#### BIBLIOGRAPHIC INFORMATION

PB94-204922

Report Nos:

<u>Title</u>: 3D-BASIS-ME: Computer Program for Nonlinear Dynamic Analysis of Seismically Isolated Single and Multiple Structures and Liquid Storage Tanks.

Date: 12 Apr 94

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

Performing Organization: State Univ. of New York at Buffalo. Dept. of Civil Engineering.

Performing Organization Report Nos: NCEER-94-0010

<u>Sponsoring Organization: \*National Center for Earthquake Engineering Research,</u> <u>Buffalo, NY.\*National Science Foundation, Arlington, VA.\*New York State Science and</u> Technology Foundation, Albany.

Contract Nos: NSF-BCS-90-25010, NYSSTF-NEC-91029

Type of Report and Period Covered: Technical rept.

NTIS Field/Group Codes: 89D (Structural Analyses), 50B (Civil Engineering)

Price: PC A09/MF A02

Availability: Available from the National Technical Information Service, Springfield, VA. 22161

Number of Pages: 192p

<u>Keywords</u>: \*Earthquake resistant structures, \*Dynamic structural analysis, \*Storage tanks, \*Computer programs, Earthquake engineering, Dynamic response, Nonlinear systems, Vibration damping, Vibration isolators, Bearings, Displacement, Structural vibration, \*3D-BASIS-ME Computer program.

<u>Abstract</u>: 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.



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# NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH

State University of New York at Buffalo



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

by

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Technical Report NCEER-94-0010

April 12, 1994 REPRODUCED BY U.S. Department of Commerce National Technical Information Service Springfield, Virginia 21151

This research was conducted at the State University of New York at Buffalo and was partially supported by the National Science Foundation under Grant No. BCS 90-25010 and the New York State Science and Technology Foundation under Grant No. NEC-91029.

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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

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April 12, 1994

Technical Report NCEER-94-0010

NCEER Task Numbers 90-2101, 91-5411B and 91-2102B,

NSF Grant Number BCS-8857080 and Taisei Corporation Grant 150-6889A

NSF Master Contract Number BCS 90-25010 and NYSSTF Grant Number NEC-91029

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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

Program 3D-BASIS-ME was developed with funding from the National Center for Earthquake Engineering Research (Projects No. 902101, 915411B and 912102B), the National Science Foundation (Grant No. BCS-8857080), the Taisei Corporation (Grant No. 150-6889A) and industrial contributions from Taylor Devices, Inc. and Earthquake Protection Systems, Inc. These projects dealt with testing and modeling of seismic isolation and energy dissipation systems.

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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.
- 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.

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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.

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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)

$$F_x = K_x (u_x^{\theta} - e_y^{\theta} u_r^{\theta})$$
(2.1)

$$F_{y} = K_{y}(u_{y}^{B} + e_{x}^{B} u_{r}^{B})$$
(2.2)

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





#### 2.2.2 Linear Viscous Element

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

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

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

$$T = C_r \dot{u}_r^8 + C_y e_x^8 \dot{u}_y^8 - C_x e_y^8 \dot{u}_x^8$$
(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 :

$$F_{x} = \alpha \frac{F^{y}}{Y} U_{x} + (1 - \alpha) F^{y} Z_{x}, \qquad F_{y} = \alpha \frac{F^{y}}{Y} U_{y} + (1 - \alpha) F^{y} Z_{y}$$
(2.7)

in which,  $\alpha$  is the post-yielding to pre-yielding stiffness ratio,  $F^{y}$  is the yield force and Y is the yield displacement, 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 :

$$\begin{cases} \dot{Z}_{x} & Y \\ \dot{Z}_{y} & Y \end{cases} = \begin{cases} A & \dot{U}_{x} \\ A & \dot{U}_{y} \end{cases} - \begin{pmatrix} Z_{x}^{2}(\gamma Sgn(\dot{U}_{x}Z_{x}) + \beta) & Z_{x}Z_{y}(\gamma Sgn(\dot{U}_{y}Z_{y}) + \beta) \\ Z_{x}Z_{y}(\gamma Sgn(\dot{U}_{x}Z_{x}) + \beta) & Z_{y}^{2}(\gamma Sgn(\dot{U}_{y}Z_{y}) + \beta) \end{pmatrix} \begin{cases} \dot{U}_{x} \\ \dot{U}_{y} \end{cases}$$
(2.8)

in which A,  $\gamma$  and  $\beta$  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.

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

$$Z_{\rm r} = \cos \theta, \qquad Z_{\rm r} = \sin \theta \tag{2.9}$$

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

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

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

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

$$O_{X_{x}}^{2} = \left\{ (1 - \alpha)^{2} F^{y^{2}} + \alpha^{2} \frac{F^{y^{2}}}{Y^{2}} U^{2} + 2\alpha (1 - \alpha) \frac{F^{y^{2}} U}{Y} \right\}^{1/2}$$

$$(2.11)$$

Equation 2.11 clearly describes a circle. At the lower limit of inelastic behavior, i.e. U = 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)

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

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

$$\dot{U} = \left(\dot{U}_{x}^{2} + \dot{U}_{y}^{2}\right)^{1/2}$$
(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 :

$$\mu_{s} = f_{\max} - (f_{\max} - f_{\min}) \exp(-a |\dot{U}|)$$
(2.14)

in which,  $f_{\text{max}}$  is the maximum value of the coefficient of friction and  $f_{\text{min}}$  is the minimum (at 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  $f_{\text{max}}$ ,  $f_{\text{min}}$  and a for interfaces used in sliding bearings have been reported in Constantinou et al. 1990 and Mokha et al. 1991. In general, parameters  $f_{\text{max}}$ ,  $f_{\text{min}}$  and a are functions of bearing pressure and angle  $\theta$ , though the dependency on  $\theta$  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 :

- 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

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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.

3-3

As in program 3D-BASIS, the extended 3D-BASIS-M program has two options for the representation of the superstructure. In the first option, each superstructure is represented by a shear building representation. In this representation, the stiffness characteristics of each story of each superstructure are represented by the story translational stiffnesses, rotational stiffness and eccentricities of the story center of resistance with respect to the center of mass of the floor (see Figure 3-2). Furthermore, and only for the shear type representation, it is assumed that the centers of mass of 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.  $\mathbf{u}_{j}^{i}$  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 the center 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.

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Figure 3-3 Displacement Coordinates of Isolated Structure.

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

$$\mathbf{M}_{N_{b}\times N_{b}}\ddot{\mathbf{u}}_{N_{b}\times 1} + \mathbf{C}_{N_{b}\times N_{b}}\dot{\mathbf{u}}_{N_{b}\times 1} + \mathbf{K}_{N_{b}\times N_{b}}\mathbf{u}_{N_{b}\times 1} = -\mathbf{M}_{N_{b}\times N_{b}}\mathbf{R}_{N_{b}\times 3}\{\ddot{\mathbf{u}}_{b} + \ddot{\mathbf{u}}_{g}\}_{3\times 1}$$
(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  $(\ddot{u}_b)$  and ground  $(\ddot{u}_g)$  acceleration vectors from the center of mass of the base to the center of mass of each floor of each superstructure building. The

subscripts in Equation 3.1 denote the dimension of the matrices.  $N_b$  is the number of degrees of freedom in the part above the base. It is equal to the total number of degrees of freedom minus the three degrees of freedom of the base. In extended form, Equations 3.1 are expressed as

$$\begin{pmatrix} \mathbf{m}^{i} & 0 & 0 & 0 & 0 \\ 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & \mathbf{m}^{i} & 0 & 0 \\ 0 & 0 & 0 & \dots & 0 \\ 0 & 0 & 0 & 0 & \mathbf{m}^{ns} \end{pmatrix} \begin{pmatrix} \mathbf{\dot{u}^{i}} \\ \vdots \\ \mathbf{\ddot{u}^{i}} \\ \vdots \\ \mathbf{\ddot{u}^{i}} \\ \mathbf{\ddot{u$$

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) :

$$\mathbf{r}^{i} = \begin{pmatrix} \mathbf{R}_{\mathbf{x}^{i}} \\ \vdots \\ \mathbf{R}_{j^{i}} \\ \vdots \\ \mathbf{R}_{1} \end{pmatrix}$$
(3.3)

where

$$\mathbf{R}_{j} = \begin{pmatrix} 1 & \mathbf{0} & -\mathbf{Y}_{j} \\ \mathbf{0} & 1 & \mathbf{X}_{j} \\ \mathbf{0} & \mathbf{0} & 1 \end{pmatrix}$$
(3.4)

in which  $X_j$ ,  $Y_j$  are the distances to the center of mass of floor (j) of superstructure (i) from the center of mass of the base (see Figure 3-2).

The equilibrium equation of dynamic equilibrium of the base is:

$$\mathbf{R}_{3\times N_{b}}^{T}\mathbf{M}_{N_{b}\times N_{b}}\{\ddot{\mathbf{u}}_{N_{b}\times 1}+\mathbf{R}_{N_{b}\times 3}\{\ddot{\mathbf{u}}_{b}+\ddot{\mathbf{u}}_{g}\}_{3\times 1}\}+\mathbf{M}_{b_{3\times 3}}\{\ddot{\mathbf{u}}_{b}+\ddot{\mathbf{u}}_{g}\}_{3\times 1}+\mathbf{C}_{b_{3\times 3}}\{\dot{\mathbf{u}}_{b}\}_{3\times 1}+\mathbf{K}_{b_{3\times 3}}\{\mathbf{u}_{b}\}_{3\times 1}+\{\mathbf{f}_{N}\}_{3\times 1}=0$$
(3.5)

in which  $M_b$  is the mass matrix of the base,  $C_b$  is the resultant damping matrix of viscous elements of the isolation system,  $K_b$  is the resultant stiffness matrix of elastic elements of the isolation system at the center of mass of the base and  $f_N$  is a vector containing the forces mobilized in the nonlinear elements of the isolation system.

Employing modal reduction :

$$\mathbf{u}_{3nj'}^{i} = \mathbf{\Phi}_{3nj' \times ne'}^{i} \mathbf{Y}_{ne' \times 1}^{i}$$
(3.6)

where  $\tilde{\Phi}^i$  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<sup>i</sup> is the number of eigenvectors of superstructure (i) retained in the analysis.

Combining Equations 3.2 to 3.6, the following equation is derived

$$\begin{pmatrix} \mathbf{I} & \Phi^{T}\mathbf{M}\mathbf{R} \\ \mathbf{R}^{T}\mathbf{M}\Phi & \mathbf{R}^{T}\mathbf{M}\mathbf{R} + \mathbf{M}_{b} \end{pmatrix}_{(M_{b}+3)\times(M_{b}+3)} \begin{cases} \ddot{\mathbf{Y}} \\ \ddot{\mathbf{u}}_{b} \end{cases} + \begin{pmatrix} 2\xi\omega & \mathbf{0} \\ \mathbf{0} & \mathbf{C}_{b} \end{pmatrix}_{(M_{b}+3)\times(M_{b}+3)} \begin{cases} \dot{\mathbf{Y}} \\ \dot{\mathbf{u}}_{b} \end{cases} + \begin{pmatrix} \dot{\mathbf{y}} \\ \dot{\mathbf{u}}_{b} \end{pmatrix}_{(M_{b}+3)\times(M_{b}+3)} \end{cases} + \begin{pmatrix} \mathbf{0} \\ \mathbf{f}_{N} \end{pmatrix}_{(M_{b}+3)\times1} = - \begin{pmatrix} \Phi^{T} & \mathbf{M} & \mathbf{R} \\ \mathbf{R}^{T} & \mathbf{M} & \mathbf{R} + \mathbf{M}_{b} \end{pmatrix}_{(M_{b}+3)\times3} \{ \ddot{\mathbf{u}}_{g} \}_{3\times1}$$

$$(3.7)$$

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

Equation 3.7 may be written as :

$$\tilde{\boldsymbol{M}}\,\tilde{\boldsymbol{y}}_{i}+\tilde{\boldsymbol{C}}\,\tilde{\boldsymbol{y}}_{i}+\tilde{\boldsymbol{K}}\,\tilde{\boldsymbol{y}}_{i}+f_{i}=\tilde{\boldsymbol{P}}_{i} \tag{3.8}$$

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

$$\tilde{M}\tilde{\tilde{y}}_{i+\Delta t} + \tilde{C}\tilde{\tilde{y}}_{i+\Delta t} + \tilde{K}\tilde{y}_{i+\Delta t} + f_{i+\Delta t} = \tilde{P}_{i+\Delta t}$$
(3.9)

Taking the difference between Equations 3.8 and 3.9 gives the incremental equation of equilibrium  $\tilde{M}\Delta \ddot{y}_{i+\Delta t} + \tilde{C}\Delta \dot{y}_{i+\Delta t} + \tilde{K}\Delta \tilde{y}_{i+\Delta t} + \Delta f_{i+\Delta t} = \tilde{P}_{i+\Delta t} - \tilde{M} \ddot{y}_{i} - \tilde{C} \dot{y}_{i} - \tilde{K} \tilde{Y}_{i} - f_{i}$ (3.10)

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

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#### **3.4 Solution Algorithm**

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

- Solution of the equations of motion using the unconditionally stable (for both positive and negative tangent stiffness - Cheng 1988) Newmark's constant-average-acceleration method (Newmark 1959).
- (ii) Solution of the differential equations governing the nonlinear behavior of the isolation elements using an unconditionally stable semi-implicit Runge-Kutta method suitable for stiff differential equations (Rosenbrock 1964). The solution algorithm of the pseudo force method with iteration is presented in Table 3-I.

## 3.4.2 Varying Time Step for Accuracy

The solution algorithm has the option of using a constant time step or variable time step. The time step is reduced from  $\Delta t_{stip}$  (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 :

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

in which,  $\vec{u}$  is the resultant velocity at the center of mass of the base,  $\Delta t_{stict}$  is the reduced time step when the base velocity is low ( $\Delta t_{stip} > \Delta t_{stict} > \Delta t_{stip}/nl$ , 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  $\tilde{K}$ , mass matrix  $\tilde{M}$ , and damping matrix  $\tilde{C}$ . Initialize  $\tilde{u}_0$ ,  $\dot{\tilde{u}}_0$  and  $\ddot{\tilde{u}}_0$ .

2. Select time step  $\Delta t$ , set parameters  $\delta = 0.25$  and  $\theta = 0.5$ , and calculate the integration constants:

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

3. Form the effective stiffness matrix  $\mathbf{K}^* = a_1 \mathbf{\tilde{M}} + a_4 \mathbf{\tilde{C}} + \mathbf{\tilde{K}}$ 

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  $\Delta f_{t+\Delta t}^i = 0$  in iteration i = 1.

