3D-BASIS-TABS: Version 2.0
Computer Program for Nonlinear Dynamic Analysis of Three Dimensional Base Isolated Structures

by

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The program 3D-BASIS-TABS has been developed using computational modules in 3D-BASIS—developed at the State University of New York at Buffalo, and ETABS—developed by the University of California at Berkeley. The program 3D-BASIS-TABS has been developed, for research purposes, with financial support from National Center for Earthquake Engineering Research, Center for Infrastructure Research and Development, University of Buffalo, and University of Missouri - Columbia. The following DISCLAIMER OF WARRANTY applies to the use of computer program 3D-BASIS-TABS and the associated subroutines (including routines from 3D-BASIS and ETABS).

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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.

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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.

The new computer program documented in this report, 3D-BASiS-TABS, Version 2.0, is an enhanced version of 3D-BASiS-TABS and 3D-BASiS which are special purpose programs developed by NCEER for nonlinear dynamic analysis of three-dimensional base isolated structure (see reports NCEER-93-0011 and NCEER-91-0005). One limitation associated with the use of 3D-BASiS is that the superstructure member forces cannot be computed - since no data regarding individual members is specified by the user in this version. 3D-BASiS-TABS overcomes this limitation by computing superstructure member forces, after the completion of the nonlinear time history analysis, followed by output of peak member forces, which can be used for the design of members. This report briefly describes the development of 3D-BASiS-TABS and the enhancements from Version 1.0 (NCEER Report 93-0011), which include addition of new isolation elements for modeling nonlinear dampers, special sliding friction bearings, improvement of other hysteretic elements, additional verification, several new example problems, new input/output format, and updated user's manual.
The computer program 3D-BASIS-TABS is a special purpose program developed for nonlinear dynamic analysis of three-dimensional base isolated structures. The program can analyze base isolated structures with linear superstructure and nonlinear isolation system. 3D-BASIS-TABS has three options for modeling the linear superstructure (i) option 1 -- three-dimensional shear building representation, in which case the global stiffness matrix of the superstructure is assembled internally by the program using story stiffnesses, specified by the user, followed by the dynamic analysis; (ii) option 2 -- full three-dimensional representation, in which case beam, column, shear wall and bracing elements of the superstructure are modeled explicitly, followed by assembly of the global stiffness matrix, condensation, dynamic analysis, and recovery of internal forces in structural elements by backsubstitution; (iii) option 3 -- three-dimensional representation, in which case the dynamic characteristics of the superstructure, such as frequencies and mode shapes, specified by the user, are used to compute the superstructure stiffness matrix, followed by dynamic analysis. The isolation system is modeled by representing the force-displacement relationship of each individual isolator explicitly. The aforementioned approach for options 1 and 3 yields accurate global response results; however, the disadvantage is that superstructure member forces cannot be computed, since no data is available for individual members (this is the principle disadvantage of the previous version 3D-BASIS). Option 2 in 3D-BASIS-TABS overcomes the aforementioned shortcoming by computing superstructure member forces, after the completion of the nonlinear time history analysis, followed by output of peak member forces, which can be used for the design of members.

This report describes the development of computer program 3D-BASIS-TABS Version 2.0. The new program is an enhanced version of 3D-BASIS-TABS. The report should be viewed as a continuation and addition to previous reports NCEER-93-0011 and NCEER-91-0005. The enhancements that have been made include (i) addition of new isolation
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SECTION 1
INTRODUCTION

A class of computer programs have been developed by the authors to provide comprehensive analysis capabilities for nonlinear dynamic analysis of three-dimensional base isolated structures, which are, 3D-BASIS (Nagarajaiah et al. 1991a; 1991b), 3D-BASIS-M (Tsopelas et al. 1991; 1994), and 3D-BASIS-TABS (Nagarajaiah et al. 1993c). The newest of the class is computer program 3D-BASIS-TABS Version 2.0 described in this report.

Computer programs 3D-BASIS have been specifically developed for analysis of base isolated structures with linear superstructure and nonlinear elastomeric and/or sliding isolation systems. Salient features of 3D-BASIS programs which make them specially suitable for analysis of base isolated structures with different isolation systems are as follows:

1. Capability to analyze isolation systems that are a combination of elastomeric and sliding isolation systems;
2. Unified model capable of representing the biaxial behavior of either elastomeric or sliding bearings and other isolation devices;
3. Capability to capture the highly nonlinear behavior of sliding isolation systems in plane motion;
4. Pseudo-force solution algorithm for accurate and efficient solution of stiff differential equations that arise in sliding systems due to stick-slip behavior;
5. Solution algorithm with the accuracy of predictor-corrector methods and efficiency suitable for analyzing large base isolated structures;
6. Capability to model multistory base isolated buildings and capture the lateral-torsional behavior under bidirectional earthquake motion;
7. Simplicity of input requirements and execution on both main and microcomputers.
With the above mentioned capabilities 3D-BASIS programs have become increasingly popular amongst both researchers and practising engineers leading to several applications (i) preliminary studies in preparation for shake table tests at SUNY-Buffalo and UC-Berkeley; (ii) evaluation of the important effects of nonlinear biaxial interaction between orthogonal lateral forces in isolation bearings, on the response of base isolated structures, by Nagarajaiah et al. (1990) and by Mokha et al. (1993); (iii) simulation of shake table test results using measured properties of the structure and the isolation system (Nagarajaiah et al. 1992); (iv) study of lateral torsional response of base isolated structures (Nagarajaiah et al. 1993a; 1993b); (v) evaluation of SEAOC code provisions for base isolated structures (Constantinou et al. 1993, Theodossiou et al. 1991, Winters et al. 1993); (vi) analysis of new base isolated buildings and existing buildings to be retrofitted using base isolation (Amin et al. 1993, Asher et al. 1993, Button et al. 1993, Cho et al. 1993); (vi) post-earthquake evaluation studies of existing base isolated buildings in seismically active areas such as the region of San-Andreas fault (Clark et al. 1993).

The computer program 3D-BASIS-TABS is a special purpose program developed for nonlinear dynamic analysis of three-dimensional base isolated structures. The program can analyze base isolated structures with linear superstructure and nonlinear isolation system. 3D-BASIS-TABS has three options for modeling the linear superstructure (i) option 1 -- three-dimensional shear building representation, in which case the global stiffness matrix of the superstructure is assembled internally by the program using story stiffnesses, specified by the user, followed by the dynamic analysis; (ii) option 2 -- full three dimensional representation, in which case beam, column, shear wall and bracing elements of the superstructure are modeled explicitly, followed by assembly of the global stiffness matrix, condensation, dynamic analysis, and recovery of internal forces in structural elements by backsubstitution; (iii) option 3 -- three-dimensional representation, in which case the dynamic characteristics of the superstructure, such as frequencies and mode shapes, specified by the user, are used to
compute the superstructure stiffness matrix, followed by dynamic analysis. The isolation system is modeled by representing the force-displacement relationship of each individual isolator explicitly. The aforementioned approach for options 1 and 3 yields accurate global response results; however, the disadvantage is that superstructure member forces cannot be computed, since no data is available for individual members (this is the principal disadvantage of the previous version 3D-BASIS). Option 2 in 3D-BASIS-TABS overcomes the aforementioned shortcoming by computing superstructure member forces, after the completion of the nonlinear time history analysis, followed by output of peak member forces, which can be used for the design of members.

This report describes the development of computer program 3D-BASIS-TABS Version 2.0. The new program is an enhanced version of 3D-BASIS-TABS. The enhancements that have been made include (i) addition of new isolation elements and models for nonlinear dampers and nonlinear bearings; (ii) additional verifications; (iii) several new example problems; (iv) new input/output format for easier usage; (v) updated user's manual.

The input format for the superstructure in 3D-BASIS-TABS has been retained in the same format as in ETABS to facilitate usage. It is to be noted that the aforementioned beam, column, shear wall and bracing elements, substructure condensation, global assembly, and backsubstitution procedures are adopted from the computer program ETABS (Wilson et al. 1975).
SECTION 2
3D-BASIS-TABS

A complete description of computer program 3D-BASIS-TABS has been presented by Nagarajaiah et al. (1993c); however, for the sake of completeness a brief description of the structural model and the solution algorithm is presented in this section. The major steps involved in the assembly of the structural model and the solution algorithm are presented in the Flowchart 2.1. The detailed description of each step is described in the following subsections.

2.1 INPUT DATA

The input format has been retained in the same format as in ETABS to facilitate usage (since many designers are familiar with the superstructure input requirements for ETABS). The data in the form of beam, column, shear wall, and bracing member properties, connectivity, etc., need to be input. In addition the isolation system data in the form of isolator properties, connectivity, etc., need to be input. The data needed for the dynamic analysis also has to be input. The user's manual in APPENDIX A specifies the data input requirements.

