E+02
 -0.11618E+02   -0.13430E+02    0.14257E+02   -0.98065E+01   -0.72072E+01
  0.14532E+02    0.12248E+02   -0.56712E+01   -0.27962E+01    0.57500E+01
 -0.14178E+01    0.15753E+01    0.20755E+02    0.11027E+01   -0.28159E+02
  0.72072E+01    0.40526E+02    0.28317E+02    0.46866E+01   -0.10003E+02
 -0.23394E+02   -0.17053E+02    0.63014E+00    0.17014E+02    0.12997E+02
  0.90582E+00    0.94520E+00   -0.58681E+01   -0.23630E+01    0.88613E+01
  0.16108E+02   -0.15753E+01   -0.32058E+02   -0.88219E+01    0.91764E+01
  0.40959E+01    0.36666E+02    0.31389E+02   -0.16738E+02   -0.37139E+02
 -0.10318E+02    0.47654E+01    0.83493E+01    0.22764E+02    0.98459E+01
...........
...........
```

WAVEY.DAT

```
  0.12878E+02    0.22055E+01   -0.22842E+01   -0.16935E+01    0.88219E+01
  0.31507E+01   -0.20361E+02   -0.16502E+02    0.46079E+01    0.78767E+01
  0.36233E+01   -0.14572E+02   -0.10122E+02    0.16187E+02    0.19652E+02
 -0.66952E+00   -0.94914E+01   -0.26781E+01   -0.24418E+01   -0.13587E+02
 -0.14926E+02    0.12721E+02    0.29538E+02    0.83493E+01   -0.24851E+02
 -0.17526E+02    0.90582E+01    0.17368E+02   -0.60257E+01   -0.21779E+02
 -0.24378E+02   -0.10437E+02    0.26190E+02    0.50686E+02    0.10082E+02
 -0.44582E+02   -0.47772E+02   -0.19731E+02    0.87825E+01    0.41234E+02
  0.38753E+02   -0.40565E+01   -0.36745E+02   -0.37375E+02   -0.10673E+02
  0.21464E+02    0.27017E+02    0.39384E+01   -0.22527E+02   -0.35209E+02
 -0.29301E+02    0.67346E+01    0.46236E+02    0.47890E+02    0.44897E+01
...........
...........
```

WAVEZ.DAT

```
  0.17092E+02    0.23354E+02    0.32688E+01   -0.31625E+02    0.59075E+00
  0.33240E+02   -0.16344E+02   -0.15675E+02    0.68921E+01   -0.24969E+02
  0.14099E+02    0.30522E+02   -0.24536E+02    0.20479E+01    0.40211E+02
 -0.18510E+02   -0.53365E+02    0.19810E+02    0.42219E+02   -0.23433E+02
 -0.42810E+02   -0.59075E+01    0.29538E+02    0.48757E+02    0.33870E+02
 -0.37966E+02   -0.93851E+02   -0.26781E+02    0.48481E+02    0.63447E+02
  0.47260E+02    0.12800E+02   -0.28553E+02   -0.48481E+02   -0.10988E+02
  0.21622E+02    0.35445E+00   -0.70496E+01    0.22055E+01    0.68527E+01
 -0.14178E+02    0.12681E+02    0.56397E+02    0.74435E+01   -0.15045E+02
  0.43322E+01   -0.41471E+02   -0.47497E+02    0.32216E+02    0.68960E+02
...........
...........
```

```
C*****************************************************FOVM**************

      FUNCTION FOVM( OVMX,OVMY,XP,YP,I )

C***********************************************************************
C
C     CALCULATING AXIAL FORCES IN THE BEARINGS FROM OVERTURNING MOMENTS
C     DEVELOPED BY................PANAGIOTIS TSOPELAS....FEB 1993
C
C***********************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /MAIN1   /NB,NP,MNF,MNE,NFE,MXF
      COMMON /BEARAREA/AREA(500)
      DIMENSION OVMX(NB+1,2),OVMY(NB+1,2),XP(NP),YP(NP)