2. Calculate the effective load vector at time  $t + \Delta t$ :

$$\mathbf{P}_{t+\Delta t}^{*} = \Delta \tilde{\mathbf{P}}_{t+\Delta t} - \Delta f_{t+\Delta t}^{t} + \tilde{\mathbf{M}}(a_{2}\mathbf{\hat{u}}_{t} + a_{3}\mathbf{\hat{u}}_{t}) + \tilde{\mathbf{c}}(a_{5}\mathbf{\hat{u}}_{t} + a_{6}\mathbf{\hat{u}}_{t})$$
$$\Delta \tilde{\mathbf{P}}_{t+\Delta t} = \tilde{\mathbf{P}}_{t+\Delta t} - (\tilde{\mathbf{M}}\mathbf{\hat{u}}_{t} + \tilde{\mathbf{C}}\mathbf{\hat{u}}_{t} + \tilde{\mathbf{K}}\mathbf{\hat{u}}_{t} + \mathbf{f}_{t})$$

3. Solve for displacements at time  $t + \Delta t$ :  $\mathbf{K}^* \Delta \mathbf{u}_{t+A} = \mathbf{P}_{t+A}^*$ 

4. Update the state of motion at time  $t + \Delta t$ :

$$\ddot{\mathbf{u}}_{t+\Delta t} = \ddot{\mathbf{u}}_{t} + a_{1} \Delta \tilde{\mathbf{u}}_{t+\Delta t}^{t} - a_{2} \dot{\mathbf{u}}_{t} - a_{3} \ddot{\mathbf{u}}_{t}; \quad \dot{\mathbf{u}}_{t+\Delta t} = \dot{\mathbf{u}}_{t} + a_{4} \Delta \tilde{\mathbf{u}}_{t+\Delta t}^{t} - a_{5} \dot{\mathbf{u}}_{t} - a_{6} \dot{\mathbf{u}}_{t}; \quad \tilde{\mathbf{u}}_{t+\Delta t} = \tilde{\mathbf{u}}_{t} + \Delta \tilde{\mathbf{u}}_{t+\Delta t}^{t}$$

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  $\Delta f_{t+\Delta t}^{t+1}$ .

7. Compute

$$Error = \frac{\|\Delta f_{i+\Delta i}^{i+1} - \Delta f_{i+\Delta i}^{i}\|}{Ref. \operatorname{Max} . Moment}$$

Where  $\|.\|$  is the euclidean norm 8. If Error  $\geq$  tolerance, further iteration is needed, iterate starting form step B-1 and use  $\Delta f_{r+\Delta r}^{r+1}$  as the pseudo-force and the state of motion at time t,  $\tilde{\mathbf{u}}_{r}$ ,  $\tilde{\mathbf{u}}_{r}$  and  $\tilde{\mathbf{u}}_{r}$ .

9. If Error  $\leq$  tolerance, no further iteration is needed, update the nonlinear force vector:

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

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.

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#### **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

$$F = \begin{cases} \frac{K_1U}{(K_2 - K_1)} \frac{(U - D_1)^2}{2} sgn(U) + K_1U & , & U \le D_1 \\ \frac{(K_1 - K_2)(D_1 + D_2)}{2} sgn(U) + K_2U & , & U > D_2 \end{cases}$$
(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

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

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

$$F_{x} = F \cos \theta, \qquad F_{y} = F \sin \theta$$
 (4.3)

where

$$\theta = \theta^*$$
 when  $U_x$ ,  $U_y > 0$  (4.4a)

$$\theta = \theta' + \pi/2$$
 when  $U_x < 0$ ,  $U_y > 0$  (4.4b)

 $\theta = \theta' + \pi$  when  $U_x$ ,  $U_y < 0$  (4.4c)



Figure 4-1 Model of Stiffening Bilinear Spring.

$$\theta = -\theta^*$$
 when  $U_x > 0$ ,  $U_y < 0$  (4.4d)

 $\theta = \pi/2$  and  $U = U_y$  when  $U_x = 0$  (4.4e)

$$\theta = 0$$
 and  $U = U_x$  when  $U_y = 0$  (4.4f)

and

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

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

$$F_x = Q Z_x + F_{xx}, \qquad F_y = Q Z_y + F_{yx}$$
 (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.

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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

$$Q = \frac{\pi \beta K_1 U}{2 - \pi \beta}$$
(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).

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

4-6



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  $U_x = 2U_0 \sin(2\pi ft), U_y = U_0 \cos(2\pi ft), f = 0.5Hz, U_0 = 120mm$ .

## 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

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

in which R is the radius of curvature of the spherical sliding surface, N is the normal load and  $\mu_r$ , 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<sub>i</sub>. To reduce computational effort, all the linear elastic elements may be combined in a global element described by translational stiffnesses  $K_x = K_y = \Sigma W_i/R$  ( $\Sigma W_i$  =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

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

where  $W_i$  is the weight,  $\dot{U}_v$  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<sub>i</sub> 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).

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

$$F_x = \frac{N}{R}U_x + \mu_s NZ_x, \qquad F_y = \frac{N}{R}U_y + \mu_s NZ_y$$
 (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<sub>OM</sub> (eq. 4.10), the model collapses to the original constant normal load (N=W<sub>i</sub>) 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  $O_{-\frac{1}{2}}O$ 

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

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

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

$$F_{y} = C_{y} \left| \dot{U}_{y} \right|^{\alpha} sgn(\dot{U}_{y})$$

$$(4.14)$$

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  $\alpha$  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.

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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

$$\mu_{s} = f_{\max} - (f_{\max} - f_{\min}) \exp(-a |\dot{U}|)$$
(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  $f_{max}$  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 independent 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/MAINI / 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 expression

$$f_{\max} = f_{\max 0} - (f_{\max 0} - f_{\max p}) \tanh(\varepsilon_p)$$
(4.16)

where p is the pressure,  $f_{maxp}$  is the maximum coefficient of friction at very high pressures,  $f_{maxp}$ is the vakue of the coefficient at zero pressure,  $\varepsilon$  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 :  $f_{max0}=0.12$ ,  $f_{maxp}=0.05$ ,  $\varepsilon=0.012$  (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<sup>2</sup> 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 :  $f_{max0} = 0.12$ ,  $f_{maxp} = 0.05 f_{min} = 0.04$ ,  $\varepsilon = 0.012$  (*MPa*)<sup>-1</sup> and a = 0.0429 s/mm. The bearing pressure under

$$\mathbf{\partial}_{\mathcal{M}}$$



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

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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 SOOE 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.

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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 SOOE 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<sup>3</sup>, for steel 490 lb/ft<sup>3</sup> and for concrete 150 lb/ft<sup>3</sup>. 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.





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.

5-3



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.

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The properties for each bearing are

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

# 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  $C_{707AL}$ =43.32 kip-s/in. Thus, for a SDOF system with  $K_{707AL}$ =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

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

where  $\alpha=0.5$  and  $C_N=26.67$  kip(s/in)<sup>1/2</sup>. 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  $\alpha$  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.

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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)<sup>1/2</sup> 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.

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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.

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#### 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,

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- (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.

ISOLATION SYS- TEM	TYPE OF ANALY- SIS	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 <sup>1</sup> (in/s, kips)
High Damping Rubber Bearing	Without Vertical Motion and Overturn- ing 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 Overturn- ing 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 Overturn- ing 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 <sup>2</sup> 184.40 <sup>3</sup>
Low Damping Rubber-Nonlinear Fluid Damper	Without Vertical Motion and Overturn- ing 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 Overturn- ing 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	[439.0	7228.0	40.72 9.97	

# Table 5-I Summary of Dynamic Analysis Results

<sup>1</sup> Force of one damper, <sup>2</sup> At artificial (without stiffness) bearings, <sup>3</sup> Calculated from velocity

5-14



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

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

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

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# **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) = Num!	per of floors of	superstructure	excluding base.	(If NF<1	then NF s	set = 1	)
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- 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	)
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- 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 $\theta$ Direction (Input only if ISEV = 1)

NF cards ST(I),I=1,NF

- $ST(I) = Torsional stiffness of story I in the <math>\theta$  direction about the center of mass of the floor.
- Note: 1. Torsional stiffness of each story in the  $\theta$  direction starting from the top story to the first story.

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## **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 I<sup>th</sup> mode.

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

2. Eigenvalues are frequencies squared ( $\omega^2$  in rad<sup>2</sup>/s<sup>2</sup>)

# **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 K<sup>th</sup> floor of eigenvector of J<sup>th</sup> 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  $(\Phi^T M \Phi = \{1\})$ .

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# **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 co	orresponding to mode	٤L
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Note: 1. Input from the first mode to the NE mode.

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

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

- XN(I) = Distance of the center of mass of the floor I from the center of mass of the base in the X direction.
- YN(I) = Distance of the center of mass of the floor I from the center of mass of the base in the Y direction. (If ISEV = 1 then XN(I) and YN(I) set 0)

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

# **B.7 Height of the Base and Different Floors**

NF+1 cards H(I),I=1,NF+1

H(I) = Height from the ground to the floor I.

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

# **C.1 ISOLATION SYSTEM DATA**

# C.2 Stiffness Data for Linear Elastic Isolation System

# One card SXE,SYE,STE,EXE,EYE

- SXE = Resultant stiffness of linear elastic isolation system in the X direction.
- SYE = Resultant stiffness of linear elastic isolation system in the Y direction.
- STE = Resultant tortional stiffness of linear elastic isolation system in the  $\theta$  direction about the center of mass of the base.
- EXE = Eccentricity of the center of resistance of the linear elastic isolation system in the X direction from the center of mass of the base.
- EYE = Eccentricity of the center of resistance of the linear elastic isolation system in the Y direction from the center of mass of the base.
- Note: 1. Data for linear elastic elements can also be input individually (refer to C.5.1).
  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  $\theta$  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.

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#### **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<sub>max</sub> 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.

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# **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).

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# 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.

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# 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 t'e 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<sub>1</sub> (see Equation 4.1);
- ALP(K,5) = Tangent stiffness K<sub>2</sub> (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 EARTHOUAKE 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(1,2),I=1,LOR

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

## E.1 OUTPUT DATA

# **E.2 Output Parameters**

Une 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

- 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.

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**APPENDIX B** 

INPUT-OUTPUT OF 3D-BASIS-ME

0.01

# HIGH DAMPING RUBBER BEARING SYSTEM

# WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

52 IMPROVED DAMPIN	Q RUBBER BE	ARINGS OCT2
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		
0.0		
0.0		
42.24784		
1700000.00000		
0.005 0.005 0.005		
0.0		
284.40. 18.00		
46716.90		
46716.90		
6618227.50		
0.0		
31.07037		
1700000.00000		
0.02 0.02 0.02		
0.0		
0.0		
9.90109		
427528.00000		
00000		
-834.96 0.00		
0.00 820.55		
-14.40 0.00		
3 7		
85.735 48,425 96.	85 11.40	11.88 0.57
3 7 45 735 48 425 06	85 11 40	11 88 0 57
3 7	•••	
85.735 48,425 96	85 11.40	11.88 0.57
85.735 48.425 96.	.85 11.40	11.88 0.57
342.84 193.7 387	7.4 11.40	11.88 0.57
021		
12345		
T		
-14.40 0.00		

INPUT

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#### HAVEX.DAT

-0.30719E+01	-0.10240 <b>5</b> +02	-0.480482+01	0.102002+02	-0.26356E+01
-0.819182+01	0.120518+02	-0.131618+02	-0.134302+02	0.146118+02
-0.116188+02	-0.134308+02	0.142578+02	-0.980652+01	-0.72072 <b>5</b> +01
0.14532E+02	0.122482+02	-U.56712E+01	-0.27362E+01	0.575008+01
-0.14170E+01	0.15753E+01	ù.207558+02	0.110272+01	-0.281598+02
0.720722+01	0.405262+02	0.283178+02	0.46866E+01	-0.100038+02
-0.23394E+02	-0.17053E+02	0.63014E+00	0.17014 <b>2+0</b> 2	0.129978+02
0.905622+00	0.945208+00	-0.58681E+01	-0.23630 <b>2+01</b>	0.886132+01
0.16108E+02	-0.15753 <b>E</b> +01	-0.320588+02	-0.88219 <b>2+</b> 01	0.917642+01
0.40959X+01	0.36666E+02	0.313892+02	-0.16738E+02	-0.37139E+02
-0.10318E+02	0.476542+01	0.834938+01	0.227642+02	0.984592+01
• • • • • • • • • • • •				
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#### WAVEY.DAT

0.128785+02	0.22055E+01	-0.228428+01	-D.16935E+01	0.882192+01
0.31507 <b>E</b> +01	-0.20361 <b>5</b> +02	-0.16502E+02	0.46079E+01	0.787672+01
0.36233E+01	-0.14572E+02	-0.10122E+02	0.161872+02	0.196528+02
-0.669522+00	-0.949148+01	-0.267812+01	-0.244182+01	-0.135878+02
-0.149268+02	0.127215+02	0.295388+02	0.834932+01	-0.248512+02
-0.17526E+02	0.905828+01	0.17368E+02	-0.602578+01	-0.21779E+02
-0.243785+02	-0.104378+02	0.261908+02	0.506862+02	0.100822+02
-C.445828+02	-0.477728+02	-0.197318+02	0.878258+01	0.412348+02
0.38753X+02	-0.40563E+01	-0.36745E+02	-0.373752+02	-0.10673E+02
0.214648+02	0.27017E+02	0.393848+01	-0.225278+02	-0.352098+02
-0.29301E+02	0.67346E+01	0.46236E+02	0.478908+02	0.44897E+01
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- 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 , N. C. CONSTANTINOU AND A. N. REINHORN DEPARTMENT OF CIVIL ENGINEERING STATE UNIV. OF NEW YORK AT BUFFALO

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

VERSION 30-BASIS-ME, JANUARY 1993

DEVELOPED BY...P. C. TSOPELAS, N. C. CONSTANTINOU AND A. M. REINHORN DEPARTMENT OF CIVIL ENGINEERING

STATE UNIV. OF NEW YORK AT BUFFALD

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B-7

52 INPROVED DAMPING RUBBER BEARINGS

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

\* CONTROL PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

ND. 01	F BUILDINGS	2
NO. 01	F 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 1S DESIRED=	5
TIME STEP OF INTEGRATION (NEWMARK)= INDEX FOR TYPE OF TIME STEP=	0. <b>00500</b> 1
INDEX = 1 FOR CONSTANT TIME STEP INDEX = 2 FOR VARIABLE TIME STEP	
GAMA FOR NEWMARKS METHOD	0.50000
BETA FOR NEWMARKS NETHOD	0.25000
TOLERANCE FOR FORCE COMPUTATION	10.00000
REFERENCE NOMENT OF CONVERGENCE =	1.00000
MAX NUMBER OF ITERATIONS WITHIN T.S	500
INDEX FOR GROUND MOTION INPUT	2
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

	SUPERSTRUCTUR	1E : 1				
53	STIFFNES	S DATA				
Ċ	STIFFNESS (T Level	HREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
	1	35.12000	35.12000	3659 , 00590	0.00001	0.00000
	SUPERSTRUCTUR LEVEL	TRANSL. MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
	1	42.24794	1700000.00000	0.00000	0.00000	
	SUPERSTRUCTUR Mode Shape	E DAMPING DAMPING RATID				
	1 2	0.00500 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

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

	STIFFNESS (TH Level	REE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
	1	46716.90000	46716.90000	66 18227 . 50000	0.00001	0.00000
	SUPERSTRUCTURE LEVEL	MASS TRANSL. MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
• 1	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

#### 

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

STIFFNESS OF LINEAR-ELASTIC SYS. IN	X DIR. = C	.00000
STIFFNESS OF LINEAR ELASTIC SYS. IN	Y DIR. = C	00000
STIFFNESS OF LINEAR ELASTIC SYS. IN	R DIR. = C	00000
ECCENT. IN X DIR. FROM CEN. OF MAS	\$= C	00000
ECCENT. IN Y DIR. FROM CEN. OF MAS	s= c	00000

- MASS AT THE CENTER OF MASS OF THE BASE .... TRANSL. MASS ROTATIONAL MASS
- MASS 9.90109 427528.00000

GLOBAL ISOLATI	ON DAMPING AT	THE CENTER OF N	ASS OF THE BASE 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 =

	ELEMENT FORCE-DISP CHR. STRENGTH	LACEMENT LOOP	PARAMETERS K 2	D1	D2	VIELD 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

1

#### \*\*\*\*\*\*\*\*\*\*\*\* OUTPUT PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*

TIME HISTORY OPTION .....