2.2 SUPERSTRUCTURE STIFFNESS ASSEMBLY

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, i.e., two translational and one rotational degree of freedom attached to the center of mass. The base and floors are assumed to be rigid diaphragms.

3D-BASIS-TABS is designed to include three options for modeling the superstructure; option 1 for 3D-shear building, in which case story stiffnesses are to be input; option 2 for full 3D-building, in which case member properties for beam, column, etc., are to be input, for detailed member by member representation of the superstructure; option 3 for full 3D-building, in which case eigenvalues/eigenvectors are to be input. If option 1 or 3 is used, member forces are not output, as no data for representing individual members is available.
FLOW CHART OF MAJOR STEPS IN 3D-BASIS-TABS

INPUT DATA

STIFFNESS ASSEMBLY
BEAM, COLUMN, WALL ELEMENT STIFFNESSES
CONDENSATION TO 3 DOF/FLOOR

EIGENVALUE ANALYSIS
FIXED BASE MODE SHAPES AND FREQUENCIES

GLOBAL SYSTEM ASSEMBLY
GLOBAL SYSTEM - COMBINED SUPERSTRUCTURE AND ISOLATION SYSTEM

SOLUTION FOR GLOBAL SYSTEM RESPONSE
SOLUTION USING PSEUDOFORCE SOLUTION ALGORITHM

BACKSUBSTITUTION
BACKSUBSTITUTION TO COMPUTE MEMBER FORCES

OUTPUT
SUPERSTRUCTURE RESPONSE - MEMBER FORCES
ISOLATION SYSTEM RESPONSE
In option 1, the superstructure of the three-dimensional shear building is represented by a global stiffness matrix assembled using story stiffnesses specified by the user. The global displacement coordinate system consists of three degrees of freedom at the center of mass of the floors. It is assumed that the center of mass of all the floors lie on a common vertical axis; floors and beams are rigid; walls and columns are inextensible.

In option 2, the procedure for assembly of the global stiffness matrix from ETABS (Wilson et al. 1975) is adopted. The procedure involves (i) formulation of the lateral stiffness matrix of each frame, which is treated as separate substructure with an associated frame displacement coordinate system; (ii) assembly of the global stiffness matrix, using the frame substructure stiffness transformed to the global displacement coordinate system, with the assumption that all frame substructures are connected at each floor level by a diaphragm which is rigid in its own plane. Each joint in the structure is modeled with six degrees of freedom. Within each frame joint three degrees of freedom (two translations and one rotation in the floor plane) are transformed, using the rigid floor diaphragm assumption, to the frame displacement coordinate system at that floor level. The remaining three frame joint degrees of freedom are eliminated by static condensation. The condensed frame substructure stiffness is transformed to the global displacement coordinate system and added to the global structural stiffness. The global displacement coordinate system consists of three degrees of freedom at the center of mass of the floors. The position of the center of mass may vary from floor to floor; hence, the mass matrix, required for dynamic analysis, will be a diagonal matrix --which simplifies the eigenvalue analysis. The global stiffness matrix of the superstructure, in the fixed base condition, is used for eigenvalue analysis.

In option 3, the superstructure of the three-dimensional building is represented by a global stiffness matrix, assembled using the dynamic characteristics, such as frequencies and mode shapes specified by the user (minimum of three modes of vibration, with the global displacement coordinate system of three degrees of freedom at the center of mass of the floors,
to be specified). Implicit in this approach is that the axial deformation of columns, bending and shear deformation of column and beam members, and arbitrary location of the center of mass, are accounted for by the condensed dynamic characteristics.

2.3 EIGENVALUE ANALYSIS

The eigenvalue analysis is performed to determine the eigenvalues and eigenvectors, i.e., frequencies and mode shapes in the fixed base condition using the global stiffness matrix. The frequencies and mode shapes are used in the global system assembly of the superstructure and the isolation system. The frequencies and mode shapes obtained correspond to the global coordinate system with three degrees of freedom at the center of mass of the floors.

2.4 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.

The following are the elements available for modeling the behavior of an isolation system (i) linear elastic element --spring; (ii) linear viscous element --damper; (iii) hysteretic element for elastomeric bearings and steel dampers; (iv) hysteretic element for sliding bearings; (v) nonlinear damper element --a new element for modeling damping devices; (vi friction pendulum (FPS) element; (vii) new biaxial element for sliding.

2.4.1 Linear Elastic Element

The linear elastic element can be used to approximately simulate the behavior of elastomeric bearings along with the viscous element. All linear elastic devices of the isolation system specified are combined, internally by the program, in global elements at the center of mass of the base, having the combined properties of all the elastic devices, with the translational stiffnesses, $K_x$ and $K_y$ and the rotational stiffness, $K_r$. 

2-4
2.4.2 Linear Viscous Element

The linear viscous element can be used to simulate the viscous properties of the isolation devices. All linear viscous devices are combined, internally by the program, in global viscous elements at the center of mass of the base, having the combined properties of all the viscous devices, with the translational damping coefficients $C_x$ and $C_y$ and rotational damping coefficient $C_r$.

2.4.3 Model for Biaxial Isolation Elements

At a bearing undergoing plane motion with displacement components $U_x$ and $U_y$ and velocity components $\dot{U}_x$ and $\dot{U}_y$ in the X and Y directions, lateral forces develop and these forces exhibit biaxial interaction. In addition a torsional moment develops at the bearing. The contribution of this torsional moment to the total torque exerted to the structure supported by several bearings is insignificant.

The direction of the resultant force at the bearing opposes the direction of the motion given by:

$$\theta = \tan^{-1} \left( \frac{\dot{U}_y}{\dot{U}_x} \right)$$

The model presented herein accounts for the direction and magnitude of the resultant hysteretic force.

The model for biaxial interaction is based on the following set of equations proposed by Park, Wen and Ang (1986):

$$\begin{align*}
\{ \hat{Z}_x Y \} & = \begin{pmatrix} A \dot{U}_x \end{pmatrix} - \begin{pmatrix} Z_x^2 (\gamma \text{Sign}(U_x Z_x) + \beta) & Z_x Z_y (\gamma \text{Sign}(U_y Z_y) + \beta) \end{pmatrix} \begin{pmatrix} \dot{U}_x \end{pmatrix} \\
\{ \hat{Z}_y Y \} & = \begin{pmatrix} A \dot{U}_y \end{pmatrix} - \begin{pmatrix} Z_x Z_y (\gamma \text{Sign}(U_x Z_x) + \beta) & Z_y^2 (\gamma \text{Sign}(U_y Z_y) + \beta) \end{pmatrix} \begin{pmatrix} \dot{U}_y \end{pmatrix}
\end{align*}$$

(2.2)
in which, $Z_x$ and $Z_y$ are hysteretic dimensionless quantities, $Y$ is the yield displacement, $A$, $\gamma$ and $\beta$ are dimensionless quantities that control the shape of the hysteresis loop. The values of $A = 1$, $\gamma = 0.9$ and $\beta = 0.1$ are used in this report. When yielding commences, Eq. 2.2 has the following solution, provided that $A/(\beta + \gamma) = 1$:

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

(2.3)

$Z_x$ and $Z_y$ are bounded by values $\pm 1$ and account for the direction and biaxial interaction of hysteretic forces. The interaction curve given by Eq. 2.2 is circular.

### 2.4.3.1 Biaxial Model for Sliding Bearings

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

$$F_x = \mu_s W Z_x, \quad F_y = \mu_s W Z_y$$

(2.4)

in which, $W$ is the vertical load carried by the bearing and $\mu_s$ is the coefficient of sliding friction which depends on the value of bearing pressure, angle $\theta$ and the instantaneous velocity of sliding $U$:

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

(2.5)

$Z_x$ and $Z_y$, given by Eq. 2.2, are bounded by the values $\pm 1$, account for the conditions of separation and reattachment (instead of a signum function) and also account for the direction and biaxial interaction of frictional forces.

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

$$\mu_s = f_{\text{max}} - (f_{\text{max}} - f_{\text{min}}) \exp(-\alpha |U|)$$

(2.6)

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. $f_{\text{max}}$, $f_{\text{min}}$ and $\alpha$ may be, in general, functions of bearing pressure and angle $\theta$. 

2-6
2.4.3.2 Biaxial Model for Elastomeric Bearings and Steel Dampers

For a elastomeric bearing, the mobilized forces are described by the equations:

\[ F_x = \alpha \frac{F^y}{y} U_x + (1 - \alpha) F^y Z_x, \quad F_y = \alpha \frac{F^y}{y} U_y + (1 - \alpha) F^y Z_y \]  

(2.7)

in which, \( \alpha \) is the postyielding to preyielding stiffness ratio, \( F^y \) is the yield force and \( Y \) is the yield displacement. \( Z_x \) and \( Z_y \), given by Eq. 2.2 account for the direction and biaxial interaction of hysteretic forces.