      IF(I.EQ.1) THEN
      OMX=0.0
      OMY=0.0
      DO 10 K=1,NB+1
      OMX=OMX+OVMX(K,1)
      OMY=OMY+OVMY(K,1)
 10   CONTINUE
      ENDIF

      IF(I.EQ.5) FOVM=0.0
      IF(I.EQ.4) FOVM= OMY/1641.12
      IF(I.EQ.3) FOVM= OMX/1641.12
      IF(I.EQ.2) FOVM=-OMY/1641.12
      IF(I.EQ.1) FOVM=-OMX/1641.12

      RETURN
      END



C*****************************************************FFMAX**************

      FUNCTION FFMAX(FRMAX,FRMIN,FNOR,I)

C***********************************************************************
C
C     CALCULATING MAXIMUM FRICTION COEFFICIENT AS FUNC OF PRESSURE
C     DEVELOPED BY................PANAGIOTIS TSOPELAS....FEB 1993
C
C***********************************************************************
      IMPLICIT REAL*8(A-H,O-Z)
      COMMON /MAIN1   /NB,NP,MNF,MNE,NFE,MXF
      COMMON /BEARAREA/AREA(500)
      EXTERNAL WGTCF

      FACT=FNOR
      PRESS=15.0*FACT
      ALP=0.10729586
      DF=0.065

      FFMAX=FRMAX-(DF)*DTANH(ALP*PRESS)

      RETURN
      END
```

OUTPUT

```
*******************************************************************

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


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


*******************************************************************'

            VERSION   3D-BASIS-ME,  JANUARY 1993

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


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



52  FPS BEARINGS - VARIABLE NORMAL LOAD




UNITS
LENGTH :  in
MASS   :  Kips/in*sec↑2
TIME   :        secs




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



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





NO. OF BUILDINGS........................=           2
NO. OF ISOLATORS........................=           5
INDEX FOR  SUPERSTRUCTURE STIFFNESS DATA=           1
```

```
  INDEX = 1 FOR 3D SHEAR BUILDING  REPRES.
  INDEX = 2 FOR FULL 3D REPRESENTATION
NUMBER OF ISOLATORS, OUTPUT IS DESIRED..=           5

TIME STEP OF INTEGRATION (NEWMARK)......=     0.00100
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.........=    50.00000
REFERENCE MOMENT OF CONVERGENCE.........=     1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S.....=         500

INDEX FOR GROUND MOTION INPUT...........=           4

  INDEX = 1 FOR X          DIR. INPUT
  INDEX = 2 FOR X & Y      DIR. INPUT
  INDEX = 3 FOR X & Z      DIR  INPUT
  INDEX = 4 FOR X , Y & Z  DIR. INPUT

TIME STEP OF RECORD ....................=     0.02000
LENGTH OF RECORD........................=        2000
LOAD FACTOR.............................=     1.00000
ANGLE OF EARTHQUAKE INCIDENCE...........=     0.00000



************* SUPERSTRUCTURE DATA ************


SUPERSTRUCTURE  :  1


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

 STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
LEVEL           STIFF  X           STIFF  Y           STIFF  R      ECCENT  X      ECCENT  Y

    1            35.12000           35.12000         3659.00590        0.00001        0.00000


SUPERSTRUCTURE MASS..........
LEVEL           TRANSL. MASS     ROTATIONAL MASS        ECCENT  X      ECCENT  Y

    1            42.24794       1700000.00000           0.00000        0.00000


SUPERSTRUCTURE DAMPING.......
MODE SHAPE     DAMPING RATIO

    1              0.00500
    2              0.00500
```

```
   3               0.00500


 HEIGHT.........
 LEVEL        HEIGHT

    1       284.400
    0        18.000

 EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

 MODE NUMBER     EIGENVALUE         PERIOD

      1        0.215236E-02   0.135432E+03
      2        0.831283E+00   0.689137E+01
      3        0.831283E+00   0.689137E+01