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

NO. OF TIME STEPS AT WHICH TIME HISTORY 2 ACCELERATION-DISPLACEMENTS PROFILES OPTION .. = INDEX = O 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 PERIOO 1 0.389307E+01 0.318444E+01 0. 162038E+00 0.150358E+04 2 0.150358E+04 0.162038E+00 3 MODE SHAPES LEVEL 2 1 -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 9.315 0.4041E+02 4.735 -. 1209E+02 3.925 0.2539E-03 1 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 MAX DISPL Y MAX RES. DISPL. SQRT(DX12+DY12) ISOLATOR TIME X DIRECT Y DIRECT TIME X DIRECT Y DIRECT TINE DISPLACEMENT 5.565 -. 1780E+02 -. 7321E+01 3.915 -. 1564E+02 -. 8738E+01 5.570 0.19252+02 1 5.565 -.1798E+02 -.7502E+01 3.915 -. 1585E+02 -. 8949E+01 5.575 O.1949E+O2 2 5.565 -.1780E+02 -.7678E+01 3.915 -. 1564E+02 -. 9153E+01 5.575 Q. 1939E+O2 3 5.565 - 17622+02 - 75022+01 3.915 -. 1544E+02 -. 8949E+01 5.570 0.1916E+02

**B-1** 

MAXIMUM BEARING VELOCITIES

	MAX VELOCITY X	MAX VELOCITY Y	MAX RES. VELOCITY SQRT(VX+2+VY+2)
I SOLATOR	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	SORT(FX12+FY12)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME FORCE	
1	5.5551266E+045444E+03	3.895 1068E+04 6427E+03	5.565 0.1380E+04	
2	5.5551283E+045598E+03	3.900 1080E+046615E+03	5.565 0.1403E+04	
3	5.5551266E+045737E+03	3.910 1033E+04 6760E+03	5.565 0.1392E+04	
4	5.5551248E+045589E+03	3.9051023E+046576E+03	5.565 0.1369E+04	
5	5.5555063E+04 .2236E+04	3.9004231E+042637E+04	5.565 0.5544E+04	

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS

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B-12
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- SUPERSTRUCTURE: 1 J 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

 $\odot$ 

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

Y

MAXIMUM BASE DISPLACEMENT IN X DIRECTION TIME : 5.565

SUPERSTRUCTURE : 1 X

LEVEL	015P	ACCEL	DISP	ACCEL
1	12.6955	- 10 . 2606	5.3307	-4.4877
BASE	-17.7974	252 . 2362	~7.5024	113.4474
SUPERS	TRUCTURE :	2	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

	INGCIONC .	•				
	X		¥			
LEVEL	DISP	ACCEL	DISP	ACCEL		
1	28.1312	-23.2372	7.6564	-6.2798		
BASE	-15.6448	210.4397	-8.9492	130.3809		
SUPERS	TRUCTURE :	2				
	X	¥				
LEVEL	DISP	ACCEL	DISP	ACCEL		
1	-0.1513	226.5920	-0.0909	136.4874		
BASE	- 15 . 6448	210.4397	-8.9492	130.3809		

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

SUPERSTRUCTURE : 1

MAX ACCELERATION IN X DIRECTION TIME : 9.300

1	LEVEL	DISP	ACCEL	DISP	ACCEL
1	1	40. <b>3988</b>	-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

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TIMÉ : 5.545
```

LEVEL 1 BASE	DI5 -0. -17.	iP 17∝3 7337	ACCE 262.1 244.8	L 055 050	DISP -0.07 -7.34	747 111	ACCEL 112.65 108.31	42 66						
MAX A TIME	CCELER : J.	ATION 900	IN Y	DIRECT	TION									
LEVEL 1 BASE	DIS -0. -15.	P 1579 8107	ACCE 236.9 211.0	L 759 198	DISP -0.09 -8.92	) 19 285	ACCEL 138.24 126.19	70 89						
. MAXIN	UM STR	UCTURA		RS										
SUPERS 1 2	T. No	TIME 9.300 5.545	FDRC 1419 0.814	E X DE+04 4E+04	TIME 4.725 3.900	FORC 0.425 0.429	E Y OE+03 SE+04	TIME 3.67 4.69	Z 5 16 0 0 . 22	MQMENT 85E+01 91E+04				
í.														
. MAXIM TIME 5.55	JM BAS Forc 5 10	E SHEA E X 13E+05	RS TIME 3.900	FORCE 0521	y 14E+04	TIME 3.91	Z NO 015	MENT 52E+0	TIME 5 5.5	RES. 65 0.11	SHEAR 09E+0	SQRT ( 5	FX†2+FY†2	)
MAXIM	JM STO	RY SHE	ARS		•••									
SUPERS' LEVEL	TIME	RE : Forc	1 E X	TIME	FORCE	. <b>v</b>	TIME	z	MOMENT	TIME	RES.	SHEAR	SQRT(FX1	2+F¥12)
1	9.300	141	9E+04	4.725	0.4250	)E+03	3.675	16	85E+01	9.295	0.14	23E+04		
SUPERS LEVEL	TIME	RE : Forc	2 E X	TIME	FORCE	: <b>Y</b>	TIME	z	MOMENT	TIME	RES.	SHEAR	SQRT(FX1	2+FY12)
1	5.545	0.814	4E+04	3.900	0.4295	iE+04	4.690	0.22	91E+04	5.550	0.88	79E+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 -4.4987 3.7221 -12.0864 10.0587 1 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 -0.1743 262.1055 -0.0747 112.6542 1 BASE -17.7337 244.8050 -7.3411 108.3166 hà MAX STRUC SHEAR IN Y DIRECTION And TIME : 3.900 53 LEVEL DISP ACCEL DISP ACCEL 1 -0.1579 236.9759 -0.0919 138.2470 BASE -15.8107 211.0198 -8.9285 126.1969

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

MAXIMUM BASE SHEAR IN X DIRECTION TIME : 5.555

SUPERSTRUCTURE : 1

**B-15** 

X Y DISP ACCEL LEVEL DISP ACCEL 1 13.0038 - 10.5406 5.2631 -4.4421 BASE -17.7815 247.1465 -7.4272 110.0184 SUPERSTRUCTURE : 2 X ¥ DISP ACCEL LEVEL 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 LEVEL DISP ACCEL DISP ACCEL 28.3480 -23.4494 7.7809 -6.4016 1 BASE -15.8107 211.0198 -8.9285 126.1989 SUPERSTRUCTURE : 2 х Y LEVEL DISP ACCEL DISP ACCEL -0.1579 236.9759 -0.0919 138.2470 1 BASE -15.8107 211.0198 -8.9285 126.1989 1.4 B-16 \*\*\*\*\*\*\*\*\*\*\*\*\*\*FORCE PROFILES\*\*\*\*\*\*\*\*\*\* 100 " " MAX OVERTURNING MOMENT X DIRECTION MAX STRUCTURAL SHEAR X DIRECTION TIME MAX STUCTURAL SHEAR SUPR/STURE TIME OVERTURNING MOMENT 1 9.300 -403689.7058 9.300 -1419.4434 FLOOR INERTIA FORCES INERTIA FORCES -1419.4434 -1419.4434 1 1018.1382 FORCE AT C.M. OF ENTIRE BASE BASE 1018.1382 OVERTURNING MOMENT SUPR/STURE TIME TIME MAX STUCTURAL SHEAR 5.545 1714089.1752 5.545 8143.7152 2 FLOOR INERTIA FORCES INERTIA FORCES 8143.7152 8143.7152 4 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 424.9596 424.9596 1 -1223.3757 -1223.3757 FORCE AT C.M. OF ENTIRE BASE BASE

SUPR/STURE 2	TIME 3.900	OVERTURNING NOMENT 904092.6905	TIME 3.900	MAX STUCT	URAL SHEAR 4295.3853			
FLOOR 1 BASE		INERTIA FORCES 4295.3853 1249.5070		INERTIA	FORCES 4295.3853 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 CODR : -834.960
           Y CODR : 0.000
    COLUMN LINES
   1
LEVEL TIME X DIR TIME Y DIR TIME X DIR TIME
1 9.315 0.1517E+00 4.735 0.4470E-01
                                                                 Y DIR TIME
                                                                                   X DIR TIME
                                                                                                    Y DIR
   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
1 -
ς :
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B-17
## 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 10 Kips/10\*sect2 secs 1 2 9 9 386.22 1 3 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 0.0 284.40, 18.00 46716.90 46716.90 6618227.50 0.0 0.0 0.0 31.07037 170000.00000 0.02 0.02 0.02 0.0 210.48, 18.00 0 0 0 0 8.50109 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 0.00 806.16 0.00 -14.40 820.56 0.00 -495.48 0.00 495.48 -500.88 0.00 481.08 0.00 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 1 198.38 198.38 021
123456759 1 -834.96 0.00 1 -14.40 0.00

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### WAVEX . DAT

-0.30719 <b>E+</b> 01	-0.102402+02	-0.480482+01	0.10200E+02	-0.283568+01
-0.81918E+01	0.12051E+02	-0,101612+02	-0.13430E+02	0.146118+02
-0.1161#E+02	-0.13430E+02	0 142578+02	-0.98065E+01	-0.720722+01
0.14532E+02	0.122488+02	-0.567128+01	-0.279628+01	0.575008+01
-0.1417#E+01	0.157538+01	0.207558+02	0.110278+01	-0.281592+02
0.72072E+01	0.40526E+02	0.283176+02	0.46866E+01	-0.100035+02
-0.233942+02	-0.17053E+02	0.630142+00	0.17014E+02	0.12997E+02
0.905822+00	0.945202+00	-0,58681E+01	-0.236308+01	0.886138+01
0.1610#E+02	-0.15753 <b>B+01</b>	-0.320588+02	-0.082192+01	0.91764E+01
0.40959 <b>8</b> +01	0.36666 <b>8+</b> 02	0.313892+02	-0.167382+02	-0.371392+02
-0.1031# <b>E</b> +02	0.47654E+01	0.834932+01	0.22764E+02	0.98459E+01
••••				

## NAVEY . DAT

0.12876 <b>5</b> +D2	0.220552+01	-0,228428+01	-0.16935E+01	0.882198+01
0.31507E+01	-0.203612+02	-0.165022+02	0.460792+01	0.787678+01
0.36233E+01	-0.145722+02	-0.101228+02	0.161878+02	0.196522+02
-0.669528+00	-0.94914E+01	-0.267018+01	-0.244185+01	-0.135878+02
-0.14926 <b>2</b> +02	0.12721E+02	0.295388+02	0.83493E+01	-0.248518+02
-0.17526E+02	0.905822+01	0.173682+02	-0.602578+01	-0.21779E+02
-0.24376E+02	-0.10437E+02	0.261905+02	0.506862+02	0.100828+02
-0.445828+02	-0.47772E+02	-0.197318+02	0.878252+01	0.41234E+02
0.387538+02	-0.40565E+01	-0.367458+02	-D.373758+02	-0.10673E+02
0.214642+02	0.27017E+02	0.393842+01	-0.225278+02	-0.35209E+02
-0.29301 <b>E</b> +02	0.673462+01	0.462368+02	0.478902+02	0.448972+01
••••				
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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. N. REINHORN
           DEPARTMENT OF CIVIL ENGINEERING
           STATE UNIV. OF NEW YORK AT BUFFALO
NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
STATE UNIVERSITY OF NEW YORK, BUFFALD
VERSION 3D-BASIS-ME, JANUARY 1993
DEVELOPED BY ... P. C. TSOPELAS, N. C. CONSTANTINOU AND A. M. REINHORN
           DEPARTMENT OF CIVIL ENGINEERING
           STATE UNIV. OF NEW YORK AT BUFFALD
52 LOW DAMPING RUBBER BEAR. + 24 LINEAR FLUID DAMPERS
```

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

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\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* CONTROL PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*

NO.	OF	BUILDINGS*	2
NO.	OF	ISOLATORS	9
INDE	ΧI	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)= INDEX FOR TYPE OF TIME STEP=	0.00500 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	
TNDEX # 2 FOR X & Y DIR INPUT	
INDEX = 3 FOR X & 7 DIR INPUT	
INDEX & A FOD Y YA 7 DID INDUT	
THER - 4 TOR A , TO E DIR. THEOT	
TIME STEP OF RECORD .	0.02000
LENGTH OF DECORD	2000
LAND EACTOR	1 00000
	0.00000
APRILE OF EARINGUANE INCLUENCE	0.0000

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SUPERSTRUCTURE : 1

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

استداد ∼ ۲	STIFFNESS (TH	REE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
	1	35.12000	35.12000	3659.00590	0.00001	0.00000
	SUPERSTRUCTURE LEVEL	MASS TRANSL. MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
	1	42.24794	1700000.00000	0.00000	0.00000	
	SUPERSTRUCTURE	DAMPING Damping Ratio				

1 0.00500 2 0.00500

3 0.00500

HEIGHT..... HEIGHT LEVEL

> 1 284.400

18.000 0

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
- t Y 0.0000000 0.0000000 0.1538499
- 1 R 0.0007670 0.0000000 0.0000000

SUPERSTRUCTURE : 2

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## .....STIFFNESS DATA.....