2.4.4 Model for Uniaxial Isolation Elements

The biaxial interaction can be neglected when the off-diagonal elements of the matrix in Eq 2.2 are replaced by zeros. This results in a uniaxial model with two either frictional or bilinear independent elements in the two orthogonal directions. Eq. 2.2 collapses to the uniaxial model governed by the following equation (Wen 1976):

\[ Z = A\dot{U} - |Z|^n (\gamma \text{sgn}(U) + \beta) \dot{U} \]  

(2.8)

where \( n = 2 \) in the biaxial case and this parameter controls the transition from elastic range to the postyielding range. The value of this parameter can be increased to achieve near-bilinear behavior rather than smooth bilinear behavior. The interaction curve in the uniaxial case is effectively square. In the case of uniaxial sliding element the velocity used for calculation of the coefficient of friction from Eq. 2.6 is either \( U_x \) or \( U_y \).

2.4.5 Nonlinear Damping Element

Many physical systems exhibit nonlinear damping mechanisms such as Coulomb damping, viscous damping, orifice damping, and velocity raised to power \( p \) damping. Several fluid viscous damping and friction damping devices have been proposed. The nonlinear damping force of such devices can be described as being proportional to the the power \( p \) of relative velocity across the damper:

\[ F_d = \left( \sum_{i=1}^{n} F_{\alpha_i} + C_i |U|^{p_i} \right) \text{sgn}(U) \]  

(2.9)
where \( F_{oi} \) is an offset constant for stage \( i \), the damping coefficient \( C_i \) and the exponent \( p_i \) may have any positive value. The signum function \( Sgn(\dot{U}) \) accounts for the phase between the damping force \( F_d \) and the relative velocity \( \dot{U} \), and \( n \) is the number of stages (maximum 2). The applications of such generalized formulation of the damping force are demonstrated as follows:

Coulomb damping \((p_i = 0)\)

\[
F_d = C_i Sgn(\dot{U})
\]  

(2.10)

Linear viscous damping \((p_i = 1)\)

\[
F_d = C_i |\dot{U}| Sgn(\dot{U})
\]  

(2.11)

Nonlinear viscous damping \((p_i = 2)\)

\[
F_d = C_i |\dot{U}|^2 Sgn(\dot{U})
\]  

(2.12)

where \( C_i \) for \( p_i = 0 \) is the magnitude of the Coulomb damping force, \( C_i \) for \( p_i = 1 \) is the coefficient of viscous damping, and \( C_i \) for \( p_i = 2 \) is the coefficient of nonlinear viscous damping. Devices with values of exponent \( p_i \) in the range of 0.4 to 2 have been produced.
2.5 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 Fig. 2.1. 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 Fig. 2.1 or upside-down with the spherical surface down rather than up. In both installation methods the behavior is identical.

![Fig. 2.1 FPS Bearing Section.](image)

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

\[ F = \frac{W}{R} U + \mu_s W \text{sgn}(U) \]  (2.13)

in which \( R \) is the radius of curvature of the spherical sliding surface, \( W \) is the normal load and \( \mu_s \) is the coefficient of the sliding friction. In cases in which the normal load may be assumed to be constant and equal to the carried weight \( W_i \), modeling of an FPS bearings may be accomplished by combining the linear elastic element of Section 2.4.1, using stiffness \( K_{xi} = K_{yi} = W_i/R \), and the biaxial element for sliding bearing of Section 2.4.3, using \( W = W_i \). To reduce computational effort, all the linear elastic elements may be combined in a global element described by translational stiffnesses \( K_x = K_y = \sum W_i/R \) (\( \sum W_i = \text{total weight} \)) and corresponding rotational stiffness \( K_r \) and associated eccentricities \( e_x^b \) and \( e_y^b \) (see Section 2.4.1 and Nagarajaiah et al. 1989 and 1991).
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:

\[
W' = W_i \left(1 + \frac{\ddot{U}_v}{g} + \frac{N_{om}}{W_i}\right)
\]

(2.14)

where \(W_i\) is the weight \(\ddot{U}_v\) is the vertical ground acceleration (positive when the direction is upwards) and \(N_{om}\) is the additional axial force due to the overturning moment effects (\(N_{om}\) is positive when compressive - see requirements for subroutine in Section 2.10.1.)

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 \(W' = W_i\) rather than Eq. (2.14) 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 2 \(W_i\), \(W_i\) being the gravity load (Al-Hussaini et al. 1994).

The forces in the FPS element are described by (Tsopelas et al. 1994):

\[
F_x = \frac{W}{R} \cdot U_x + \mu_s \cdot N_x Z_x \quad \text{and} \quad F_y = \frac{W}{R} \cdot U_y + \mu_s \cdot W Z_y
\]

(2.15)

which \(Z_x\) and \(Z_y\) are described by Eq. 2.2 and \(W\) is described by Eq. 2.14. The current program requires user-supplied routines to:

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

b) Describe the variation of coefficient \(f_{max}\) in Eq. 2.6 with bearing pressure.

Details of these routines are given in Section 2.12.
2.6 NEW BIAXIAL ELEMENT FOR SLIDING BEARINGS

The new biaxial element for flat sliding bearings is described by equations (2.4-2.6 and 2.2) with the exception that $W$ is not constant but rather described by Eq. 2.14. The element requires the user-supplied routines (Tsopelas et al. 1994) described in Sections 2.5 and 2.10. It should be noted that when $\dot{U}_u$ is not given and when the user-supplied routine returns zero for the additional axial load $N_{OM}$ (Eq. 2.14), the model collapses to the original constant normal load ($W' = W_d$) model.

2.7 GLOBAL SYSTEM ASSEMBLY

The formulation for global system assembly of the combined superstructure and the isolation has been presented in detail by Nagarajaiah et al. (1993c); hence, it is presented only briefly herein.

A typical base isolated multistory building and the displacement coordinates that will be used in the formulation are shown in Fig. 2.2 ($U_i$, $U_b$, $U_g$ may be in X or Y direction). The superstructure is modeled as an elastic frame-wall structure with three degrees of freedom per floor, as described earlier. The three degrees of freedom are attached to the center of mass of each floor and base. The floors and the base are assumed to be infinitely rigid inplane. The isolation system may consist of elastomeric and/or sliding isolation bearings, linear springs, viscous elements, and nonlinear damping elements.

The equations of motion for the elastic superstructure are expressed in the following form:

$$M_{n \times n} \ddot{u}_{n \times 1} + C_{n \times n} \dot{u}_{n \times 1} + K_{n \times n} u_{n \times 1} = -M_{n \times n} R_{n \times 3} (\ddot{u}_g + \ddot{u}_b)_{3 \times 1} \quad (2.16)$$

in which, $n$ is three times the number of floors, $M$ is the diagonal superstructure mass matrix, $C$ is the superstructure damping matrix, $K$ is the superstructure stiffness matrix.
Fig. 2.2 Displacement Coordinates of the Base Isolated Structure
and $R$ is the matrix of earthquake influence coefficients i.e., the matrix of displacements and rotation at the center of mass of the floors resulting from a unit translation in the $X$ and $Y$ directions and unit rotation at the center of mass of the base (with respect to global structure reference axis). Furthermore, $\ddot{u}$, $\ddot{u}$ and $u$ represent the floor acceleration, velocity and displacement vectors relative to the base, $\ddot{u}_b$ is the vector of base acceleration relative to the ground and $\ddot{u}_g$ is the vector of ground acceleration.

The equations of motion for the base are as follows:

$$R\dot{u}_b \cdot M \dot{u}_b + \sum_{i}^{3} (\ddot{u}_b + \ddot{u}_g) \cdot M_{i3} \cdot \ddot{u}_3 + C_{b} \cdot \ddot{u}_b + K_{b} \cdot \ddot{u}_b + \ddot{f}_\delta = 0$$

(2.17)

in which, $M_b$ is the diagonal mass matrix of the rigid base, $C_b$ is the resultant damping matrix of viscous isolation elements, $K_b$ is the resultant stiffness matrix of elastic isolation elements and $f$ is the vector containing the forces mobilized in the nonlinear elements of the isolation system such as the presented elements for sliding, elastomeric bearings, etc.