 MODE SHAPES
 LEVEL             1            2            3

    1  X   0.0000000 0.1538499 0.0000000

    1  Y   0.0000000 0.0000000 0.1538499

    1  R   0.0007670 0.0000000 0.0000000



 SUPERSTRUCTURE  :  2


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

  STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) ....
 LEVEL            STIFF  X            STIFF  Y            STIFF  R      ECCENT  X      ECCENT  Y

    1         46716.90000         46716.90000       6618227.50000        0.00001        0.00000

 SUPERSTRUCTURE MASS..........
 LEVEL            TRANSL. MASS     ROTATIONAL MASS       ECCENT  X      ECCENT  Y

    1              31.07037      1700000.00000          0.00000        0.00000

 SUPERSTRUCTURE DAMPING.......
 MODE SHAPE      DAMPING RATIO

    1                0.02000
    2                0.02000
    3                0.02000

 HEIGHT.........
 LEVEL        HEIGHT

    1       210.480
    0        18.000
```

```
************* ISOLATION SYSTEM DATA ************


STIFFNESS DATA FOR LINEAR-ELASTIC ISOLATION SYSTEM......

STIFFNESS OF LINEAR-ELASTIC SYS. IN X DIR. =              0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN Y DIR. =              0.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN R DIR. =              0.00000
ECCENT. IN  X  DIR. FROM CEN. OF MASS......=              0.00000
ECCENT. IN  Y  DIR. FROM CEN. OF MASS......=              0.00000



MASS AT THE CENTER OF MASS OF THE BASE ....
            TRANSL. MASS   ROTATIONAL MASS

MASS                 9.90109   427528.00000


GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE.....
                      X              Y              R              ECX            ECY

DAMPING              0.00000        0.00000        0.00000        0.00000        0.00000



ISOLATORS LOCATION INFORMATION.........
ISOLATOR      X           Y

     1     -834.9600    0.0000
     2        0.0000 -820.5600
     3      806.1600    0.0000
     4        0.0000  820.5600
     5      -14.4000    0.0000

......ELEMENT TYPE =


F. P. S. BEARING PARAMETERS.......
ISOLATOR     RADIUS    FMAX  X    FMAX  Y    FMIN  X    FMIN  Y      PA X       PA Y   YIELD DISPL. X  YIELD DISPL. Y    NORMAL FORCE

     1       82.4000   0.10500    0.10500    0.03000    0.03000      0.800      0.800         0.02000         0.02000      4017.62500
     2       82.4000   0.10500    0.10500    0.03000    0.03000      0.800      0.800         0.02000         0.02000      4017.62500
     3       82.4000   0.10500    0.10500    0.03000    0.03000      0.800      0.800         0.02000         0.02000      4017.62500
     4       82.4000   0.10500    0.10500    0.03000    0.03000      0.800      0.800         0.02000         0.02000      4017.62500
     5       82.4000   0.10500    0.10500    0.03000    0.03000      0.800      0.800         0.02000         0.02000     16070.50000

************ OUTPUT PARAMETERS *************


TIME HISTORY OPTION .......................=             1

 INDEX = 0 FOR NO TIME HISTORY OUTPUT
 INDEX = 1 FOR TIME HISTORY OUTPUT
```

```
NO. OF TIME STEPS AT WHICH TIME HISTORY
OUTPUT IS DESIRED .........................=           10
ACCELERATION-DISPLACEMENTS PROFILES OPTION..=           1

 INDEX = 0 FOR NO PROFILES OUTPUT
 INDEX = 1 FOR PROFILES OUTPUT

FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED...................=
                                           1    2    3    4    5

EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION)....