STIFFNES: Level	S (THREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
1	46716.90000	46716.90000	6618227.50000	0.00001	0.00000
SUPERSTRU	CTURE 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

0.02000 1 0.02000 2 3

# HEIGHT....HEIGHT

210.480 1

0

#### \*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* ISOLATION SYSTEM DATA \*\*\*\*\*\*\*\*\*\*\*\*

### STIFFNESS DATA FOR LINEAR-ELASTIC ISDLATION SYSTEM......

STIFFNESS OF	LINEAR-E	LASTIC SYS.	IN X DIR.	•	0.00000
STIFFNESS OF	LINEAR E	LASTIC SYS.	IN Y DIR.	•	0.00000
STIFFNESS OF	LINEAR E	LASTIC SYS.	IN R DIR.	-	0.00000
ECCENT. IN	( DIR. F	ROM CEN. OF	MAS5	-	0.00000
ECCENT. IN 1	Í DIR. F	ROM CEN. OF	MASS		0.00000

- MASS AT THE CENTER OF MASS DF THE BASE .... TRANSL. MASS ROTATIONAL MASS
- MASS 9.90109 427528.00000

GLOBAL ISOLATION DAMPING AT THE CENTER OF MASS OF THE BASE					
	x	¥	R	ECX	ECY
DAMPING	7.65000	7.65000	2374932.00000	0.00000	0.00000

Β	ISOLATORS	LOCATION	INFORMATION
26	ISOLATOR	X	Y
-	1	-834.9600	0.0000
	2	0.0000	-820.5600
	3	806.1600	0.0000
	4	0.0000	820.5600
	1.5	-14.4000	0.0000
	6	-509.8800	0.0000
	[ <b>1</b> 7	0.0000	-495.4800
	KU 8	481.0800	0.0000
	9	0.0000	495.4800

....ELEMENT TYPE -

1

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

10.83000	10.83000	1.00000
10.83000	10.83000	1.00000
10.83000	10.83000	1.00000
10.83000	10.83000	1.00000
	10 - 83000 10 - 83000 10 - 83000 10 - 83000 10 - 83000	10.83000       10.83000         10.83000       10.83000         10.83000       10.83000         10.83000       10.83000

#### \*\*\*\*\*\*\*\*\*\*\*\* OUTPUT PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*\*

```
TIME HISTORY OPTION ......
                                              1
INDEX = O FOR NO TIME HISTORY OUTPUT
INDEX + 1 FOR TIME HISTORY OUTPUT
NO. OF TIME STEPS AT WHICH TIME HISTORY
2
ACCELERATION-DISPLACEMENTS PROFILES OPTION .. =
                                              4
INDEX . O FOR NO PROFILES OUTPUT
INDEX = 1 FOR PROFILES OUTPUT
FORCE-DISPLACEMENT TIME HISTORY DESIRED
AT ISOLATORS NUMBERED.....=
                                      2
                                          3
                                  1
                                              4
                                                  5
                                      7
                                          8
                                              9
                                  6
```

#### 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	O. 150358E+04	0.162038E+00

#### MODE SHAPES

LE	VEL		- 1	:	2	3
	1	x	0.0000000	0. 1794018	0.0000000	
tin. Kin	1	¥	0.0000000	0.0000000	0.1794018	
	1	8	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 9.890 0.3776E+02 4.780 -.7885E+01 3.925 0.1870E-03 1

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. SORT(DX+2+DY+2)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME DISPLACEMENT
1	3.8501111E+025784E+01	3.905 1079E+02 5939E+01	3.860 0.1253E+02
2	3.850 - 1125E+02 - 5932E+01	3.9051094E+026094E+01	3.860 O. 1273E+O2
3	3.850 -, 1111E+02 -, 6074E+01	3.905 1079E+02 6244E+01	3.860 0.1267E+02
Ā	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	3.9051088E+026094E+01	3.860 0.1268E+02
8	3.850 1111E+02 6017E+01	3.9051079E+026184E+01	3.860 0.1265E+02
9	3.850 1102E+02 5932E+01	3,905 1070E+02 6094E+01	3.860 0.1253E+02

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#### MAXIMUM BEARING VELOCITIES

	MAX VELOCITY X	MAX VELDCITY Y	MAX RES. VELOCITY SQRT(VX12+VY12)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME VELOCITY
4	3.4655122E+02 1990E+02	3.5954099E+022870E+02	3.450 0.5507E+02
2	3.4655182E+022050E+02	3.5954166E+02 -/2938E+02	3.450 0.5588E+02
3	3.4655122E+022109E+02	3.595 - 4099E+02 - 3004E+02	3.445 0.5555E+O2
4	3.4655063E+022050E+02	3.5954032E+022938E+02	3.450 0.5475E+02
5	3.4655122E+022049E+02	3.5954099E+022937E+02	3.450 0.5531E+02
6	3.4655122E+022013E+02	3.5954099E+022897E+02	3.450 0.5517E+02
7	3.4655158E+022050E+02	3.5954140E+022938E+02	3.450 0.5565E+02
. 8	3.4655122E+022085E+02	3.5954099E+022977E+02	3.450 0.5545E+02
2 <b>5</b> 9	3.4655086E+022050E+02	3.5954059E+022938E+02	3.450 0.5497E+02

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#### 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	
· •	3.8505508E+032868E+03	3.90553528+0329458+03	3.860 0.6216E+03	
2	3.850 - 5580E+03 - 2942E+03	3,9055428E+033022E+03	3.860 0.6315E+03	
Э	3.8505508E+033013E+03	3.9055352E+033097E+03	3.860 0.6285E+03	
4	3.8505436E+032942E+03	3.9055276E+033022E+03	3.860 0.61876+03	
5	3,8502203E+041176E+04	3.9052141E+041208E+04	3.860 0.2500E+04	
6	3.4705547E+032166E+03	3.6004401E+033136E+03	3.450 0.5974E+03	
7	3.4705585E+032205E+03	3.6004445E+033181E+03	3.450 0.6027E+03	
8	3.4705547E+032243E+03	3.6004401E+033224E+03	3.450 0.6006E+03	
9	3.4705508E+032205E+03	3.6004357E+033181E+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 -. 31392+02 4.765 0.65572+01 3.170 0.55922-06

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

LEVEL	DISP	ACCEL	DISP	ACCEL
1	23.1487	- 19. 1878	5.1369	-4.2166
BASE	-11.1062	126.9532	-5.9316	68.4944
SUPERS	TRUCTURE :	2		
	X		¥	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	-0.0851	127.6845	-0.0463	69.5495
BASE	-11.1062	126.9532	-5.9316	68.4944

MAXINUM BASE DISPLACEMENT IN Y DIRECTION TIME : 3.905 SUPERSTRUCTURE : 1 X ¥ LEVEL DISP ACCEL DISP ACCEL 22.6028 -18.6650 4.7075 -3.8247 1 BASE -10.7910 110.4702 -6.0943 64.0398 SUPERSTRUCTURE : 2 X ¥ ACCEL LEVEL DISP ACCEL DISP -0.0740 110.8643 1 -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.

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SUPERSI	RUCTURE :	1		
MAX AC TIME	CELERATION : 9.880	IN X DIRE	CTION	
LEVEL	DISP 27 7611	ACCEL	DISP	ACCEL
BASE	2.8223	-8.1532	0.1258	-7.7618
MAX AC TIME	CELERATION : 4.765	IN Y DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
1 BASE	3.5186 7.6046	-2.9080 -62.1106	-7.8803 3.8444	6.5571 -48.8624
SUPERSI	RUCTURE :	2		
NAX AQ TIME	CELERATION : 3.740	IN X DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
1 BASE	-0.0976 -9.7787	146 . 7578 141 . 5995	-0.0463 -4.6387	69.6603 71.8017
MAX AC TIME	CELERATION : 3.785	IN Y DIRE	CTION	
LEVEL	DISP	ACCEL	DI SP	ACCEL
BASE	-10.6610	140.6156	-5.3194	73.5688 69.2991

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.MAXIMUM	STRI	JCTURAL	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	Q. 2286E	+04	3.895	1710E+04	ł

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.MAXIMUM BASE SHEARS...... TIME FORCE X TIME FORCE Y TIME Z MOMENT TIME RES. SHEAR SQRT(FX12+FY12) 3.740 ~.51542+04 3.160 0.28242+04 8.515 0.49412+04 3.750 0.58212+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(FX12+FY12)

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

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MAX STRUC SHEAR IN X DIRECTION
TIME : 9.880
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}.mi	LEVEL 1 BASE	DISP 37.7621 2.8223	ACCEL -31.3932 -8.1532	DISP -4.7726 0.1258	ACCEL 4.0137 -7.7618
	MAX ST TIME	RUC SHEAR : 4.765	IN Y DIREC	T10N	
	LEVEL	DISP 3 5186	ACCEL	DISP -7 8803	ACCEL
	BASE	7.6046	-62.1106	3.8444	-48.8624

SUPERSTRUCTURE : 2

MAX STRUC SHEAR IN X DIRECTION TIME : 3.740

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LEVEL	DISP	ACCEL	DISP -0.0462	ACCEL
BASE	-9.7787	141.5995	-4.6387	71.8017
	_			
	DINC CMEAD :	IN V DIGERY	11041	
TIME	RUC SHEAR 1 : 3.785	IN Y DIRECT	LION	
TIME	RUC SHEAR : : 3.785 DISP	IN Y DIREC'	DISP	ACCEL
TIME	RUC SHEAR : : 3.785 DISP -0.0945	IN Y DIREC' Accel 142.0019	DISP -0.0489	ACCEL 73.5698

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

MAXIMUM BASE SHEAR IN X DIRECTION TIME : 3.740

SUPERST	RUCTURE :	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
SUPERST	RUCTURE :	2		
	X		Ŷ	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	-0.0976	146.7578	-0.0463	69.6603
BASE	-9.7787	141.5995	-4.6387	71.8017
	RASE SHEAR	TN Y DIR	ECTION	

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
SUPERST	RUCTURE :	2		
	X		¥	
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

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SUPR/STURE	TIME	OVERTURNING NOMENT	TIME MAX STUCTURAL SHEAR
1	9.880	~377 199 . 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
•	MX OVER	TURNING MOMENT Y DIRECTION	MAX STRUCTURAL SHEAR Y DIRECTION
SUPR/STURE	T I NE	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
5UPR/STURE ជ្រ 2 យ	TIME 3.785	OVERTURNING MOMENT 481124.0512	TIME MAX STUCTURAL SHEAR 3.785 2285.8421
FLOOR		INERTIA FORCES	INERTIA FORCES
1		2285.8421	2285.8421
BASE		686.1370	686.1370 Force at C.M. DF 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 : -834.960 Y COOR : -834.960 Y COOR : -834.960 Y COOR : -0.000 COLUMN LINES 1 LEVEL TIME X DIR TIME Y DIR TIME X DIR TIME X DIR TIME X DIR TIME Y DIR 1 9.880 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

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

1

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

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INPUT

## WAVEX .DAT

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		A 484488-41		
-0.30/19 <b>8</b> +01	-0.102408404	-0.40040E+UI	0.102006+02	-0.383302401
-0.81918 <b>8</b> +01	0.120515+02	-0.10161E+02	-0.13430 <b>E</b> +02	0.146118+02
-0.11618E+02	-0.13430 <b>E+02</b>	0.142572+02	-0.94065E+01	-0.720728+01
0.145328+02	0.122488+02	-0.567128+01	-0.279622+01	0.575008+01
-0.14178E+01	0.15753E+01	0.207558+02	0.11027E+01	-0.281592+02
0.72072E+01	0.40526E+02	D.28317E+02	0.46866E+01	-0.10003 <b>2</b> +02
-0.23394 <b>8</b> +02	-0.17053 <b>E</b> +02	0.630142+00	0.170148+02	0.129978+02
0.905822+00	0.945202+00	-0.586818+01	-0.23630E+01	0.086132+01
0.161086+02	-0.15753 <b>E</b> +01	-0.32058E+02	-0.882195+01	0.917642+01
0.409598+01	0.366668+02	0.31389E+02	-0.16738E+02	-0.37139 <b>5+0</b> 2
-0.1031 <b>8E+02</b>	0.476548+01	D.83493E+01	0.22764E+02	Q.98459E+Q1
• • • • • • • • • • • •				

## WAVEY.DAT

0.128788+02	0.220552+01	-0.228428+01	-0.16935E+01	0.882192+01	
0.31507 <b>2</b> +D1	-0.20361 <b>E</b> +02	-0.16502E+02	0.46079E+01	0.787672+01	
0.362338+01	-0.145722+02	-0.10122E+02	0.161875+02	0.196528+02	
-0.669522+00	-0.949142+01	-0.26781E+01	-0.24418E+01	-0.13587E+02	
-0.14926E+02	0,127212+02	0.295366+02	0.834938+01	-0.248518+02	
-0.17526E+02	0.905822+01	0.173682+02	-0.50257E+01	-0.21779 <b>E+0</b> 2	
-0.24378E+02	-0.104378+02	0.261902+02	0.50686X+02	0.100828+02	
-0.445828+02	-0.47772E+02	-0.19731E+02	Q. 87825E+01	0.412342+02	
0.387538+02	-0,405658+01	-0.367458+02	-0.373758+02	-0.10673E+02	
0.214642+02	0,27017E+02	0.393842+01	-0.225272+02	-0.35209 <b>2+0</b> 2	
-0.29301E+02	0.673462+01	0.462362+02	0.478908+02	0.448978+01	
• • • • • • • • • • • • •					
• • • • • • • • • • • •					

120

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PROGRAM 3D-BASIS-N..... A GENERAL PROGRAM FOR THE NONLINEAR
Dynamic Analysis of three dimensional base isolated
multiple building structures
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DEVELOPED BY.;.P. C. TSOPELAS, S. NAGARAJAIAH , M. C. CONSTANTINOU AND A. M. REINHORN Department of civil engineering State UNIV. Of New York At Buffald

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

VERSION 30-BASIS-ME, JANUARY 1993

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

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



B-40

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* 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) INDEX FOR TYPE OF TIME STEP	<b>0.00500</b> 1
INDEX = 1 FOR CONSTANT TIME STEP INDEX = 2 FOR VARIABLE TIME STEP	
GAMA FOR NEWMARKS METHOD	0.50000 0.25000 50.00000 1.00000 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 2000 1.00000 0.00000

1

	SUPERSTRUCTURE	: 1 DATA				
	STIFFNESS (TH	REE DIMENSIONAL STIFF X	SHEAR BUILDING) Stiff y	STIFF R	ECCENT X	ECCENT Y
		35.12000	35.12000	3659.00590	0.00001	0.00000
2]	SUPERSTRUCTURE LEVEL	MASS TRANSL, MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
	1	42.24794	1700000.00000	0.00000	0.00000	
$\zeta$	SUPERSTRUCTURE	DAMPING Damping Ratio				
	1 2	0.00500				

HEIGHT

LEVEL HEIGHT

> 284.400 1 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	O.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

521

### .....STIFFNESS DATA.....

STIFFNES LEVEL	S (THREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
1	46716.90000	46716.90000	5618227.50000	0.00001	0.00000
SUPERSTRU LEVEL	CTURE MASS TRANSL. MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
1	31.07037	1700000.00000	0.00000	0.00000	

T

SUPERSTRUCTURE DAMPING..... NODE SHAPE DAMPING RATIO

1	0.02000
2	0.02000
3	0.02000

210.480 1 0 18.000

#### 

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

STIFFNESS OF L	INEAR-ELASTIC	SYS. IN X DI	(R. =	396.76000
STIFFNESS OF L	INEAR ELASTIC	SYS. IN Y DI	IR. =	396.76000
STIFFNESS OF L	INEAR ELASTIC	SYS. IN R DI	(R. = 1232	70280.00000
ECCENT. IN X	DIR. FROM CEI	N. OF MASS	=	14.40000
ECCENT. IN Y	DIR. FROM CEN	N. 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					
	×	Y	R	ECX	ECY
DAMPING	50.97000	50.97000 130	010010.60000	14.40000	0.00000

1

1

2

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

2

MODE NUMBER	EIGENVALUE	PERIOD
t	0.389307E+01	0.318444E+01
2	0.150358E+04	0.162038E+00
3	0.150358E+04	0.162038E+00

1

NODE SHAPES

**B-4**3

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. SORT(DX12+DY12) ISOLATOR TIME X DIRECT Y DIRECT TIME X DIRECT Y DIRECT TIME DISPLACEMENT 3 0.000 0.0000E+00 0.0000E+00 0.000 0.0000E+00 0.0000E+00 0.000 0.0000E+00 1  $\sim$ MAXIMUM BEARING VELOCITIES MAX VELOCITY X MAX VELOCITY Y MAX RES. VELOCITY SORT(VX12+VY12) 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(FX12+FY12) 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

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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
  C TIME : 3.850
  14
     SUPERSTRUCTURE : 1
  ** 1
                    X
                                          Y
     LEVEL
              DISP
                        ACCEL
                                   DISP
                                              ACCEL
              23.1247 -19.1693
                                    5.1287
                                              -4.2100
       1
      BASE -11.0773 128.0581
                                    -5.9176
                                              67.4256
B-45
     SUPERSTRUCTURE : 2
                     x
                                          ¥
     LEVEL
              DISP
                                    DISP
                                              ACCEL
                        ACCEL
              -0.0843
                                    -0.0461
                                              69.3254
       1
                       126.4401
      BASE -11.0773 128.0581
                                              67.4256
                                    -5.9176
     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
SUPERS	RUCTURE :	2		
	X		Ŷ	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	-0.0740	110.8232	-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