Employing modal reduction:

$$u_n = \Phi_{nxm} \cdot u_{mxi}$$

(2.18)

in which, $\Phi$ is the modal matrix normalized with respect to the mass matrix and $u^*$ is the modal displacement vector relative to the base and $m$ is the number of eigenvectors retained in the analysis, and combining Eqs. 2.16 to 2.18 the following equation is derived:

$$\begin{pmatrix}
[1] & \Phi^T MR \\
[R^T M \Phi] & [R^T MR + M_b]
\end{pmatrix}_{(m-3)x(m-3)} \begin{pmatrix}
\ddot{u}_b \\
\ddot{u}_g
\end{pmatrix}_{(m-3)\times 1} + \begin{pmatrix}
[2\xi_i, \omega_i] & 0 \\
0 & [C_b]_{(m-3)x(m-3)}
\end{pmatrix}_{(m-3)x(m-3)} \begin{pmatrix}
\ddot{u}_b \\
\ddot{u}_g
\end{pmatrix}_{(m-3)\times 1} + \begin{pmatrix}
\ddot{f}
\end{pmatrix}_{(m-3)\times 1} = -\begin{pmatrix}
\Phi^T MR \\
R^T MR + M_b
\end{pmatrix}_{(m-3)x(m-3)} \ddot{u}_{g3x1}
$$

(2.19)

in which, $\xi_i$ = the modal damping ratio, and $\omega_i$ = the natural frequency, of the fixed base structure in the mode $i$. In Eq. 2.19 matrices $[2\xi_i, \omega_i]$ and $[\omega_i^2]$ are diagonal.

2-13
Eq. 2.16 can be written as follows:
\[
\ddot{\mathbf{u}}_t \mathbf{M} \ddot{\mathbf{u}}_t + \mathbf{C} \dot{\mathbf{u}}_t + \mathbf{K} \mathbf{u}_t + f_t = \mathbf{P}_t \\
\]
(2.20)

At time \(t + \Delta t\)
\[
\ddot{\mathbf{u}}_{t+\Delta t} \mathbf{M} \ddot{\mathbf{u}}_{t+\Delta t} + \mathbf{C} \dot{\mathbf{u}}_{t+\Delta t} + \mathbf{K} \mathbf{u}_{t+\Delta t} + f_{t+\Delta t} = \mathbf{P}_{t+\Delta t} \\
\]
(2.21)

Written in incremental form
\[
\ddot{\mathbf{u}}_{t+\Delta t} \mathbf{M} \Delta \ddot{\mathbf{u}}_{t+\Delta t} + \mathbf{C} \Delta \dot{\mathbf{u}}_{t+\Delta t} + \mathbf{K} \Delta \mathbf{u}_{t+\Delta t} + \Delta f_{t+\Delta t} = \mathbf{P}_{t+\Delta t} - \mathbf{M} \ddot{\mathbf{u}}_t - \mathbf{C} \dot{\mathbf{u}}_t - \mathbf{K} \mathbf{u}_t - f_t \\
\]
(2.22)
in which, \(\mathbf{M}, \mathbf{C}, \mathbf{K}\) and \(\mathbf{P}\) represent the reduced mass, damping, stiffness and load matrices (see Eq. 2.19). Furthermore, the state of motion of modal superstructure and base is represented by vectors \(\ddot{\mathbf{u}}_t, \dot{\mathbf{u}}_t\) and \(\mathbf{u}_t\) (see Eq. 2.19).

2.8 LOADING CONDITIONS

Vertical static loading conditions for representing dead loads, and earthquake loads--representing seismic excitation, can be specified. The vertical loading conditions can include up to three independent vertical load distributions (I,II,III) and these distributions are combined to form load cases for the complete building. For earthquake loading conditions, bidirectional lateral ground motions can be specified.

2.9 SOLUTION FOR GLOBAL SYSTEM RESPONSE

The incremental nonlinear force vector \(\Delta f_{t+\Delta t}\) in Eq. 2.22 is unknown. This vector is brought on to the right hand side of Eq. 2.22 and treated as a pseudo-force vector. The two steps in the solution algorithm are (i) The solution of equations of motion using unconditionally stable Newmark's constant-average-acceleration method (Newmark 1959); (ii) The solution of differential equations governing the behavior of the nonlinear isolation elements using unconditionally stable semi-implicit Runge-Kutta method (Rosenbrock 1964) suitable for solution of stiff differential equations. Furthermore, a iterative procedure consisting of corrective pseudo-forces is employed within each time step until equilibrium is achieved. Detailed explanation of the solution algorithm can be found in Nagarajaiah et al. (1991a;1991b).
2.10 BACKSUBSTITUTION

The time history of member forces are computed by backsubstitution, after the nonlinear time history analysis is completed. The peak member forces are output to facilitate the design of members. The backsubstitution procedure from ETABS is adopted.

2.11 OUTPUT DATA

The output data consists of three sets (i) input data for the structure and isolation system; (ii) dynamic characteristics of the structure; (iii) peak response results in the form of maximum response quantities; (iv) time history of response. The dynamic characteristics of the structure output are periods and mode shapes. The peak response results of member response and isolator response is output. A full range of options for output are available, the details of which can be found in the user's manual in APPENDIX A.

2.12 USERS - SUPPLIED ROUTINES IN PROGRAM 3D-BASIS-TABS

2.12.1 Routine for Additional Axial Load Due to Overturning Moment Effects

The routine (a function) has the form:

\[ \text{FOVM}(OVMX,OVMY,XP,YF,I) \]

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 Fig. 2.3. 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.
Fig. 2.3 Definition of Overturning Moments OVMX and OVMY, and Additional Force FOVM.

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

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

This default version of function FOVM in 3DBASIS-TABS.
2.12.2 Routine for Describing the Dependency of Parameter $f_{\text{max}}$ on Bearing Pressure

Constantinou et al. 1990 and 1993 described the dependency on bearing pressure of the parameters in the model of friction in Eq. 2.6. Specifically, the coefficient of sliding friction is given by:

$$\mu_s = f_{\text{max}} - (f_{\text{max}} - f_{\text{min}}) \exp(-\alpha |U|)$$

(2.23)

where $\alpha$ is nearly independent of pressure, whereas $f_{\text{min}}$ 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 $f_{\text{max}}$ is generally dependent on bearing pressure. Since parameter $f_{\text{max}}$ describes the maximum friction force that is transmitted through the bearing, its dependency on pressure is explicitly modeled in this program. However, the much less significant dependency on pressure of parameters $\alpha$ and $f_{\text{min}}$ is neglected.

The user-supplied routine (function) has the form:

FUNCTION FMAX(FRMAX,FRMIN,FNOR,I)

in which $I$ is the bearing number, $\text{FNOR}$ 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 $f_{\text{max}}$ and $f_{\text{min}}$ under almost zero static pressure of bearing $I$. Function FMAX returns the value of $f_{\text{max}}$ at the bearing pressure resulting from the instantaneous normal load. Note that parameter $f_{\text{min}}$ is assumed independent of pressure, that is $f_{\text{min}} = f_{\text{min}}$.

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

Function FMAX should be:

FUNCTION FMAX(FRMAX,FRMIN,FNOR,I)
IMPLICIT REAL *8
COMMON/MAIN1/NB,NP,MNF,MNE,NFE,MXF
FMAX = FRMAX
RETURN
END
This is the default version of function FFMX.

Consider now the case of pressure dependent parameter $f_{max}$. Figure 2.4 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:

$$f_{max} = f_{max0} - (f_{max0} - f_{maxp}) \tanh(\epsilon P)$$  

(2.24)

where $P$ is the instantaneous bearing pressure, $f_{maxp}$ is the maximum coefficient of friction at very high pressures, $f_{max0}$ is the value of the coefficient at zero pressure, $\epsilon$ is a constant that controls the transition of $f_{max}$ between very low and very high pressure.

Fig. 2.4 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: \( f_{\text{max}} = 0.12, \ f_{\text{maxp}} = 0.05, \ \epsilon = 0.012 \) (\( P \) the bearing pressure is in the units of MPa). For this case function \( \text{FFMAX} \) should be of the form:

\[
\text{FUNCTION FFMAX(FRMAX,FRMIN,FNOR,I)} \\
\text{IMPLICIT REAL *8} \\
\text{COMMON MAIN1/NB,NP,MNF,MNE,NFE,MXF} \\
\text{DIMENSION P(500)} \\
\text{DATA/P(J) = 17.2,J = 1,../} \\
\text{etc. etc.} \\
\text{PRES = FNOR*P(I)} \\
\text{FFMAX = FRMAX - 0.07*DTANH(0.012*PRES)} \\
\text{END} \\
\]

Note that \( P(J) \) contains the bearing pressure under static conditions of bearing \( J \). Quantity \( \text{PRES} \) is the instantaneous bearing pressure in units of MN/m\(^2\) or MPa.
SECTION 3
VERIFICATION AND EXAMPLE PROBLEMS

3D-BASIS-TABS has been verified by the authors (Nagarajaiah et al. 1993c). This section describes the previous verification briefly, for completeness sake, and also describes additional verification of 3D-BASIS-TABS.