MODE NUMBER     EIGENVALUE         PERIOD

      1       0.389307E+01   0.318444E+01
      2       0.150358E+04   0.162038E+00
      3       0.150358E+04   0.162038E+00


MODE SHAPES
LEVEL              1          2          3

    1  X   0.0000000 0.1794018 0.0000000

    1  Y   0.0000000 0.0000000 0.1794018

    1  R   0.0007670 0.0000000 0.0000000


MAX. RELATIVE DISPLACEMENTS AT CENTER OF MASS OF LEVELS
                                 (WITH RESPECT TO THE BASE)


SUPERSTRUCTURE :  1
LEVEL  TIME   DISPL  X   TIME   DISPL  Y   TIME   ROTATION

  1   10.042 0.4072E+02  4.755 -.9973E+01  3.918 0.3829E-03


SUPERSTRUCTURE :  2
LEVEL  TIME   DISPL  X   TIME   DISPL  Y   TIME   ROTATION

  1    3.837 -.1281E+00  3.848 -.8832E-01  4.717 -.4879E-03


MAX. DISPLACEMENTS AT CENTER OF MASS OF BASE
LEVEL  TIME   DISPL  X   TIME   DISPL  Y   TIME   ROTATION
 BASE  3.854 -.1329E+02  3.893 -.8303E+01  3.918 -.3828E-03


MAXIMUM BEARING DISPLACEMENTS

                MAX DISPL    X                      MAX DISPL    Y                      MAX RES. DISPL. SQRT(DX↑2+DY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT       TIME   X  DIRECT  Y  DIRECT       TIME  DISPLACEMENT
    1     3.854 -.1329E+02 -.7924E+01       3.888 -.1319E+02 -.7994E+01       3.864 0.1549E+02
    2     3.856 -.1359E+02 -.8230E+01       3.893 -.1346E+02 -.8303E+01       3.865 0.1589E+02
    3     3.854 -.1329E+02 -.8509E+01       3.897 -.1312E+02 -.8604E+01       3.865 0.1580E+02
    4     3.853 -.1300E+02 -.8217E+01       3.893 -.1285E+02 -.8303E+01       3.864 0.1539E+02
```

```
    5     3.854 -.1329E+02 -.8217E+01      3.893 -.1315E+02 -.8298E+01      3.865 0.1564E+02


MAXIMUM BEARING VELOCITIES

                 MAX VELOCITY X                       MAX VELOCITY Y                      MAX RES. VELOCITY SQRT(VX↑2+VY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME   VELOCITY
    1     3.474 -.5490E+02 -.2441E+02      3.598 -.4465E+02 -.3288E+02      3.470 0.6012E+02
    2     3.473 -.5576E+02 -.2533E+02      3.600 -.4528E+02 -.3371E+02      3.469 0.6128E+02
    3     3.474 -.5490E+02 -.2612E+02      3.602 -.4427E+02 -.3453E+02      3.469 0.6085E+02
    4     3.474 -.5404E+02 -.2528E+02      3.600 -.4363E+02 -.3371E+02      3.470 0.5970E+02
    5     3.474 -.5490E+02 -.2527E+02      3.600 -.4446E+02 -.3370E+02      3.469 0.6048E+02


MAXIMUM BEARING FORCES

                 MAX FORCE    X                       MAX FORCE    Y                      MAX RES. FORCE  SQRT(FX↑2+FY↑2)
ISOLATOR  TIME   X  DIRECT  Y  DIRECT      TIME   X  DIRECT  Y  DIRECT      TIME     FORCE
    1     4.720 0.7791E+03 0.4426E+03      3.855 -.5955E+03 -.5061E+03      4.725 0.8970E+03
    2     3.803 -.7639E+03 -.4950E+03      3.840 -.7032E+03 -.5281E+03      3.812 0.9130E+03
    3     3.819 -.9104E+03 -.6537E+03      3.841 -.8701E+03 -.6887E+03      3.827 0.1124E+04
    4     3.813 -.8656E+03 -.6059E+03      3.848 -.7896E+03 -.6577E+03      3.828 0.1066E+04
    5     3.804 -.3263E+04 -.2167E+04      3.847 -.2940E+04 -.2367E+04      3.820 0.3954E+04