	DISP	ACCEL	DISP	ACCEL
1	37.7935	-31.4193	-4.7617	4.0047
BASE	2.7896	-3.7790	0.1157	-7.2207
MAX AC	CELERATION	IN Y DIRE	CTION	
1196	: 4.770			
EVEL	DISP	ACCEL	DISP	ACCEL
1	3.5225	-2.9124	-7.8634	6.5410
BASE	1.2814	-00.4330	3.8376	-46.1184
UPERSI	RUCTURE :	2		
MAX AC TIME	CELERATION : 3.735	IN X DIRE	CTION	
EVEL	DISP	ACCEL	DISP	ACCEL
1	-0.0975	146.6272	-0.0462	69.5194
BASE	-9.6144	139.0588	-4.5405	70.9963
NAX AC TIME	CELERATION	IN Y DIRE	CTION	
	1			
EVEL	DISP	ACCEL	DISP	ACCEL
1 8455	-0.0938	140.0062	-0.0486	73.1071
DAGE	10.5507		0.2084	

.MAXIMUM BASE SHEARS.....

```
TIME FORCE X TIME FORCE Y TIME Z MOMENT TIME RES. SHEAR SQRT(FX12+FY12)
  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 SORT(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(FX12+FY12)
  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
```

6.5410

3.8376 -48.1184

-3

7.5914 -65.4995 BASE

1

3.5225

SUPERSTRUCTURE : 2

MAX STRUC SHEAR IN X DIRECTION TIME : 3.735

LEVEL DISP DISP ACCEL ACCEL

-2.9124

-7.8634

1	-0.0975	146.6272	-0.0462	69.5194	
BASE	-9.6144	139.0568	-4.5405	70.9963	
-					
- HEA 3	NUC SHEAK	IN 1 DIREC	1101		
LTMF	: 3.780				
I EVEI	DISP	ACCEL	DISP	ACCEL	
1	-0.0938	140 9062	-0.0486	73 1071	
BASE	-10 6507	143 2004	-5 7304	68 9791	
UNJE	10.0007	140.2004	J. 1384		
	2 AF TATAL	40051 FRATTO			
PROFILE	S OF TOTAL	ACCELERATION	N AND UISPLA	GEMENT AT T	THE OF
MAXIMU	I BASE SHEAI	IN X DIR	ECTION		
TIME :	3.735				
SUPERST	RUCTURE :	1			
	X		Y		
LEVEL	DISP	AGCEL	0150	AGGEL	
	22.7904	-19.0552	5.3075	-4.4373	
BASE	-9.6144	139.0588	-4.5405	70.9963	
		-			
SUPERSI	RUCIURE :	2	M		
		1005	•••••		
LEVEL	DISP	ACCEL	DISP	ACCEL	
1	-0.0975	145.6272	-0.0462	69.5194	
BASE	-0.6144	139.0588	-4.5405	70.9963	
MAXIMUM	I BASE SHEAF	EIN Y DIRE	ECTION		
TIME :	3.155				
SUPERST	RUCTURE :	1			

		X		¥	
•	LEVEL	DISP	ACCEL	DISP	ACCEL
	1	-0.6457	0. 1722	-1.9796	1.5830
ŗ	BASE	10.9257	- 104 . 66 14	5.1257	-70.5990
	SUPERST	RUCTURE :	2		
		X		Y	
	LEVEL	DISP	ACCEL	DISP	ACCEL
	1	0.0704	- 105 . 4977	0.0465	-69.8758
	BASE	10.9257	- 104 . 66 14	5.1257	-70.5990

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*FORCE PROFILES\*\*\*\*\*\*\*\*\*\*\*

M	AX OVERT	URNING MOMENT X DIRECTION	MAX S	TRUCTURAL SHEAR X DIRECTION
SUPR/STURE	TIME	OVERTURNING NOMENT	TIME MA	X STUCTURAL SHEAR
	9.880	-377512.6513	9.880	~1327.4003

MAX BASE SHEARS

FLOOR 1 BASE		INERTIA FORCES - 1327.4003 -37.4167	INERTIA FORCES - 1327 - 4003 - 37 - 4167	FORCE AT C.M. DF ENTIRE BASE
SUPR/STURE 2	T I ME 3.735	OVERTURNING MOMENT 958896.4609	TIME MAX STUCTURAL SHEAR 3.735 4555.7605	
FLOOR 1 BASE		INERTIA FORCES 4555.7605 1376.8334	INERTIA FORCES 4555.7605 1376.8334	FORCE AT C.M. OF ENTIRE BASE
M	IAX OVER	TURNING NOMENT Y DIRECTION	MAX STRUCTURAL SHEAR Y	DIRECTION
SUPR/STURE 1	TIME 4.770	DVERTURNING MOMENT 78592.7073	TIME MAX STUCTURAL SHEAR 4.770 276.3457	
FLOOR 1 BASE		INERTIA FORCES 276.3457 -476.4251	INERTIA FORCES 276.3457 -476.4251	FORCE AT C.M. OF ENTIRE BASE
SUPR/STURE 2	TIME 3.780	DVERTURNING MOMENT 478097.6979	TIME MAX STUCTURAL SHEAR 3.780 2271.4638	
U S FLOOR S BASE		INERTIA FORCES 2271.4638 682.9684	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 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

DIR \* TIME X DIR TIME Y DIR TIME X DIR TIME COLUMN LINES 1 LEVEL TIME X DIR TIME Y DIR 1 3.735 0.5066E-03 3.740 0.2252E-03

## LOW DAMPING RUBBER BEARING - NONLINEAR VISCOUS FLUID DAMPER SYSTEM

## WITHOUT VERTICAL GROUND MOTION AND OVERTURNING MOMENT EFFECTS

INPUT

```
52 LOW DAMPING RUBBER BEAR. + 24 NON-LINEAR DAMPERS
                                       Kips/in+sect2
                                                                                Secs
  10
1 2 9 9 386.22
1 3
i 3
0.0002 10 100 500 1
0.8 0.28
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
284.40, 18.00
46716.90
46716.90
45716.90
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
-834.95 0.00
0.00 -820.56
806.16 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

3 0 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
```

## HAVEX . DAT

-0.30719E+01	-0.10240 <b>E</b> +02	-0.480482+01	0.102005+02	-0.283562+01
-0.81918E+01	0.120512+02	•0.10161 <b>8+0</b> 2	-0.13430 <b>2</b> +02	0.146115+02
-0.116182+02	-0.134308+02	0.142578+02	-0.980652+01	-0.720728+01
0.145328+02	0.122488+02	-0.567128+01	-0.279628+01	0.575008+01
-0.141782+01	0.157538+01	0.207552+02	0.110278+01	-0.28159E+02
D.72072E+01	0.405268+02	0.283178+02	0.468662+01	-0.10003E+02
-0.233942+02	-0.17053 <b>8+0</b> 2	0.630148+00	0.17014B+02	0.129972+02
0.905828+00	0.945208+00	-0.58681E+01	-0.23630E+01	0.886138+01
0.16108E+02	-0.15753E+01	-0.32058E+02	-0.88219 <b>E</b> +01	0.917642+01
0.40959E+01	0.366668+02	0.31389E+02	-0.167382+02	-0.371392+02
-0.10318E+02	0.47654E+01	0.83493E+01	0.227642+02	0.984592+01

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## WAVEY.DAT

0.128785+02	0.22055E+01	-0.228428+01	-0.16935 <b>8+0</b> 1	0.882198+01
0.315078+01	-0.20361 <b>8</b> +02	-0.16502 <b>8+0</b> 2	0.460792+01	0.787672+01
0.362338+01	-0.14572E+02	-0.10122E+02	0.16187E+02	0.196528+02
-0.663522+00	-0.949148+01	-0.267818+01	-0.244182+01	-0.135878+02
-0.14926E+02	0.127218+02	0.295386+02	0.834938+01	-0.248518+92
-0.17526E+02	0.905828+01	0.173688+02	-0.602578+01	-0.217798+02
-0.243788+02	-0.10437E+02	0.261902+02	0.50686E+02	0.100822+02
-0.445828+02	-0.477722+02	-0.197318+02	0.878258+01	0.41234E+02
0.387538+02	-0.405658+01	-0.367452+02	-0.37375E+02	-0.10673E+02
0.214642+02	0.270175+02	0.393842+01	-0.22527E+02	-0.35209E+02
-0.29301E+02	0.673462+01	0.462362+02	0.47890E+02	0.448972+01
•••••				

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*******	***************************************
PROGRAM	3D-BASIS-M A GENERAL PROGRAM FOR THE NONLINEAR Dynamic Analysis of three dimensional base isolated Multiple building structures
DEVELOPE	D BYP. C. TSOPELAS, S. NAGARAJAIAH , N. C. CONSTANTINOU AND A. M. REINHORN Department of CIVIL Engineering State Univ. Of New York at Buffalo
NATIONAL State un	CENTER FOR EARTHQUAKE ENGINEERING RESEARCH Iversity of New York, Buffalo
*******	••••••••••••••••••••••••
	VERSION 30-BASIS-ME, JANUARY 1993
DEVELOPEI	D BYP. C. TSOPELAS, M. C. CONSTANTINOU AND A. M. REINHORN Department of civil engineering State Univ. Of New York at Buffalo
*******	
52 LOW (	DAMPING RUGBER BEAR. + 24 NON-LINEAR DAMPERS
UNITS LENGTH : MASS : TIME :	in Kips/in*sect2 secs
	INPUT DATA

NO. OF BUILDINGS	2
NO. OF ISOLATORS	9
INDEX FOR SUPERSTRUCTURE STIFFNESS DATA-	Ť

OUTPUT

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)= INDEX FOR TYPE OF TIME STEP=	0.00020 1
INDEX = 1 FOR CONSTANT TIME STEP INDEX = 2 FOR VARIABLE TIME STEP	
GAMA FOR NEWMARKS METHOD BETA FOR NEWMARKS METHOD TOLERANCE FOR FORCE COMPUTATION REFERENCE MOMENT OF CONVERGENCE MAX NUMBER OF ITERATIONS WITHIN T.S=	0.50000 0.25000 10.00000 100.00000 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= LENGTH OF RECORD= LOAD FACTOR= ANGLE OF EARTHQUAKE INCIDENCE=	0.02000 2000 1.00000 0.00000

SUPERSTRUCTURE : 1

.....STIFFNESS DATA..... ) a 7 y STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) .... LEVEL STIFF X STIFF Y STIFF R ECCENT X ECCENT V 35.12000 1 35.12000 3659.00590 0.00001 0.00000 SUPERSTRUCTURE MASS..... LEVEL TRANSL. MASS ROTATIONAL MASS ECCENT X ECCENT Y 1 42.24794 0.00000 1700000.00000 0.00000 SUPERSTRUCTURE DAMPING..... DAMPING RATIO MODE SHAPE

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
 0

 2
 0.831283E+00
 0.689137E+01
 0

 3
 0.831283E+00
 0.689137E+01
 0

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 ( Level	THREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
	1	467 16 . 90000	46716.90000	6618227.50000	0.00001	0.00000
	SUPERSTRUCT	JRE MASS TRANSL. MASS	ROTATIONAL MASS	ECCENT X	ECCENT Y	
j.	1	31.07037	1700000.00000	0.00000	0.00000	
-1 -1 -1	SUPERSTRUCTU MODE SHAPE	URE DAMPING DAMPING RATIO				
	1	0.02000				
	2	0.02000				
	3	0.02000				
		METCHT				
	LEVEL					
	1	210.480				
	0	18.000				
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. DF MASS..... 0.00000 ECCENT. IN Y DIR. FROM CEN. DF 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 O	F MASS OF THE I R	BASE ECX	ECY
	7.65000	7.65000	2374832.00000	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	\$20.5600
	5	-14.4000	0.0000
	6	-509.8800	0.0000
1.5	7	0.0000	-495.4800
1 2	8	481.0800	0.0000
;	9	0.0000	495.4800
( <b>`</b>			

.....ELEMENT TYPE .

LINEAR ELASTIC	ELEMENT PARAMETER	5
ISOLATOR	STIFFNESS X	STIFFNESS Y
t	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	00000.08	0.50000
7	BO.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 - O FOR NO TIME HISTORY OUTPUT INDEX - 1 FOR TIME HISTORY OUTPUT			
ND. OF TIME STEPS AT WHICH TIME HISTORY OUTPUT IS DESIRED ACCELERATION-DISPLACEMENTS PROFILES OPTION=			50 1
INDEX = 0 FOR NO PROFILES OUTPUT INDEX = 1 FOR PROFILES OUTPUT			
FORCE-DISPLACEMENT TIME HISTORY DESIRED AT ISOLATORS NUMBERED	27	3	4

## EIGENVALUES AND EIGENVECTORS (30 SHEAR BUILDING REPRESENTATION)....

5

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

## HODE SHAPES

LE	/EL		1	:	2	3
1.5	1	x	0.0000000	0.1794018	0.0000000	
() ()	1	Y	0.0000000	0.0000000	0.1794018	
0	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

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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(DX12+DY12)
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 Q.1133E+02
2	3.824 1030E+02 5185E+01	3.843 1027E+02 5202E+01	3.829 O.1153E+O2
3	3.824 1015E+02 5335E+01	3.843 1012E+02 5352E+01	3.829 0.11478+02
4	3.8249995E+015185E+01	3.8439966E+015202E+01	3.829 O.1126E+02
5	3.824 1015E+02 5182E+01	3.8431012E+025199E+01	3.829 O.1140E+02
6	3.824 1015E+02 - 5090E+01	3.843 1012E+02 5107E+01	3.829 O.1135E+O2
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	3.8431012E+025291E+01	3.829 0.1144E+02
9	3.8241006E+025185E+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	3,4544717E+021832E+02	3.5913666E+022381E+02	3.418 0.5119E+02
2	3.4514783E+021930E+02	3.5923707E+022432E+02	3.417 0.5221E+02
Э	3.4544717E+021961E+02	3,5923651E+022482E+02	3.417 0.5185E+02
4	3.4594653E+021853E+02	3.5923606E+022432E+02	3.418 0.5083E+02
5	3.4544717E+021896E+02	3.5923657E+022431E+02	3.417 0.5151E+02
6	3.4544717E+021857E+02	3,5913663E+022401E+02	3.418 0.5132E+02
7	3.4524757E+02 1918E+02	3.5923687E+O22432E+O2	3.417 0.5194E+02
8	3.4544717E+021935E+02	3.5923654E+O22462E+O2	3.417 0.5172E+02
9	3.4574678E+021873E+02	3.5923626E+022432E+02	3.418 0.5110E+02