The verification is performed using three example problems. The first example problem consists of a three story reinforced concrete building with sliding isolation system. The second example considered is a single story structure on lead-rubber isolation system. The third example problem consists of a six story reinforced concrete building with lead-rubber bearing isolation system.

The verification using the three story reinforced concrete building with sliding isolation system is accomplished by comparing the dynamic analysis results of program 3D-BASIS-TABS, in the form of peak member forces at a chosen instant of time during the time history, with the pseudo-static analysis results of finite element program STAAD; thus, validating the member force computations in the program 3D-BASIS-TABS. The pseudo-static analysis, performed using commercially available finite element program STAAD, consists of application of lateral forces or inertial forces, at the same instant of time as chosen in 3D-BASIS-TABS time history analysis, at the center of mass of the three floors. The lateral forces or inertial forces are extracted from the dynamic analysis using 3D-BASIS-TABS.

The verification using the single story structure with lead-rubber bearing isolation system is accomplished by comparing the results at the center of mass from program 3D-BASIS-TABS with the results of program ANSR (Mondkar and Powell 1975); thus, validating the global results.

The verification using the six story reinforced concrete building with lead-rubber bearing isolation system is accomplished by comparing the results of 3D-BASIS-TABS with the results of a two dimensional analysis performed using DRAIN-2D (Kannan and Powell 1975). Also,
results, at the center of mass, from program 3D-BASIS-TABS --modeling the superstructure explicitly element-by-element-- are compared with the results of program 3D-BASIS (Nagarajaiah et al. 1991b) using the dynamic characteristics of the superstructure, i.e., eigenvalues and eigenvectors; thus, validating the global results.

3.1 THREE STORY REINFORCED CONCRETE BUILDING WITH SLIDING ISOLATION SYSTEM

The three story reinforced concrete building considered has three bays in each direction and has a square plan with dimensions 12 x 12 meters as shown in Fig. 3.1. The dimensions of the various members shown in Fig. 3.1 are (i) beams 300 x 400 mm; (ii) interior columns 300 x 400 mm; (iii) exterior columns 300 x 300 mm; (iv) R/C bracing members 300 x 300 mm; (v) shear wall or panel of 100 mm thickness. The floor slab is 150 mm thick. The floor masses are (i) translational mass of 119.4 kN-sec^2/m; and (ii) mass moment of inertia of 2985.6 kN-m-s^2. The modulus of elasticity of the concrete is assumed to be $E_c = 29862560$ kN/m^2. The damping ratio in the superstructure is assumed to be 5% of critical.

The building is base isolated using a sliding isolation system as shown in Fig. 3.2 and Fig. 3.3. The sliding isolation system consists of 16 sliding bearings placed concentrically under each column and 4 recentering springs placed at the four corners of the building as shown in Fig. 3.3. Design of the isolation system is based on appropriate code provisions. The sliding isolation bearings are made of unfilled Teflon and polished stainless steel plates. The sliding bearings have a coefficient of friction $f_{\text{max}} = 0.1$ and $f_{\text{min}} = 0.07$. The recentering helical springs are designed to provide an isolation period $T_b = 3$ sec. The sliding bearings and helical springs are shown in Fig. 3.2 in greater detail (see the enlarged detail Fig. 3.2).

3D-BASIS-TABS is used to analyze the base isolated building excited by El Centro NS earthquake. The input and output files for this building are given in APPENDIX B.
FIG. 3.1. Superstructure Member configuration and Isolation System Configuration of the Three­Story Reinforced Concrete Sliding Isolated Building. Note the Location of the Structure Axis at the Center of Mass of the Base and the Location of the Column Lines 1, 4, 13 and 16 (Refer to the Input File Given in Appendix B)
FIG. 3.2. Cross Section of the Three-Story Reinforced Concrete Sliding Isolated Building (Left Extreme Column Line is 16 and Right Extreme Column Line is 13). Note the Details of the Sliding Bearing and Recentering Spring Shown in the Inset and Plan Location Shown in FIG 3.3.
FIG. 3.3. Plan of the Sliding Isolation System with Teflon - Steel Disc Sliding Bearings and Recentering Springs
FIG. 3.4. Cross Sectional Plan of the Three-Story Reinforced Concrete Sliding Isolated Building Between Levels 2 and 3. Note the Location of the Column Lines and Bay Numbers (Refer to the Input File Given in Appendix B)
3.1.1 Verification of Member Force Computations

The local response results, in the form of peak member forces at a chosen instant of time (t = 3.05 sec) during the time history analysis, are verified by comparing the results of 3D-BASIS-TABS with the results of a pseudo-static analysis -- performed using commercially available finite element program STAAD. The pseudo-static analysis using STAAD consists of application of lateral forces or inertial forces, at the same instant of time as chosen in 3D-BASIS-TABS time history analysis, at the center of mass of the three floors. The lateral forces or inertial forces are extracted from the dynamic analysis using 3D-BASIS-TABS. A comparison between the member forces computed in 3D-BASIS-TABS and STAAD is shown in Table 3-1 and 3-2. Table 3-1 shows the column moments and forces. Table 3-2 shows the beam moments. It is evident from the comparison in Tables 3-1 and 3-2 that member force computation in 3D-BASIS-TABS is accurate.

3.2 SINGLE STORY STRUCTURE WITH LEAD-RUBBER BEARING ISOLATION SYSTEM

The single story shear building has equal base dimensions L = 480 inch (12192 mm); it is supported on four corner columns; it has a height of 180 inch (4572 mm) and a total weight of 480 Kips (2135 kN). Equal floor and base weight is considered. The center of mass of both the floor and the base are assumed to be on the same vertical axis. The vertical axis of centers of mass is offset from the geometric center of the building for inducing a mass eccentricity of 0.083L in the Y direction. Eccentricities \( e_x = e_y = 0.1L \), of the center of resistance of the superstructure from the center of mass, are considered. The uncoupled translational period of the superstructure \( T_s \) is 0.3 sec in both X and Y directions. The uncoupled torsional period of the superstructure \( T_\theta \) is equal to 0.58 \( T_s \). Viscous damping of 2 percent of critical is used for the superstructure in all the three modes.

An isolation system consisting of four lead-rubber bearings placed below the columns is considered. The design of the isolation system is based on a ground motion with
### Table 3-1 Comparison of Column Forces

<table>
<thead>
<tr>
<th>Floor</th>
<th>Member ID</th>
<th>3D-BASIS-TABS</th>
<th>STADTHI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>MOM-X (kN-m)</td>
<td>MOM-Y (kN-m)</td>
</tr>
<tr>
<td>1st</td>
<td>COL. #1 (TOP)</td>
<td>9.75</td>
<td>0.06</td>
</tr>
<tr>
<td>1st</td>
<td>COL. #1 (BOT.)</td>
<td>13.29</td>
<td>0.03</td>
</tr>
<tr>
<td>2nd</td>
<td>COL. #1 (TOP)</td>
<td>9.63</td>
<td>0.11</td>
</tr>
<tr>
<td>2nd</td>
<td>COL. #1 (BOT.)</td>
<td>9.61</td>
<td>0.10</td>
</tr>
<tr>
<td>3rd</td>
<td>COL. #1 (BOT.)</td>
<td>10.26</td>
<td>0.21</td>
</tr>
</tbody>
</table>

### Table 3-2 Comparison of Beam Moments

<table>
<thead>
<tr>
<th>Floor</th>
<th>Member ID</th>
<th>3D-BASIS-TABS</th>
<th>STADTHI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I-MOM (kN-m)</td>
<td>J-MOM (kN-m)</td>
</tr>
<tr>
<td>1st</td>
<td>BEAM AT BAY #4</td>
<td>18.95</td>
<td>15.69</td>
</tr>
<tr>
<td>2nd</td>
<td>BEAM AT BAY #4</td>
<td>18.50</td>
<td>15.58</td>
</tr>
<tr>
<td>3rd</td>
<td>BEAM AT BAY #4</td>
<td>10.29</td>
<td>8.26</td>
</tr>
</tbody>
</table>
the characteristics of the ATC 0.4g S2 spectrum and on the procedure developed by Dynamic Isolation Systems (1983). A design live load of 200 Kips (889.6 kN) is considered in addition to the total dead load of 480 Kips (2135 kN). The bearings chosen are of 13 inch (330.2 mm) diameter and with 18 layers of natural rubber (hardness 50) of 0.375 inch (9.53 mm) thickness. Lead plugs of 2.5 inch (63.5 mm) diameter are present in all four bearings. The average properties of bearings determined are the initial elastic stiffness of 17.8 K/in (3.12 kN/mm), the postyielding stiffness of 2.74 K/in (0.48 kN/mm) and the yield strength FY of 6.6 Kip (29.36 kN). The total yield strength of the isolation system is 5.5% the structural weight. The rigid body mode period is:

\[ T_b = 2\pi \left( \frac{W}{K_b g} \right)^{1/2} \]  

(3.1)

in which, W is the total weight and K_b is the total post yielding stiffness of four Lead-rubber bearings. T_b in the present case is 2.12 sec.