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS


SUPERSTRUCTURE :  1
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R

  1   10.031 -.3385E+02  4.743 0.8294E+01  3.669 -.1131E-05


SUPERSTRUCTURE :  2
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R

  1    3.836 0.1927E+03  3.847 0.1328E+03  4.697 0.1911E-02


MAX. ACCELERATIONS AT CENTER OF MASS OF BASE
LEVEL  TIME    ACCEL  X    TIME    ACCEL  Y    TIME    ACCEL  R
 BASE  7.398 -.2344E+03  8.493 0.1943E+03  3.923 0.5560E-01




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


MAXIMUM BASE DISPLACEMENT IN  X  DIRECTION
TIME :  3.854

SUPERSTRUCTURE :  1
                 X                          Y
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```
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      25.8472   -21.4288     7.6727    -6.3118
 BASE   -13.2932   104.6639    -8.2217    92.9336

SUPERSTRUCTURE :  2
                 X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.1168   173.5615    -0.0875   131.1268
 BASE   -13.2932   104.6639    -8.2217    92.9336


MAXIMUM BASE DISPLACEMENT IN  Y  DIRECTION
TIME :  3.893

SUPERSTRUCTURE :  1
                 X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      25.4976   -21.0847     7.3187    -5.9874
 BASE   -13.1509   191.1480    -8.3031    78.3010

SUPERSTRUCTURE :  2
                 X                          Y
LEVEL    DISP       ACCEL       DISP       ACCEL
  1      -0.0468    68.7997    -0.0520    75.8248
 BASE   -13.1509   191.1480    -8.3031    78.3010



 PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX ACCELERATION IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX ACCELERATION IN  X  DIRECTION
  TIME : 10.031


LEVEL    DISP       ACCEL       DISP       ACCEL
  1      40.7131   -33.8494    -4.4418     3.6887
 BASE     1.8965    18.3669     0.5464   -11.7807


 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  4.743


LEVEL    DISP       ACCEL       DISP       ACCEL
  1       0.5085    -0.3804    -9.9671     8.2944
 BASE     9.9173  -109.0376     5.6604   -77.2029


SUPERSTRUCTURE :  2


 MAX ACCELERATION IN  X  DIRECTION
```

```
 TIME :  3.836


LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.1280   192.6852     -0.0855   129.2239
 BASE   -13.2615   117.2983     -8.1198    96.2306

 MAX ACCELERATION IN  Y  DIRECTION
  TIME :  3.847

LEVEL     DISP       ACCEL        DISP       ACCEL
  1       -0.1243   185.7066     -0.0883   132.8276
 BASE   -13.2881   102.3710     -8.1870    89.1733





.MAXIMUM STRUCTURAL SHEARS.........

SUPERST. No  TIME    FORCE  X    TIME   FORCE  Y     TIME    Z  MOMENT
     1      10.031 -.1430E+04  4.743 0.3504E+03  3.669 -.1923E+01
     2       3.836 0.5987E+04  3.847 0.4127E+04  4.697 0.3248E+04




.MAXIMUM BASE SHEARS...........
 TIME    FORCE  X    TIME    FORCE  Y    TIME  Z  MOMENT    TIME  RES. SHEAR SQRT(FX↑2+FY↑2)
  3.804 -.6524E+04  3.847 -.4741E+04  3.923 -.2498E+05  3.820 0.7909E+04




.MAXIMUM STORY SHEARS.............