#### MAXIMUM BEARING FORCES

	MAX FORCE X	MAX FORCE Y	MAX RES. FORCE SQRT(FX12+FY12)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME FORCE
1	3.8245033E+032494E+03	3.8445018E+032503E+03	3.829 0.5618E+03
2	3.8245109E+032571E+03	3.8435094E+0325B0E+03	3.829 0.57218+03
3	3.824 - 5033E+03 - 2646E+03	3.8435019E+032654E+03	3.829 0.5687E+03
. 4	3.824 - 4957E+03 - 2571E+03	3.8434943E+032580E+03	3.829 0.5585E+03
5	3.8242013E+041028E+04	3.8432007E+041031E+04	3.829 0.2261E+04
. 6	3.4555495E+033447E+03	3.5914841E+033920E+03	3.407 0.6618E+03
7	3.4535517E+033502E+03	3.592 <b>4859</b> E+033945E+03	3.407 0.6665E+03
8	3.455 5495E+03 3519E+03	3.5924835E+033969E+03	3.407 0.6664E+03
9	3.457 - 54728+03 - 34628+03	3,5924818E+033945E+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
       22.4005 -18.5478
                              4.7462
                                       -3.8455
 1
BASE -10.1484 96.9077
                             -5.1848
                                       64.8046
SUPERSTRUCTURE : 2
              X
                                   Y
LEVEL
       DISP
                  ACCEL
                             DISP
                                       ACCEL
```

-0.0437

-5.1848

MAXIMUM BASE DISPLACEMENT IN Y DIRECTION TIME : 3.843

126.0661

96.9077

-0.0843

BASE -10.1484

1. SUPERSTRUCTURE : 1

1

	X		Y	
LEVEL	DI SP	ACCEL	DISP	ACCEL
1	22.2317	-18.3897	4.5285	-3.6537
BASE	-10.1186	105.5173	-5.2017	41.5514
SUPERST	RUCTURE :	2		
SUPERS	RUCTURE :	2	¥	
SUPERS	IRUCTURE : X DISP	2 ACCEL	Y DISP	ACCEL
SUPERST	IRUCTURE : X DISP -0.0685	2 ACCEL 101.3220	Y DISP -0.0395	ACCEL 58.9043

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

65.3455

64.8046

, " . |----

SUPERST	RUCTURE :	1		
NAX AC TIME	CELERATION : 10.011	IN X DIRE	CTION	
LEVEL	DISP 29 0252	ACCEL	DISP	ACCEL
BASE	2.4990	-4.3183	0.1289	-11.0347
MAX AC TIME	CELERATION : 11.009	IN Y DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
BASE	23,3868 2.6353	-19,1713 -10, <b>596</b> 7	-5.9254 -0.5949	4.9270 -7.9287
SUPERST	RUCTURE :	2		
MAX AC TIME	CELERATION : 3.735	IN X DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
1 BASE	-0.0999 -9.2473	150.2559 140.0605	~0.0511 -4.6020	76.8194 75.2855
MAX ACI TIME	CELERATION : 3.644	IN Y DIRE	CTEON	
LEVEL	DISP	ACCEL	DISP	ACCEL
BASE	-0.0893 -6.8886	134.6504 129.1985	-0.0517 -3.2762	77.8041 66.4948
) N C J MAXIMU	N STRUCTUR	AL SHEARS		
SUPERST	NO TIME	FORCE X	TIME FOR	CE Y TIME

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

Z MOMENT

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MAXINUM BASE SHEARS...... TIME FORCE X TIME FORCE Y TIME Z MOMENT TIME RES. SHEAR SQRT(FX12+FY12) 3.732 -.5263E+04 3.741 -.2945E+04 6.081 -.2907E+05 3.734 0.6029E+04

.MAXINUM STORY SHEARS.....

SUPERSTRUCTURE : 1 LEVEL TIME FORCE X TIME FORCE Y TIME Z MOMENT TIME RES. SHEAR SQRT(FX12+FY12) 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(FX12+FY12)

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	4.0681
BASE	2.4990	-4.3183	0.1289	-11.0347

MAX STRUC SHEAR IN Y DIRECTION . 4 ĊĴ ACCEL LEVEL DISP ACCEL DISP 4.9270 23.3868 -19.1713 -5.9254 1 BASE 2.6353 -10.5967 -0.5949 -7.9287

SUPERSTRUCTURE : 2

MAX STRUC SHEAR IN X DIRECTION TIME : 3.735

1 BASE	DISP -0.0999 -9.2473	ACCEL 150.2559 140.0605	DISP -0.0511 -4.6020	ACCEL 76.8194 75.2855
MAX ST TIME	RUC SHEAR : : 3.644	IN Y DIREC'	r ION	
LEVEL 1 BASE	DISP -0.0893 -6.8886	ACCEL 134.6504 129.1985	015P -0.0517 -3.2762	ACCEL 77.8041 55.4948

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
SONEK21	X	2	Y	
	× ×		T	
LEVEL	0126	ACCEL	UISP	ALLEL
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

		•		
1 5	X		v	
LEVEL	DI SP	ACCEL	DISP	ACCEL
- <b></b>	22.5554	-18.7936	5.4068	-4.4519
- BASE	-D.3761	140.3449	-4.6699	76.9049
SUPERST	RUCTURE :	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	TINE MAX STUCTURAL SHEAR
1	10.011	~389823.1014	10.011 -1370.6860
FLOOR		INERTIA FDRCES	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 OVER	TURNING NOMENT 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		206.1539	208.1539
BASE		-78.5025	-78.5025 Force at C.M. DF entire base
SUPR/STURE	TIME	OVERTURNING MOMENT	TIME MAX STUCTURAL SHEAR
	3.644	508814.5347	3.644 2417.4009
FLOOR		INERTIA FORCES 2417.4009 550.2715	INERTIA FORCES 2417.4009 658.2715 FORCE AT C.M. OF ENTIRE RACE

.MAXINUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE

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      Jak

      SUPERSTRUCTURE : 1

      C:

      COORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE

      C/L : 1 X CODR : -834.960

      Y COOR : -834.960

      COLUMN LINES

      1

      COLUMN LINES

      1

      1

      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 Kips/in\*sect2 Secs in 1 2 5 5 386.22 1 3 0.001 50 1 500 1 0.5 0.25 2 0.02 2000 0 1 35.12 3659.0059 0.0 0.0 0.0 42.24794 170000.0000 0.005 0.005 0.005 0.0 284.40, 18.00 46716.90 46716.90 5618227.50 0.0 31.07037 1700000.00000 0.02 0.02 0.02 0.0 0.0 210 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 -534.96 0.00 0.00 -820.56 806.16 0.00 0.00 820.56 -14.40 0.00 -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 з 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

1.72

# WAVEX . DAT

	0 103408+03			
-0.307198+01	-0.101408401	-0.480486+01	0.102008+02	•0.2835 <b>62+01</b>
-0.81918E+01	0.120518+02	-0.10161E+02	-0.134302+02	0.146118+02
-0,116182+02	-0.13430 <b>E</b> +02	0.142578+02	-0.980652+01	+0.720728+01
0.145322+02	0.122485+02	-0.56712E+01	-0.279622+01	0.57500E+01
-0.14178E+01	0.157538+01	0.207552+02	0.110272+01	-0.28159E+02
0.72072 <b>B</b> +01	0.405268+02	0.283178+02	0.468662+01	-0.10003 <b>E</b> +02
-0.23394E+02	-0.17053 <b>2</b> +02	0.630142+00	0.170145+02	0.12997E+02
0.905828+00	0.94520E+00	-0.58681E+01	-0.23630 <b>E</b> +01	0.886138+01
0.161088+02	-0.15753E+01	-0.320588+02	-0.88219 <b>2+</b> 01	0.917642+01
0.409592+01	0.366662+02	0.313898+02	-0.167382+02	-0.371398+02
-0.10318E+02	0.476542+01	0.834932+01	0.227645+02	0.984598+01
••••				

## WAVEY . DAT

0.128782+02	0.22055E+01	-0.228428+01	-0.16935E+01	0.882192+01
0.315072+01	-0.20361 <b>E</b> +02	-0.16502 <b>E</b> +02	0.460792+01	0.787672+01
0.36233E+01	-0.145728+02	-0.10122E+02	0.161872+02	0.196528+02
-0.669522+00	-0.949148+01	-0.267815+01	-0.24418E+01	-0.135878+02
-0.149262+02	0.127218+02	0.29538E+02	0.834932+01	-0.240512+02
-0.175262+02	0.905828+01	0.173688+02	-0.602578+01	-0.217792+02
-0.243782+02	-0.10437 <b>8</b> +02	0.261908+02	0.506868+02	0.100822+02
-0.445828+02	-0.47772E+02	-0.197315+92	0.878258+01	0.412348+02
0.387538+02	-0.40565 <b>E</b> +01	-0.367458+02	-0.37375 <b>8+0</b> 2	-0.106738+02
0.214648+02	0.270178+02	0.393842+01	-0.225278+02	-0.352098+02
-0.293012+02	0.673462+01	0.462368+02	0.478902+02	0.448972+01
•••••				

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- PROGRAM 30-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 , N. C. CONSTANTINOU AND A. M. REINHORN DEPARTMENT OF CIVIL ENGINEERING STATE UNIV. OF NEW YORK AT BUFFALD

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

VERSION 30-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 BUFFALD

52 FPS BEARINGS - CONSTANT NORMAL LOAD

UNITS LENGTH : In MASS : Kips/in\*sect2 TIME : secs 1 con

..... DATA\*\*\*\*\*\*\*

\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* CONTROL PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*

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

OUTPUT

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) INDEX FOR TYPE OF TIME STEP	0.00100 1
INDEX = 1 FOR CONSTANT TIME STEP INDEX = 2 FOR VARIABLE TIME STEP	
GANA 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 2000
LOAD FACTOR=	1.00000
ANGLE OF EARTHQUAKE INCIDENCE	0.00000

SUPERSTRUCTURE : 1 >....STIFFNESS DATA..... ; STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING) .... Level Stiff X Stiff Y STIFF R ECCENT X ECCENT Y 35.12000 35.12000 3659.00590 0.00001 0.00000 1 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 RATID 0.00500 1

2 0.00500

3 0.00500

HEIGHT..... • EVEL 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 0.000000 0.000000 0.1538499
- 1 R 0.0007670 0.0000000 0.0000000

SUPERSTRUCTURE : 2

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

	STIFFNESS (T Level	HREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
	1	46716.90000	46716.90000	6618227.50000	0.00001	0.00000
	SUPERSTRUCTUR LEVEL	E MASS Transl. Mass	ROTATIONAL MASS	ECCENT X	ECCENT Y	
frid	1	31.07037	1700000.00000	0.00000	0.00000	
રુ	SUPERSTRUCTUR MODE SHAPE	E DAMPING DAMPING RATIO				
	1 2 3	0.02000 0.02000 0.02000				
	HEIGHT LEVEL	HEIGHT				
	1 2 0	10.480 18.000				

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

STIFFNESJ OF	LINEAR	ELASTIC	SYS.	INXC	JIR. •	390.06000
STIFFNESS OF	LINEAR	ELASTIC	SYS.	IN Y C	)IR. =	390.06000
STIFFNESS OF	LINEAR	ELASTIC	SYS.	INRC	DIR. =	121188853.00000
ECCENT. IN	X DIR.	FROM CEN	. OF	MASS.	=	-14.40000
ECCENT. IN	Y DIR.	FROM CEN	. ÓF I	MASS.	=	0.00000

MASS AT THE CENTER OF MASS OF THE BASE .... Transl. Mass Rotational Mass

MASS 9.90109 427528.00000

GLOBAL 150	LATION DAMPING AT	THE CENTER OF	WASS OF THE BASE		
	x	۷	R	ECX	ECV
DAMP 1NG	0.00000	0.00000	0.00000	0.00000	0.00000

ISOLATORS LOCATION INFORMATION.....

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ISOLATOR	X	Ŷ
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 =

5	LIDING B	EARING PAR	AMETERS(	CONSTANT N	ORMAL FORCE	& FMAX)				
I	SOLATOR	FMAX X	FMAX Y	FMIN X	FMIN Y	PA X	PA Y	VIELD DISPL. X	VIELD 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	O . BOO	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
с.,	5	0.04500	0.04500	0.03000	0.03000	O. 800	0.800	0.02000	0.02000	16070.50000
1										

0

\*\*\*\*\*\*\*\*\*\*\* OUTPUT PARAMETERS \*\*\*\*\*\*\*\*\*\*\*

TIME HISTORY OPTION ......

INDEX - O FOR NO TIME HISTORY OUTPUT INDEX - 1 FOR TIME HISTORY OUTPUT

	ND. OF T Dutput I Accelera	IME STI S DESI TION-D	EPS AT WHE RED Isplacemen	ICH TIME	HISTORY ILES OPT	10N=		10 1		
	INDEX = INDEX =	O FOR	NO PROFIL PROFILES	LES OUTPO OUTPUT	υT					
	FORCE-DI At Isola	SPLACE	MENT TIME	HISTORY	DESIRED	<b></b>	2 3	4 :	5	
	EIGENVAL	UES AN	D EIGENVE	TORS (3	) SHEAR	BUILDING	REPRESE	TATION	•	
	NODE NUN	BER	EIGENVA	LUE	PERI	OD				
	1 2 3		0.389307E4 0.150358E4 0.150358E4	01 0.: 04 0. 04 0.	318444E+ 162038E+ 162038E+	01 00 00				
	MODE SHA Level	PES	1	2		3				
	1 X	0.0	.0 00000	1794018	0.000000	0				
	1 Y	0.0	00000 0.0	, 000000	). 1 <b>794</b> 01	8				
	1 R	0.0	007670 0.0	0000000	000000	0				
	MAX. REL	ATIVE (	DISPLACEN	ENTS AT (	CENTER O (WITH	F MASS OF Respect	F LEVELS To the b/	NSE }		
	SUPERSTR LEVEL T	UCTURE	: 1 DISPL X	TIME	DISPL	Y TIME	ROTAT	ION		
	1 10	.044 0	. 4053E+02	4.753 -	98 15E+	01 3.88	7 0. <b>3999</b>	E-03		
tada C -	SUPERSTR LEVEL T	UCTURE IME (	: 2 DISPL X	TIME	DISPL	Y TIME	ROTAT	(ON		
-}_{	1 3	.809 -	11366+00	3.872 -	.81952-	01 4.75	555776	E-03		
	NAX. DIS Level t Base 3	PLACEME Ime e .857	ENTS AT CE DISPL X . 1317E+O2	NTER OF Time 3.896 -	MASS OF DISPL .8243E+	BASE Y TIME Q1 3.887	ROTAT) 73998(	10 <del>N</del> E-03		

# MAXIMUM BEARING DISPLACEMENTS

	MAX DISPL X	MAX DISPL Y	MAX RES. DISPL. SORT(DX12+DY12)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME DISPLACEMENT
1	3.8571317E+027837E+01	3.8971303E+027909E+01	3.866 D.1534E+02
2	3.8571350E+028168E+01	3.8961336E+028243E+01	3.866 O.1579E+O2
3	3.8571317E+028488E+01	3.8961303E+028565E+01	3.867 Q. 1568E+02
4	3.8561285E+028164E+01	3.896 - 1271E+02 - 8243E+01	3.866 Q.1523E+O2

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#### MAXIMUM BEARING VELOCITIES

	MAX VELOCITY X	MAX VELOCITY Y	MAX RES. VELOCITY SQRT(VX12+VY12)
I SOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME VELOCITY
1	3.4755359E+022342E+02	3.5944573E+023295E+02	3.554 0.5902E+02
2	3.4745468E+022456E+02	3.5954655E+023393E+02	3.554 0.6014E+02
Э	3.4755359E+022559E+02	3.597 -,4533E+023487E+02	3.555 0.5986E+02
4	3.4775251E+022445E+02	3.5954464E+023393E+02	3.554 O.5875E+O2
5	3.4755359E+022451E+02	3.5954559E+023391E+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	3.2131808E+032562E+01	3.1493453E+01 0.1808E+03	3.149 O.1808E+03	
2	2.593 0.1808E+03 0.1507E+01	9.167 0.6027E+00 0.1808E+03	2.593 O. 1808E+03	
3	6.024 0.1808E+03 1410E+00	9.172 O.1792E+01 O.1808E+03	9.172 O.1808E+03	
4	2.593 0.1808E+03 0.1513E+01	3.1462252E+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 Q.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

1A . ERDFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX BASE DISPLACEMENTS

MAXIMUM BASE DISPLACEMENT IN X DIRECTION TIME : 3.857

SUPERSTRUCTURE : 1 Y х

LEVEL	DISP	ACCEL	DISP	ACCEL
1	25.8562	-21.4382	7.7007	-6.3355
BASE	-13.1743	126.2531	-8.1682	117.3894
SUPERS	TRUCTURE :	2	Y	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	-0.1074	160.7382	-0.0790	119.2784
8ASE	-13.1743	126.2531	-8.1682	117.3894

MAXIMUM TIME :	BASE DISPI 3.896	LACEMENT IN	Y DIRECTION	4
SUPERST	RUCTURE :	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
SUPERST	RUCTURE :	2		
	X		Y	
LEVEL	DISP	ACCEL	DISP	ACCEL
- <b>1</b>	-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 AC TINE	CELERATION : 10.033	IN X DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
S 2 1	40.5288	-33.6970	-4.5752	3.7966
BASE	1.9910	25.5478	0.5174	13.2791
MAX AC TIME	CELERATION : 4.742	IN Y DIRE	CTION	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	0.8322	-0.6490	-9.8099	8.1633
BASE	9.8686	-113.8913	5.6894	-80.1861
SUPERST	RUCTURE :	2		
NAX AC	CELERATION	IN X DIREC	CTION	