The single story base isolated building excited by 1940 El Centro is analyzed using 3D-BASIS-TABS. The S00E component is input in the X direction and S90W is input in the Y direction. The input and output files for the single story base isolated building are given in APPENDIX C.

Fig. 3.5 shows the bearing displacement response at corner bearing No. 1 (see the input/output files in APPENDIX C for details). The peak ground displacement (PGD) of 4.29 inch (108.96 mm) is used for normalizing the displacement response. The same base isolated building is analyzed using ANSR (Mondkar and Powell 1975). The comparison between the response computed using 3D-BASIS-TABS and ANSR --with completely different modeling and solution procedures-- is shown in Fig. 3.5, from which, it is evident that the results of 3D-BASIS-TABS are accurate. Also, the results of 3D-BASIS-TABS (see APPENDIX C) and the results of 3D-BASIS (refer to section 7.3 of NCEER 91-0005; Nagarajaiah et al. 1991b) are identical.
FIG. 3.5. Comparison of Response Computed Using 3D-BASIS-TABS and ANSR of Single-Story Structure on Lead-rubber Isolation System Subjected to El Centro Earthquake with Component S00E in X Direction and Component S90W in Y Direction (PGD = 108.9 mm)
3.3 SIX STORY REINFORCED CONCRETE STRUCTURE WITH LEAD-RUBBER BEARING ISOLATION SYSTEM

The analysis of a six story reinforced concrete base isolated structure with the lead-rubber bearing isolation system is considered. The plan and section of the building are shown in Fig. 3.6. The reinforced concrete superstructure is designed to resist lateral loads equivalent to a seismic base shear coefficient of 0.15 g using shear walls. Damping of 5% of critical is used for the superstructure in all the modes. 3D-BASIS-TABS is used to model the superstructure (i) using option 2 -- with member-by-member modeling; (ii) using option 3 -- with eigenvalues and eigenvectors.

The lead-rubber bearing isolation system designed based on the procedure developed by Dynamic Isolation Systems (1983) consists of 22 lead-rubber bearings (see Fig. 3.6(b)). A site specific response spectrum is used in the design of the structure/isolation system. The average isolation yield level $Q_a$ is set to $0.045W$, where $W$ is the total weight of the structure $= 25143$ kN. The rigid body isolation period $T_b$ (see Eq. 3.1) is 1.65 sec. The dynamic response is computed for a artificial accelerogram of 20 sec duration. The artificial accelerogram is realized from the site specific response spectrum. For more details about the isolation system parameters and the artificial accelerogram refer to Nagarajaiah et al. (1991b). The 3D-BASIS-TABS input and output files, for option 2 are given in APPENDIX D, and for option 3 in APPENDIX E.

To verify the response the structural stiffness properties are condensed to six degrees of freedom (one per floor in the Y direction) and used for a two dimensional analysis using DRAIN-2D (Kannan and Powell 1975). The properties of the isolation system are lumped with $F_Y = 1328$ kN, $Y = 0.00525$ meters, $\alpha = 0.148$, and $Q_a = 0.045W$ in a single isolation element, resulting in $T_b = 1.6$ sec. The artificial accelerogram used in 3D-BASIS-TABS analysis is used as the excitation. The base displacement response (Y direction) is shown in Fig. 3.7. The comparison between the results of 3D-BASIS-TABS and DRAIN-2D, shown in Fig. 3.7.
FIG. 3.6. Six-Story Reinforced Concrete Base Isolated Structure: (a) Section; (b) Plan
FIG. 3.7. Comparison of Response Computed Using 3D-BASIS-TABS and DRAIN-2D of the Six-Story Base Isolated Structure to Simulated Earthquake
indicates good agreement. Also, the results of 3D-BASIS-TABS (see APPENDIX D and E) and the results of 3D-BASIS (refer to section 8 and APPENDIX B of NCEER 91-0005; Nagarajaiah et al. 1991b) are identical.

3.4 SIX STORY STRUCTURE WITH LEAD-RUBBER BEARINGS AND SUPPLEMENTAL NONLINEAR DAMPERS

The analysis of the six-stories base isolated structure presented previously in Section 3.3 is considered again with addition of nonlinear viscous dampers at the base to limit the maximum base movement. The plan of the building and its characteristics are described in Section 3.3.

The base isolation is complemented in this example by the addition of four pairs of dampers placed at the bearings S18-9-4.0 positions along the north and south lines at the intersection with the first interior column lines (see Fig. 3.6). Each pair of dampers has rectangularly arranged dampers co-linear with the column lines. Each nonlinear damper has a linear range at low velocities \( C_{o1} = 877 \text{kN-sec/m, } p = 1, F_{o1} = 70 \text{kN} \), a nonlinear range starting at 10 cm/sec \( C_{o2} = 182.6 \text{kN-sec/m, } p = 0.5, F_{o2} = 100 \text{kN} \) and is limited to deliver a maximum force of 200 kN for velocities larger than 35 cm/sec. The design was obtained aiming to add approximately 10% of critical damping to the damping delivered by the lead rubber bearings.

The structure was reanalyzed with the same artificial accelerogram obtained from the site specific response spectrum. The 3D-BASIS-TABS input-output files are presented in Appendix G.

The response of the isolation base without supplemental damping and with the additional dampers, with linear characteristics only, is presented in Fig. 3.8(a). The response of the same structure with the supplemental nonlinear dampers is shown in Fig. 3.8(b). The effect of the nonlinear dampers is particularly strong in reducing the peak base movement from 8 to 5.2 cm. Although the forces in the superstructure may increase somewhat, this increase is not substantial to require a change in the design.
Fig. 3.8 Comparison of Response of Six-Story Base Isolated Structure To Simulated Earthquake with (a) Supplemental Linear Viscous Dampers and (b) Supplemental Nonlinear Damper
SECTION 4
CONCLUDING REMARKS

3D-BASIS-TABS Version 2.0 has been described in this report. 3D-BASIS-TABS integrates the special features of ETABS, such as the efficient modeling approach for the 3D-superstructure, and the special features of 3D-BASIS, such as the modeling approach for sliding isolation systems in plane motion and accurate solution algorithm; this enhanced program will help engineers to analyze and design base isolated structures with accuracy and efficiency.

Addition of new isolation elements for modeling nonlinear dampers has been described. Addition of frictional bearings (FPS) with variable pressure resulting from vertical earthquake components and from overturning has been described. The verification of 3D-BASIS-TABS has also been described by means of several useful examples (the input and output files of which are included in the APPENDICES). Microcomputer PC version, and main frame VAX and SUN versions of 3D-BASIS-TABS have been developed. The versatility of 3D-BASIS-TABS stems from the fact that it can analyze base isolated structures, like sliding isolated structures, with great accuracy and yet complete the analysis in a reasonable CPU time on a microcomputer.

SECTION 5
REFERENCES


APPENDIX A
3D-BASIS-TABS PROGRAM
USER'S MANUAL

A.1 INPUT FORMAT

The program 3D-BASIS-TABS prompts for the input file name, the output file name and the earthquake excitation file names; the choice of file names (e.g., EXAMPL1.DAT, EXAMPL1.OUT, WAVEX.DAT, WAVEY.DAT and WAVEZ.DAT) rests with the user. Instructions of use of the program, input information and short cuts for various operating systems (DOS, VAX, UNIX) are included in the distribution computer diskettes. In the program dynamic arrays are used; also, double precision is used for accuracy. Common block size has been set to 100,000 and should be changed if the need arises.

A free format is used to read all input data. Hence, conventional delimiters (commas, blanks) may be used to separate data items. Standard FORTRAN variable format is used to distinguish integers and floating point numbers. Input data must therefore, conform to the specified variable type. All values are to be input unless mentioned otherwise. No blank lines are to be specified.

Note: Provision is made for a line of user defined descriptive text between each set of data items (refer to variable USER_TXT in sections A.2 to A.9 and to the example data files accompanying this manual).

A.2 PROBLEM TITLE

TITLE TITLE upto 80 characters.

A.3 UNITS

UNITS UNITS upto 80 characters.
A.4 CONTROL PARAMETERS

A.4.1 General Control Information

USER_TEXT Reference information: upto 80 characters of text.