SUPERSTRUCTURE :   1
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT   TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1   10.031 -.1430E+04  4.743 0.3504E+03  3.669 -.1923E+01 10.030 0.1439E+04

SUPERSTRUCTURE :   2
LEVEL  TIME    FORCE  X    TIME    FORCE  Y    TIME    Z  MOMENT   TIME   RES. SHEAR SQRT(FX↑2+FY↑2)

  1    3.836 0.5987E+04  3.847 0.4127E+04  4.697 0.3248E+04  3.839 0.7228E+04
```

```
                 X                              Y
LEVEL     DISP         ACCEL         DISP          ACCEL
  1       25.9779     -21.6165        7.9027       -6.5571
 BASE    -13.0243     231.3975       -7.8217      144.3394

SUPERSTRUCTURE :  2
                 X                              Y
LEVEL     DISP         ACCEL         DISP          ACCEL
  1       -0.1100     165.6228       -0.0681      102.6127
 BASE    -13.0243     231.3975       -7.8217      144.3394


MAXIMUM BASE SHEAR IN  Y  DIRECTION
TIME :  3.847

SUPERSTRUCTURE :  1
                 X                              Y
LEVEL     DISP         ACCEL         DISP          ACCEL
  1       25.8884     -21.4709        7.7213       -6.3584
 BASE    -13.2881     102.3710       -8.1870       89.1733

SUPERSTRUCTURE :  2
                 X                              Y
LEVEL     DISP         ACCEL         DISP          ACCEL
  1       -0.1243     185.7066       -0.0883      132.8276
 BASE    -13.2881     102.3710       -8.1870       89.1733


                    **************FORCE PROFILES***********
       MAX OVERTURNING MOMENT  X  DIRECTION                          MAX STRUCTURAL SHEAR X DIRECTION

SUPR/STURE  TIME     OVERTURNING MOMENT                          TIME    MAX STUCTURAL SHEAR
     1     10.031          -406710.7518                          10.031            -1430.0659


  FLOOR              INERTIA   FORCES                                    INERTIA  FORCES
    1                         -1430.0659                                          -1430.0659
  BASE                          181.8523                                            181.8523  FORCE AT C.M. OF ENTIRE BASE

SUPR/STURE  TIME     OVERTURNING MOMENT                          TIME    MAX STUCTURAL SHEAR
     2      3.836           1260101.5233                         3.836              5986.7993


  FLOOR              INERTIA   FORCES                                    INERTIA  FORCES
    1                          5986.7993                                           5986.7993
  BASE                         1161.3813                                           1161.3813  FORCE AT C.M. OF ENTIRE BASE


       MAX OVERTURNING MOMENT  Y  DIRECTION                          MAX STRUCTURAL SHEAR Y DIRECTION

SUPR/STURE  TIME     OVERTURNING MOMENT                          TIME    MAX STUCTURAL SHEAR
     1      4.743             99659.2330                         4.743               350.4192


  FLOOR              INERTIA   FORCES                                    INERTIA  FORCES
    1                           350.4192                                            350.4192
  BASE                         -764.3927                                           -764.3927  FORCE AT C.M. OF ENTIRE BASE
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PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING


SUPERSTRUCTURE :  1


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME : 10.031


LEVEL    DISP       ACCEL       DISP       ACCEL
 1      40.7131   -33.8494     -4.4418     3.6887
 BASE    1.8965    18.3669      0.5464   -11.7807


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  4.743


LEVEL    DISP       ACCEL       DISP       ACCEL
 1       0.5085    -0.3804     -9.9671     8.2944
 BASE    9.9173  -109.0376      5.6604   -77.2029


SUPERSTRUCTURE :  2


 MAX STRUC SHEAR IN  X  DIRECTION
  TIME :  3.836


LEVEL    DISP       ACCEL       DISP       ACCEL
 1      -0.1280   192.6852     -0.0855   129.2239
 BASE  -13.2615   117.2983     -8.1198    96.2306


 MAX STRUC SHEAR IN  Y  DIRECTION
  TIME :  3.847


LEVEL    DISP       ACCEL       DISP       ACCEL
 1      -0.1243   185.7066     -0.0883   132.8276
 BASE  -13.2881   102.3710     -8.1870    89.1733




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


MAXIMUM BASE SHEAR IN  X  DIRECTION
TIME :  3.804

SUPERSTRUCTURE :  1
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