```
TIME : 3.808
                  ACCEL
LEVEL
        DISP
                             DISP
                                       ACCEL
                             -0.0697
        -0.1136
                170.7426
                                       104.9407
 1
                             -7.7689
                168.8793
                                       106.5026
BASE
      -12.8939
MAX ACCELERATION IN Y DIRECTION
 TINE : 3.871
LEVEL
        DISP
                  ACCEL
                             DISP
                                       ACCEL
       -0.0965
                 143.3974
                             -0.0819 123.2494
 1
BASE -13.1541
                  87.5046
                             -8.2144 87.1164
MAXIMUM STRUCTURAL SHEARS.....
SUPERST. NO TIME FORCE X TIME FORCE Y TIME Z MOMENT
          10.033 -. 1424E+04 4.742 0.3449E+03 3.706 -. 2080E+01
    .
           3.808 0.5305E+04 3.871 0.3829E+04 4.739 0.3697E+04
    2
.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
1.3
.
÷,
```

.MAXIMUM STORY SHEARS

SUPERSTRUCTURE : 1 LEVEL TIME FORCE X TIME FORCE Y TIME Z MOMENT TIME RES. 5HEAR 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(fxt2+fyt2)

1 3.806 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 40.5288 3.7966 -33.6970 -4.5752 1 BASE 1.9910 25.5478 0.5174 13.2791 MAX STRUC SHEAR IN Y DIRECTION TIME : 4.742 LEVEL DISP ACCEL DISP ACCEL -9.8099 1 0.8322 -0.6490 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 -0.1136 170.7426 -0.0697 104.9407 1 BASE -12.8939 168.8793 -7.7689 106.5026 MAX STRUC SHEAR IN Y DIRECTION TIME : 3.871 had **LEVEL** DISP ACCEL DISP ACCEL -0.0819 (15**1** --0.0965 143.3974 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 : 3.806

SUPERSTRUCTURE : 1

			, ,	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	25.9461	-21.5934	7.9075	-6.5616
BASE	-12.6939	168.8793	-7.7689	106.5026
SUPERS	TRUCTURE :	2		
	X		¥	
LEVEL	DISP	ACCEL	DISP	ACCEL
1	-0.1136	170.7425	-0.0697	104.9407
BASE	-12.8939	168.8793	-7.7689	106.5026
MAXIMU TIME :	N BASE SHEAF 3.861	R IN Y DIR	CTION	
MAXIMU TIME : SUPERS'	N BASE SHEAF 3.861 TRUCTURE :	R IN Y DIR	ECTION	
MAXIMU TIME : SUPERS	N BASE SHEAF 3.861 FRUCTURE : X	I ACCEL	CTION Y DISP	ACCEL
MAXIMU TIME : SUPERS LEVEL	N BASE SHEAF 3.861 TRUCTURE : X DISP 25 8306	1 ACCEL -21.4117	CTION Y DISP 7.6708	ACCEL
NAXIMU TIME : Supers Level 1 Base	N BASE SHEAF 3.861 TRUCTURE : X DISP 25.8306 -13.1722	1 ACCEL -21.4117 114.8752	CTION Y DISP 7.6708 -8.1843	ACCEL -6.3062 113.1370
NAXIMU TIME : SUPERS LEVEL 1 BASE SUPERS	N BASE SHEAF 3.861 TRUCTURE : X DISP 25.8306 -13.1722 TRUCTURE :	1 ACCEL -21.4117 114.8752 2	CTION Y DISP 7.6708 -8.1843	ACCEL ~6.3062 113.1370
MAXIMU TIME : SUPERS LEVEL 1 BASE SUPERS	N BASE SHEAF 3.861 TRUCTURE : 25.8306 -13.1722 TRUCTURE : X	R IN Y DIR Accel -21.4117 114.8752 2	CTION Y DISP 7.6708 -8.1843 Y	ACCEL -6.3062 113.1370
MAXIMU TIME : SUPERS' LEVEL BASE SUPERS' LEVEL	N BASE SHEAF 3.861 TRUCTURE : X DISP 25.8306 -13.1722 TRUCTURE : X DISP	R IN Y DIR ACCEL -21.4117 114.8752 2 ACCEL	Y DISP 7.6708 -8.1843 Y DISP	ACCEL -6.3062 113.1370 ACCEL
MAXIMU TIME : SUPERS' LEVEL BASE SUPERS' LEVEL	M BASE SHEAF 3.861 TRUCTURE : X DISP 25.8306 -13.1722 TRUCTURE : X DISP -0.1052	TIN Y DIR ACCEL -21.4117 114.8752 2 ACCEL 157.2186	CTION Y DISP 7.6708 -8.1843 Y DISP -0.0801	ACCEL -6.3062 113.1370 ACCEL 120.8517

**B-8**0 MAX OVERTURNING MOMENT X DIRECTION MAX STRUCTURAL SHEAR X DIRECTION TIME MAX STUCTURAL SHEAR SUPR/STURE TIME OVERTURNING MOMENT 10.033 -1423.6289 10.033 -404880.0690 1 FLOOR INERTIA FORCES INERTIA FORCES -1423.6289 -1423.6289 1 252.9515 FORCE AT C.M. OF ENTIRE BASE BASE 252.9515 SUPR/STURE TIME OVERTURNING MOMENT TIME MAX STUCTURAL SHEAR 1116603.7337 3.808 5305.0348 3.808 2 INERTIA FORCES INERTIA FORCES FLOOR 5305.0348 5305.0348 1 1672.0887 FORCE AT C.M. OF ENTIRE BASE 1672.0887 BASE MAX OVERTURNING MOMENT Y DIRECTION MAX STRUCTURAL SHEAR Y DIRECTION SUPR/STURE TIME OVERTURNING MOMENT TIME MAX STUCTURAL SHEAR 1 4.742 98064, 1321 4.742 344.8809 THEOT

FLOOR	INERTIA	FORCES	INERTIA	FORCES		
1		344.8809		344.8809		
BASE		- 793 . 9299		-793.9299	FORCE AT C.M.	OF ENTIRE BASE

SUPR/STURE	TIME	OVERTURNING MOMENT	TIME MAX STUC	TURAL SHEAR
2	3.871	806013.2396	3.871	3829.4054
FLOOR 1 BASE		INERTIA FORCES 3829.4054 862.5474	INERTIA	FORCES 3829.4054 862.5474 Force at C.M. of Entire Base

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.MAXIMUM INTERSTORY DRIFT RATIOS' FOR EACH SUPERSTRUCTURE

SUPERSTRUCTURE : 1

CDORDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER DF BASE

C/L : 1 X COOR : -834.960

Y COOR : 0.000

COLUMN LINES

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

CODRDINATES OF COLUMN LINES WITH RESPECT TO MASS CENTER OF BASE

C/L : 1 X COOR : -14.400

Y COOR : 0.000

COLUMN LINES

LEVEL TIME X DIR TIME Y DIR TIME X DIR TIME X DIR TIME Y DIR

1 2.0000

COLUMN LINES

LEVEL TIME X DIR TIME Y DIR TIME X DIR TIME X DIR TIME Y DIR

1 3.809 0.5900E-03 3.872 0.4664E-03
```

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FPS SYSTEM

WITH EFFECT OF VERTICAL GROUND MOTION AND OVERTURNING MOMENTS

101

52 FPS BEARINGS - VARIABLE NORMAL LOAD Kips/in\*sect2 in 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 42.24784 1700000.00000 0.005 0.005 0.005 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 0.0 210.48, 18.00 9.90109 427528.00000 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 0.10 0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625 3 6 32.4 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

 3
 6

 3
 6

 3
 6

 3
 6

 4
 0.105
 0.105
 0.03
 0.03
 0.8
 0.8
 0.02
 0.02
 4017.621

 3
 6
 6
 0.105
 0.03
 0.03
 0.8
 0.8
 0.02
 0.02
 4017.621

 3
 6
 6
 0.105
 0.105
 0.03
 0.8
 0.8
 0.02
 0.02
 4017.621

 3
 6
 6
 0.105
 0.103
 0.03
 0.8
 0.8
 0.02
 0.02
 4017.621

 3
 6
 6
 0.105
 0.103
 0.03
 0.8
 0.8
 0.02
 0.02
 16070.5

 0
 10
 1
 1
 2
 3
 4
 5

 0.105 0.105 0.03 0.03 0.8 0.8 0.02 0.02 4017.625 4 -834.96 0.00 1 -14.40 0.00

INPUT

------

# WAVEX . DAT

-0.102408+02	-0.48048E+01	0.10200E+02	-0.28356E+01
0.12051E+02	-0.10161E+02	-0.13430E+02	0.146118+02
-0.134308+02	0.142578+02	-0.98065E+01	-0.72072E+01
0.12248E+02	-0.56712E+01	-0.27962E+01	0.57500E+01
0.157538+01	0.20755E+02	0.110278+01	-0.281598+02
0.405268+02	0.283175+02	0.46866E+01	-0.100038+02
-0.17053E+02	0.630142+00	0.17014E+02	0.129975+02
0.945202+00	-0.58681E+01	-0.23630E+01	0.886132+01
-0.15753E+01	-0.320588+02	-0.88219E+01	0.91764E+01
0.36666E+02	0.313898+02	-0.16738E+02	-0.37139E+02
0 476548401	0 834938+01	0 227648+02	0 984598+01
	-0.10240E+02 0.12051E+02 -0.13430E+02 0.12248E+02 0.15753E+01 0.40526E+02 -0.17053E+02 0.94520E+00 -0.15753E+01 0.36666E+02	-0.10240E+02       -0.48048E+01         0.12051E+02       -0.10161E+02         -0.13430E+02       0.14257E+02         0.12248E+02       -0.56712E+01         0.15753E+01       0.20755E+02         0.40526E+02       0.28317E+02         -0.17053E+02       0.63014E+00         0.94520E+00       -0.58641E+01         -0.15753E+01       -0.32058E+02         0.31389E+02       0.31389E+02	-0.10240E+02       -0.48048E+01       0.10200E+02         0.12051E+02       -0.10161E+02       -0.13430E+02         -0.13430E+02       0.14257E+02       -0.98065E+01         0.12248E+02       -0.56712E+01       -0.27962E+01         0.15753E+01       0.20755E+02       0.11027E+01         0.40526E+02       0.28317E+02       0.46866E+01         -0.17053E+02       0.63014E+00       0.17014E+02         0.94520E+00       -0.58661E+01       -0.23630E+01         -0.15753E+01       -0.32058E+02       -0.88219E+01         0.36666E+02       0.31389E+02       -0.16738E+02

. . . . . . . . . . .

# WAVEY. DAT

0.128782+02	0.22055 <b>B+0</b> 1	-0.228428+01	-0.16935E+01	0.882198+01
0.31507E+01	-0.203615+02	-0.16502 <b>5</b> +02	0.46079E+01	0.787672+01
0.36233E+01	-0.14572E+02	-0.10122E+02	0.161872+02	0.196522+02
-0.669522+00	-0.949148+01	-0.267818+01	-0.24418E+01	-0.13587 <b>2</b> +02
-0.14926 <b>3+0</b> 2	0.127215+02	0.295388+02	0.834938+01	-0.24851E+02
-0.175268+02	0.905825+01	0.17368E+02	-0.60257E+01	-0.21779 <b>2</b> +02
-0.243782+02	-0.10437E+02	0.261905+02	0.506868+02	0.100822+02
-0.445828+02	-0.47772E+02	-0.19731E+02	0.878255+01	0.412348+02
0.38753E+02	-0.40565E+01	-0.36745E+02	-0.37375 <b>E+0</b> 2	-0.10673E+02
0.214645+02	0.27017E+02	0.393842+01	-0.225272+02	-0.35209E+02
-0.293015+02	0.67346E+01	0.462365+02	0.478902+02	0.448972+01

. . . . . . . . . . . .

# MAVES . DAT

0.170925+02	0.233542+02	0.326#82+01	-0.31625E+02	Q.590752+00
0.332405+02	-0.16344E+02	-0.15675 <b>2+0</b> 2	0.589218+01	-0.249692+02
0.140995+02	0.305228+02	-0.24536 <b>8+0</b> 2	0.204798+01	0.402118+02
-0.185108+02	-0.53365E+02	0.19810E+02	0.422198+02	-0.23433E+02
-0.428105+02	-0.59075E+01	0.295388+02	0.487578+02	0.338702+02
-0.37966E+02	-0.938518+02	-0.267818+02	0.484818+02	0.634478+02
0.472605+02	0.12800E+02	-0.28553E+02	-0.484812+02	-0.109888+02
0.216228+02	0.354452+00	-0.704968+01	0,22055 <b>8</b> +01	0.685272+01
-0.14178E+02	0.126812+02	0.563972+02	0.74435 <b>2</b> +01	-0.150452+02
0.433228+01	-0.41471 <b>E</b> +02	-0.474972+02	0.322162+02	0.689602+02
· · · · · · · · · · · · ·				

-

# **FUNCTIONS**

```
FUNCTION FOVM ( OVMX, OVMY, XP, YP, I )
С
С
    CALCULATING AXIAL FORCES IN THE BEARINGS FROM OVERTURNING MOMENTS
С
    DEVELOPED BY..... PANAGIOTIS TSOPELAS.... PEB 1993
C
IMPLICIT REAL*8(A-H, 0-Z)
    CONNON /WAINI /WB, NP, MNP, MNP, MPP, MXP
    COMMON /BEARAREA/AREA (500)
    DINENSION OVER (NB+1,2), OVMY (NB+1,2), XP (NP), YP (NP)
    IF(I.SQ.1) THEN
    CHCK=0.0
    ONT-0.0
    DO 10 K=1, MB+1
    ORX=ORX+OVEX (K, 1)
    ONY=ONY+OVNY (K, 1)
10 CONTINUE
    BOIF
    IF(1.80.5) POVM=0.0
    IF(I.EQ.4) POVM- ONY/1641.12
    IF(I.EQ.3) FOVH= CHEK/1641.12
    IF(I.BQ.2) FOVH=-ONY/1641.12
    IF(I.EQ.1) FOVN=-ONX/1641.12
    RETURN
    200
FUNCTION FPHAX (FRMAX, FRMIN, FNOR, I)
С
С
    CALCULATING MAXIMUM PRICTICS CORFFICIENT AS FONC OF PRESSURE
с
    DEVELOPED BY ..... FANAGIOTIS TEOPELAS .... FEB 1993
С
INPLICIT REAL*8 (A-H, O-Z)
    CONNENT /HAXXII /MB, MP, HEF, HEE, MPE, HXF
    COMMON /BEARAREA/AREA(500)
    EXTERIOL MOTOF
    PACTOPHOR
    PRESS-15.0*PACT
    ALP=0.10729586
    DF=0.965
    FFRAX-FRAX- (DF) *DTAINI (ALP*PRESS)
                                                    1C.1
    RETURN
```