ISEV,NST,NFQ,NP,LOR, G, IEXE

(1)* ISEV = 1 for option 1 - Data for 3D-shear building (story shear stiffnesses to be specified in the input file).

(1) ISEV = 2 for option 2 - Data for full 3D-building (member properties for beams, columns etc. to be specified in the input file).

(1) ISEV = 3 for option 3 - Data for 3D-building (Eigenvalues/Eigenvectors to be specified in the input file).

NST = Number of stories in the complete building excluding the base (If NST<1 then NST set = 1)

(2) NFQ = Number of eigenvectors/eigenvalues to be retained in the analysis (If NFQ<3 then NFQ set = 3)

(3) NP = Number of isolators such as bearings, dampers etc. (if NP<4 then NP set = 4)

LOR = Length of earthquake records (number of data points; the X, Y, and Z direction records must have the same length).

G = Gravitational acceleration

IEXE = Flag (integer) for data check
         = 1 for data check only
         = 0 data check and complete execution of analysis.
Notes: 1. For explanation of the option 1, option 2 and option 3 refer to section 3.2 (of NCEER 93-0011). If option 1 or 3 are used then member forces are not needed as output.

2. Number of eigenvectors/eigenvalues retained in the analysis should be in groups of three - the minimum being one set of three modes.

3. Number of bearings refers to the total number of bearings which could be a combination of linear elastic elements, viscous elements, elastomeric bearings, steel dampers, and sliding bearings.

A.4.2 Superstructure Control Information (for ISEV = 2 only; skip this section and go to Section A.4.3 if ISEV = 1 OR 3)

USER_TXT Reference information; upto 80 characters of text.

NDF, NTF, NLD

(1)* NDF = Number of frames with different properties or different vertical loading

(1) NTF = Total number of frame or shear wall elements in the structure

(2) NLD = Total number of load conditions

*Notes: 1. Input data for frames with identical properties and vertical loading are given only once - see also section A.5.1.3 on Frame Location.

2. Load conditions are defined as combinations of the four load cases - see section A.8 on Load Case Definition.
A.4.3 Integration Control Parameters

USER_TXT       Reference information; upto 80 characters of text.

TSI,TOL,FMNORM,MAXMI,KVSTEP

(1)* TSI = Time step of integration.
       (If TSI > TSR then TSI set = TSR;
        refer to A.4.5 for details about TSR)

(2)    TOL = Tolerance for the nonlinear force vector computation.

(3)    FMNORM = Reference moment at the center of mass of the base
        used for computing convergence.

(4)    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 given
     in A.4.5.

2. Tolerance for force computation may be 0.001.

3. The reference moment at the center of mass of the base can be calculated approximately
   by multiplying the base shear by one half the maximum dimension at the base.

4. If MAXMI is exceeded the program is terminated with an error message.
A.4.4 Newmark’s Method Control Parameters

GAM, BET

GAM = Parameter which produces numerical damping within a time step.
(if GAM = 0.0 then GAM set = 0.5)

BET = Parameter which controls the variation of acceleration within a time step.
(if GAM = 0.0 then GAM set = 0.25)

A.4.5 Earthquake Control Parameters

INDGACC, TSR, XTH, ULF

(1)a* INDGACC = 1 for a single lateral earthquake record at an angle of incidence XTH.

(1)b INDGACC = 2 for two independent lateral earthquake records along the X and Y axes.

(1)c INDGACC = 3 for two independent lateral earthquake records along the X and Z axes.

(1)d INDGACC = 4 for three independent lateral earthquake records along the X, Y, and Z axes.

(2) TSR = Time step of the earthquake record(s).
XTH = Angle of incidence of the earthquake with respect to the X axis in anticlockwise direction in degrees (for INDGACC = 1).

ULF = Load factor.

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

a) INDGACC = 1 refers to a single earthquake record input at any angle of incidence XTH with respect to the X axis. Input only one earthquake record (read through a single file e.g., WAVEX.DAT). Refer to A.9.1 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 e.g., WAVEXP1.DAT and WAVEYP1.DAT). Refer to A.9.1 and A.9.2 for wave input information.

c) INDGACC = 3 refers to two independent earthquake records in X and Z directions. Refer to A.9.1 and A.9.3 for wave input information.

d) INDGACC = 4 refers to three independent earthquake records in X, Y, and Z directions. Refer to A.9.3 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 = 1, 2, 3 and 4.

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

A.5 SUPERSTRUCTURE DATA

Go to A.5.1 for ISEV = 2 (refer to A.4.1) and specify beam, column, panel and bracing properties for full three dimensional representation of the superstructure.

Go to A.5.2 for ISEV = 1 (refer to A.4.1) and specify story stiffness for three dimensional shear building representation of the superstructure.
Go to A.5.3 for ISEV = 3 (refer to A.4.1) and specify eigenvalues and eigenvectors for three dimensional representation of the superstructure.

**A.5.1 THREE DIMENSIONAL BUILDING** (for ISEV = 2 only; Skip this section if ISEV = 1 OR 3)

**USR_TXT** Reference information; upto 80 characters of text

Note: The sections A.5.1.1 to A.5.1.3 are based on the input requirements of ETABS.

**A.5.1.1 Story Data**

**USR_TXT** Reference information; upto 80 characters of text.

\[(SD(N,I), I=2,6), N=1,NST]\]

SD(N,2) Story height [distance from the floor (or roof) level to the floor (or base) level below].

SD(N,3) = Translational mass.

SD(N,4) = Rotational mass moment of inertia about a vertical axis through the center of mass.

(1) SD(N,5) = X-distance to the center of mass measured from the STRUCTURE REFERENCE AXIS.

(1) SD(N,6) = Y-distance to the center of mass measured from the STRUCTURE REFERENCE AXIS.

Note: Input one set per story from the top story to the bottom story of the superstructure.

(1) The GLOBAL STRUCTURE REFERENCE AXIS has to be a vertical axis at the center of mass of the base.
A.5.1.2 Frame Data

Repeat the following block of data for each different frame (upto the total number of different frames = NDF).

USR_TXT Reference information; upto 80 characters of text.

A.5.1.2.1 Frame Control Parameters

USR_TXT Reference information; upto 80 characters of text.

M,NS,NC,NB,NCP,NBP,NFEF,NPAN,NTRU

(1)* M = Frame identification number.

(2) NS = Number of story levels above the base.

(3) NC = Number of vertical column lines in the frame.

NB = Number of bays in the frame.

(4) NCP = Number of sets of different column properties.

(5) NBP = Number of sets of different beam properties.

(6) NFEF = Number of sets of different fixed end moments and shears to be applied as vertical loads to beams

(7) NPAN = Number of infill shear panels in the frame.

(8) NTRU = Number of bracing elements in the frame.

*Note: One set of data must be entered for each different frame. Frames with different locations but identical properties and vertical loading need be entered only once (see also section A.5.1.3 on Frame location cards).
1. Frame identification numbers must be entered in numerical sequence beginning with number one (1). This frame may be located (repeated) at different positions in the structure.

2. If a frame does not extend the full height of the building, then only those story levels actually existing in the frame are to be input.

3. An isolated shear wall is a single column line frame. For this case all data pertaining to beams is meaningless and must be omitted in the data input section to follow.

4. Column properties may be referenced to any number of columns in the frame. The number of column property sets control A.5.1.2.3.

5. The number of beam property sets control the number sets of data to be read in section A.5.1.2.4.

6. If no vertical static loads act on the structure, then input zero, and skip section A.5.1.2.5.

7. If no panel elements are included in this frame, then input zero, and skip section A.5.1.2.8.

8. If no bracing elements are included in this frame, then input zero, and skip section A.5.1.2.9.

**A.5.1.2.2 Vertical Column Line Coordinates**

USR_TXT Reference information; upto 80 characters of text.

(M,(CLN(J,1),I = 1,2),J = 1,NC)

(1)*

M = Column line identification number

(2)

CLN(J,1) = X-distance to Jth column line from frame reference point.

CLN(J,2) = Y-distance to Jth column line from frame reference point.
*Note: 1. One set of vertical column line coordinates have to be input for each column line in the frame. For frames with a single column line a second column should be specified to define the major axis for column properties entered in section A.5.1.2.7.

2. Coordinates of column lines are measured from the frame (local) axis.

A.5.1.2.3 Column Property

USR_TXT Reference information; upto 80 characters of text.

\( (M,(CP(J,I),J=1,9),I=1,NCP) \)

(1)* \( M = \) Identification number for this column property set

\( CP(1,I) = \) Modulus of Elasticity, \( E \).

\( CP(2,I) = \) Axial Area \( A \).