PROGRAM 3D-BASIS-N..... A GENERAL PROGRAM FOR THE NONLINEAR DYNAMIC ANALYSIS OF THREE DIMENSIONAL BASE ISOLATED NULTIPLE 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 BUFFALD NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH STATE UNIVERSITY OF NEW YORK, BUFFALO VERSION 3D-BASIS-ME, JANUARY 1993 1.3 ~ DEVELOPED BY ... P. C. TSOPELAS, N. C. CONSTANTINOU AND A. M. REINHORN **C** 1 DEPARTMENT OF CIVIL ENGINEERING STATE UNIV. OF NEW YORK AT BUFFALD 52 FPS BEARINGS - VARIABLE NORMAL LOAD

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

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\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\*\* CONTROL PARAMETERS \*

NO. OF BUILDINGS	2
ND. 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 1
INDEX - 1 FOR CONSTANT TIME STEP INDEX - 2 FOR VARIABLE TIME STEP	
GAMA FOR NEWMARKS METHOD	0.50000 0.25000 50.00000 1.00000 500
INDEX FOR GROUND MOTION INPUT 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	4
TIME STEP OF RECORD	0.02000 2000 1.00000 0.00000

 Jak SUPERSTRUCTURE
 1

 Stiffness data.....
 1

 Stiffness (Three Dimensional Shear Building)
 1

 Level
 Stiff X

LEVEL	STIFF X	STIFF Y	STIFF R	ECCENT X	ECCENT Y
1	35.12000	35.12000	3659.00590	0.00001	0.00000
	MASS 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

> 284.400 1

> 18.000 0

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

MODE NUMBER	EIGENVALUE	PERIOD
1	C.215236E-02	0.135432E+03
2	0.831283E+00	0.689137E+01
3	0.831283E+00	0.689137E+01

MODE SHAPES

LE	VEL		1	:	2	
	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 LEVEL	(THREE DIMENSIONAL STIFF X	SHEAR BUILDING) STIFF Y	STIFF R	ECCENT X	ECCENT Y
1	46716.90000	46716.90000	6618227.50000	0.00001	0.00000
	URE MASS Transl. Mass	ROTATIONAL MASS	ECCENT X	ECCENT Y	
1	31.07037	1700000.00000	0.00000	0.00000	

1

SUPERSTRUCTURE DAMPING..... MODE SHAPE DAMPING RATIO 0.02000 1 0.02000 2 3

#### HEIGHT..... LEVEL HEIGHT

210.480 1

0 18.000

#### 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. DF MASS	0.00000
ECCENT. IN Y DIR. FROM CEN. OF MASS	0.00000

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

MASS 9.90109 427528.00000

GLOBAL ISOLATIC	N DAMPING AT	THE CENTER OF I	NASS OF THE BASE 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

-14.4000

المراج ..... APLEMENT TYPE =

5

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F.

F. P. S.	. P. S. BEARING PARAMETERS										
ISOLATOR	RADIUS	FMAX X	FMAZ 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	
6	82.4000	0.10500	0.10500	0.03000	0.03000	0.800	0.800	0.02000	0.02000	16070.50000	

\*\*\*\*\*\*\*\*\*\*\*\* OUTPUT PARAMETERS \*\*\*\*\*\*\*\*\*\*\*\*

0.0000

INDEX = 1 FOR TIME HISTORY OUTPUT

ND. OF TIME STEPS AT WHICH TIME HISTORY OUTPUT IS DESIRED ....... 10 ACCELERATION-DISPLACEMENTS PROFILES OPTION. ... 1 INDEX = O FOR NO PROFILES OUTPUT INDEX = 1 FOR PROFILES OUTPUT FORCE-DISPLACEMENT TIME HISTORY DESIRED 3 1 2 4 5 EIGENVALUES AND EIGENVECTORS (3D SHEAR BUILDING REPRESENTATION).... MODE NUMBER EIGENVALUE PERIOD 0.389307E+01 0.318444E+01 1 2 0.150358E+04 0.162038E+00 0.150358E+04 3 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 0.3828E-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	¥	MAX RES.	DISPL. SQRT(DX12+DY12)
<b>ISOLATOR</b>	TIME X DIRECT	Y DIRECT	TIME X DIRECT	Y DIRECT	TIME DISPLACEMENT	
1	3.8541329E+02 -	.7924E+01	3.888 1319E+02 -	.7994E+01	3.864 0.1549E+02	
2	3.8561359E+02 -	.8230E+01	3.893 1346E+02 -	.8303E+01	3.865 0.1589E+02	
3	3.8541329E+02 -	.8509E+01	3.897 1312E+02 -	.8604E+01	3.855 0.15802+02	
4	3.853 1300E+02 -	.8217E+01	3.893 1285E+02 -	.8303E+01	3.864 0.1539E+02	

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MAXIMUM BEARING VELOCITIES

	MAX VELOCITY X	MAX VELOCITY Y	MAX RES. VELDCITY SQRT(VX+2+VY+2)
ISOLATOR	TIME X DIRECT Y DIRECT	TIME X DIRECT Y DIRECT	TIME VELOCITY
1	3.4745490E+022441E+02	3.5984465E+023288E+02	3.470 0.6012E+02
2	3.4735576E+022533E+02	3.6004528E+023371E+02	3.469 0.6128E+02
3	3.4745490E+022612E+02	3.6024427E+023453E+02	3.469 Q.6085E+02
4	3.4745404E+022528E+02	3.6004363E+023371E+02	3.470 0.5970E+02
5	3.4745490E+022527E+02	3.6004446E+023370E+02	3.469 Q.6048E+02

MAXIMUM BEARING FORCES

	MAX FORCE X	MAX FOR	CE Y	MAX RES. FORCE	SQRT(FX12+FY12)
ISOLATOR	TIME X DIRECT Y DIR	ECT TIME X DIREC	T Y DIRECT TIME	FORCE	
1	4.720 0.7791E+03 0.4426E	+03 3.8555955E+0	3 ~.5061E+03 4.725	0.8970E+03	
2	3.30376396+0349506	+03 3.840 ~.7032E+0	35281E+03 3.812	0.9130E+03	
3	3.8199104E+036537E	+03 3.8418701E+0	36887E+03 3.827	0.1124E+04	
4	3.8138656E+036059E	+03 3.8487896E+0	36577E+03 3.828	0.1066E+04	
5	3.8043263E+042167E	+04 3.8472940E+0	42367E+04 3.820	0.3954E+04	

MAX. TOTAL ACCELERATIONS AT CENTER OF MASS OF LEVELS

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SUPERS	TRUCTU								
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

3.836 0.1927E+03 3.847 0.1328E+03 4.697 0.1911E-02 1

1-- 5

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 ¥

LEVEL DISP		ACCEL	DISP	ACCEL	
1 25.8472		-21.4288	7.6727	-6.3118	
BASE -13.2932		104.6639	-8.2217	92.9336	
SUPERS		2	Y		
LEVEL	DISP	ACCEL	DISP	ACCEL	
1	-0. 1 168	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		¥			
LEVEL	DISP	ACCEL	DISP	ACCEL		
1	25.4976	-21.0847	7.3187	-5.9874		
BASE	-13.1509	191.1480	-8.3031	78.3010		
SUPERS	RUCTURE :	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		

5.34 • • • •

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 AGGELERATION IN X DIRECTION

```
TINE : 3.836
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	LEVEL	DISP	ACCEL	DISP	ACCEL			
	BASE	-13.2615	117.2983	-6.1198	86.2306			
	MAX A TIME	CCELERATION : 3.847	IN Y DIRE	CTION				
	LEVEL 1 Base	DISP -0, 1243 -13, 2881	ACCEL 185.7066 102.3710	DISP -0.0883 -8.1870	ACCEL 132.8276 89.1733			
	.MAXIM	UM STRUCTUR	AL SHEARS					
	SUPERS 1 2	T. No TIME 10.03 3.83	FORCE X 11430E+04 6 0.5987E+04	TIME FOR 4.743 0.38 3.847 0.41	RCE Y TIME 604E+03 3.669 127E+04 4.697	Z MOMENT 1923E+01 0.3248E+04		
	. M/4XIM T (ME 2' . BQ	UM BASE SHE Force X 46524e+0	ARS TIME FOR 4 3.84747	 DE Y TIME 741E+04 3.9	: Z MOMENT 123 2498E+05	TIME RES. 3.820 0.79	SHEAR SORT ( IOBE+04	FX12+FY12)
<b>)</b>	.MAXIM	UM STORY SHI	EARS					
	SUPERS LEVEL	TRUCTURE : TIME FOR	1 DE X TIME	FORCE Y	TIME Z M	OMENT TIME	RES. SHEAR	SQRT(FX+2+FV+2)
	1	10.031 14:	BOE+04 4.743	3 0. <b>3504</b> E+03	3.669 192	3E+01 10.030	0.1 <b>439E+04</b>	
	SUPERS LEVEL	TRUCTURE : Time for(	2 Ce x time	FORCE Y	TIME Z N	OMENT TIME	RES. SHEAR	SORT(FX12+FY12)
	1	3.836 0.598	37E+04 3.847	0.4127E+04	4.697 0.324	8E+04 3.839	0.7228E+04	

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		×	1	Y								
	LEVEL	DISP	ACCEL	DISP	ACCEL							
	1	25.9779	-21.6165	7.9027	-6.5571							
	DAJE	-13.0243	231.39/3	-1.6211	144.3334							
	SUPER:	STRUCTURE :	2									
		X	4000	Y DICD	40051							
	LEVEL	DI 5P	AGGEL 168 6998	-0.0681	AGUEL 102 6127							
	BASE	-13.0243	231.3975	-7.8217	144.3394							
	MAXIM. TIME :	M BASE SHEA : 3.847	R IN Y DIR	ECTION								
	CLIDEDS		•									
	307 100	X	•	Y								
	LEVEL	DISP	ACCEL	DISP	ACCEL							
	1	25.8884	-21.4709	7.7213	-6.3584							
	BASE	-13.2861	102.3710	-5.1870	89.1733							
	SUPERS	TRUCTURE :	2									
		X		¥								
• .	LEVEL	DISP	ACCEL	DISP	ACCEL							
	1	-0.1243	185.7066		132.8276							
	BAJE	-13.2001	102.3710	-0.10//	69.1/33							
<b>P</b>			••••		RUE PROFILES***							
8	a de la companya de la	MAX OVERTURN	ING MOMENT >	DIRECTION	I	M	AX STRUCTUR	AL SHEAR X	DIRECTION	4		
•						T 1 M						
51	A HER A	10 031	406710 7	12701 7640		10.031	MAX STUCI	-1430 OF59				
	•	10.001				10.001		1400.0000				
	_											
	FLOOR	IN	ERTIA FORCE	5			INERTIA	FORCES				
	1 Rase		181 8	NG 38 1523				181 8523	FORCE AT	C M	OF EN	TIDE RASE
	4-45								TURUE H	<b>Q</b> .m.		
SL	PR/STURE	TIME OV	ERTURNING MON	IENT		TIME	MAX STUCT	URAL SHEAR				
	2	3.836	1260101.5	1233		3.836		5986.7993				
	FLOOR	IN	ERTIA FORCE	S			INERTIA	FORCES				
	1		5986.7	/993				5986.7993				
	BASE		1161.3	1813				1161.3813	FORCE AT	C.M.	DF ENT	TIRE BASE
	M	MAX OVERTURN	ING MOMENT Y	DIRECTION		M/	X STRUCTUR	AL SHEAR Y	DIRECTION	ł		
SU	PR/STURE		ERTURNING MON	IENT		TIME	MAX STUCT	URAL SHEAR				
•-	1	4.743	99659.2	330		4.743		350.4192				
	FLOOP	TAI	ERTIA FORCE	S			INERTIA	FORCES				
	1	14	350.4	192				350.4192				
	BASE		-764.3	927				-764.3927	FORCE AT	C.M.	OF ENT	IRE BASE
MAX STRUC SHEAR IN X DIRECTION TIME : 10.031 ACCEL LEVEL DISP ACCEL DISP 40.7131 -33.8494 -4.4418 3.6887 1 BASE 1.8965 18.3669 0.5464 -11.7807 MAX STRUC SHEAR IN Y DIRECTION TIME : 4.743 LEVEL DISP ACCEL DISP ACCEL 0.5085 -0.3804 -9.9671 8.2944 1 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 -0.0855 129.2239 -0.1280 192.6852 1 BASE -13.2615 117.2983 -8.1198 96.2306 hand MAX STRUC SHEAR IN Y DIRECTION 4.7 TIME : 3.847 LEVEL DISP ACCEL DISP ACCEL -0.1243 185.7066 -0.0883 132.8276 1 8ASE -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

SUPERSTRUCTURE : 1

1. .

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PROFILES OF TOTAL ACCELERATION AND DISPLACEMENT AT TIME OF MAX STRUCT SHEAR IN EACH BUILDING
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## NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH LIST OF TECHNICAL REPORTS

The National Center for Earthquake Engineering Research (NCEER) publishes technical reports on a variety of subjects related to earthquake engineering written by authors funded through NCEER. These reports are available from both NCEER's Publications Department and the National Technical Information Service (NTIS). Requests for reports should be directed to the Publications Department, National Center for Earthquake Engineering Research, State University of New York at Buffalo, Red Jacket Quadrangle, Buffalo, New York 14261. Reports can also be requested through NTIS, 5285 Port Royal Road, Springfield, Virginia 22161. NTIS accession numbers are shown in parenthesis, if available.

- NCEER-87-0001 "First-Year Program in Research, Education and Technology Transfer," 3/5/87, (PB88-134275).
- NCEER-87-0002 "Experimental Evaluation of Instantaneous Optimal Algorithms for Structural Control," by R.C. Lin, T.T. Soong and A.M. Reinhorn, 4/20/87, (PB88-134341).
- NCEER-87-0003 "Experimentation Using the Earthquake Simulation Facilities at University at Buffalo," by A.M. Reinhorn and R.L. Ketter, to be published.
- NCEER-87-0004 "The System Characteristics and Performance of a Shaking Table," by J.S. Hwang, K.C. Chang and G.C. Lee, 6/1/87, (PB88-134259). This report is available only through NTIS (see address given above).
- NCEER-87-0005 "A Finite Element Formulation for Nonlinear Viscoplastic Material Using a Q Model," by O. Gyebi and G. Dasgupta, 11/2/87, (PB88-213764).
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- NCEER-87-0013 "Frequency Response of Secondary Systems Under Seismie Excitation," by J.A. HoLung, J. Cai and Y.K. Lin, 7/31/87, (PB88-134317).
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- NCEER-87-0015 "Detection and Assessment of Seismic Structural Damage," by E. DiPasquale and A.S. Cakmak, 8/25/87, (PB88-163712).

- NCEER-87-0016 "Pipeline Experiment at Parkfield, California," by J. Isenberg and E. Richardson, 9/15/87, (PB88-163720). This report is available only through NTIS (see address given above).
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- NCEER-87-0019 "Modal Analysis of Nonclassically Damped Structural Systems Using Canonical Transformation," by J.N. Yang, S. Sarkani and F.X. Long, 9/27/87, (PB88-187851).
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