(2) \( CP(3,I) = \) Shear area associated with shear forces in major axis direction.

(2) \( CP(4,I) = \) Shear area associated with shear forces in minor axis direction.

\( CP(5,I) = \) Torsional inertia.

\( CP(6,I) = \) Flexural inertia for bending in the major axis direction.

\( CP(7,I) = \) Flexural inertia for bending in the minor axis direction.

(3) \( CP(8,I) = \) Rigid zone depth at the top of column (for both axis). \( DT \).

(4) \( CP(9,I) = \) Rigid zone depth at the bottom of column. \( DB \).
*Note: One set of data must be supplied for each different column in this frame.

1. Property set identification numbers must be in increasing numerical sequence beginning with one (1).

2. Shearing deformations are ignored if shear areas are zero.

3. The rigid zone depth is used to reduce the effective length of the column about both axis.

4. Usually zero unless beam extends above the floor level.

Fig. A-1 - Typical Column Model.
A.5.1.2.4 Beam Property

USR.TXT Reference information; upto 80 characters of text.

\[ (M,(BP(J,I),J = 1,9),I = 1,NBP) \]

1. Identification number for this beam property set

\[ BP(1,I) = \text{Modulus of Elasticity, } E. \]

2. Shear Area A.

\[ BP(3,I) = \text{Torsional inertia.} \]

3. Flexural inertia, I.

\[ BP(4,I) = \text{F} \]

\[ BP(5,I) = K_{II} - \text{stiffness factor (e.g., 4)} \]

\[ BP(6,I) = K_{JJ} - \text{stiffness factor (e.g., 4)} \]

\[ BP(7,I) = \text{K}_{JJ} - \text{stiffness factor (e.g., 2)} \]

3. Rigid zone length at end I of the beam.

\[ BP(8,I) = \text{Rigid zone length at end J of the beam.} \]

*Note: One set of data must be supplied for each different beam in the frame; skip this input if the frame has only one column line.

1. Property set identification numbers must be input in increasing numerical sequence beginning with one (1).

2. Shearing deformations are ignored if shear areas are zero.

3. The beam rigid zone lengths are used to reduce the effective length of the beam.
A.5.1.2.5 Fixed-End Beam Loads

(if NFEF = 0 in section A.5.1.2.1 skip this section)

USR_TEXTR

Reference information; upto 80 characters of text.

(M,IFEF(I),(FEF(J,I),J=1,5),I=1,NFEF)

(1)*

M = Identification number for this vertical loading set

IFEF(I) = Index:

EQ. 0; Fixed-end forces are applied at the column faces

EQ. 1; Fixed-end forces are applied at the column centerlines

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(2) \[ FEF(1,1) = \text{Fixed-end reaction, } M_1 \]
\[ FEF(2,1) = \text{Fixed-end reaction, } V_1 \]
\[ FEF(3,1) = \text{Fixed-end reaction, } M_2 \]
\[ FEF(4,1) = \text{Fixed-end reaction, } V_2 \]

(3) \[ FEF(5,1) = \text{Uniform force per unit length, } w, \text{ acting downward to be added to fixed-end reactions} \]

*Note: One set of data must be supplied for each different type of vertical beam loading; omit this data set if this is a single column line frame

1. Load set numbers must be input in sequence.

2. Reactions act on the beam ends and are positive as shown in the Fig. A-3.

3. Additional fixed-end forces due to the uniform load, \( w \), are calculated using:
\[ M = \frac{w \cdot l^2}{12}; \quad V = \frac{w \cdot l}{2} \]
and are added to any specified fixed-end reactions. The forces due to uniform load, \( w \), are exact only for prismatic beams.

![Fig. A-3 - Typical Beam Loading](image)
A.5.1.2.6 Beam Location, Properties and Loads

USR_TXT Reference information; upto 80 characters of text.

\[[ \{ I,(LB(N,M,L),L=1,3),K,(LDB(N,M,L),L=1,3) \},N=1,NS \},M=1,NB \]

I = Bay identification number for this beam.

(1)*

LB(N,M,1) = Column line number at end I.

LB(N,M,2) = Column line number at end J.

(2)

LB(N,M,3) = Beam property set identification number for this beam.

(3)

K = Number of beams in sequence below to be generated having the same properties and vertical loading as this beam.

(4)

LDB(N,M,1) = Vertical loading set identification number for vertical load case I.

LDB(N,M,2) = Vertical loading set identification number for vertical load case II.

LDB(N,M,3) = Vertical loading set identification number for vertical load case III.

*Note: One set of data must be input from top to bottom and from bay to bay in the frame (unless the data generation option is used)

1. Position of I and J ends defines local coordinate axis with local "y" positive from I to J and local "z" positive vertically upwards. A right hand screw rule sign convention applies.

2. Beams with zero stiffness (missing beams) may be input as having a property set number of zero; if the beam has finite stiffness, the set number must reference an existing property set defined previously is section A.5.1.2.4.
3. The generation option can only be used to define girders within the current bay; a new bay must be started with a new beam card.

4. The vertical loading sets defined in section A.5.1.2.5, are applied to the beams defined herein. Three independent vertical load distributions (I,II,III) are allowed, and these distributions are combined to form load cases for the complete building; see section A.8.

A.5.1.2.7 Column Location and properties

USR_TXT Reference information; upto 80 characters of text.

\[
\{ \{ \text{KK},(\text{LC}(\text{N},\text{M},1),1,2),\text{K} \},\text{N}=1,\text{NS} \},\text{M}=1,\text{NC} \]

\(\text{KK} = \) Column line identification number for this column.

(1)* \(\text{LC}(\text{N},\text{M},1) = \) Column property set identification number.

(2) \(\text{LC}(\text{N},\text{M},2) = \) Column line number defining direction of major axis.

(3) \(K = \) Number of columns in sequence below to be generated having the same properties as this column member.

*Note: One card per column must be input from top to bottom and from column line to column line of the frame (unless the data generation option is used).

1. Missing columns may be input as having a property set number of zero (0); if the column has finite stiffness, then the set number referenced must correspond to one of the property sets defined previously in section A.5.1.2.3.

2. Defines direction on local "y" axis; local "z" axis is in the vertical plane with positive upwards. A right hand screw rule convention applies.

3. Generation is allowed only within the current column line; begin a new column line with a new column card.
A.5.1.2.8 Panel Properties

USR.TXT Reference information; up to 80 characters of text.

(LP(1,I), LP(2,I), LP(3,I), (PP(J,I), J = 1, 5), I = 1, NPAN)

(1)*

LP(1,I) = Level identification number at the top of this panel.

LP(2,I) = Column line number at the I side of this panel.

LP(3,I) = Column line number at the J side of this panel.

PP(1,I) = Modulus of elasticity, E.

PP(2,I) = Gross sectional area, A.

PP(3,I) = Moment of inertia, I.

PP(4,I) = Effective shear area, A_v.

PP(5,I) = Shear modulus, G.

*Note: Input one set of data per panel in any order; no generation is allowed.

1. Base is defined as level zero, and the roof level number is equal to the total number of stories in the building.

2. A zero (0) value for the moment of inertia selects the pure shear deformation panel model. The pure shear panel uses the gross sectional area, not the effective area, to calculate stiffness and stress values.
A.5.1.2.9 Bracing Properties

USR_TXT  Reference information; upto 80 characters of text.

(LT(1,I),LT(2,I),LT(3,I),TP(1,I),TP(2,I),I=1,NTRU)

LT(1,I) = Level identification number at the top of this brace.
LT(2,I) = Column line number at the upper end of this brace.
LT(3,I) = Column line number at the lower end of this brace.
TP(1,I) = Modulus of elasticity, E.
TP(2,I) = Cross sectional area, A.

*Note: Input one set of data per brace in any order; no generation is allowed.

A.5.1.3 Frame location cards

USR_TXT  Reference information; upto 80 characters of text.

IF,IFC,X1,Y1,ANG

(1)* IF = Frame identification number

(2) IFC = Force calculation code;

EQ. 0; Frame forces will be calculated and printed.

EQ. 1; Frame forces will not be calculated.

(3) X1 = Distance, X1.

Y1 = Distance, Y1.
(4) \[ \text{ANG} = \text{Angle between the frame } x \text{ axis and the structure (global) } X \text{ axis (anti-clockwise from } X \text{ to } x). \]

*Note: One set of data must be entered in this section for each frame (or single column) in the building; the total number of frame locations to be read is controlled by the entry in section A.4.2.

1. Frame identification numbers may be repeated, but location data set must be input in frame identification number sequence.

2. A frame force calculation code of one (1) will suppress output of member forces.

3. Distance from Structure (Global) axis to the origin of the frame (Local) axis. Structure reference axis has to be at the center of mass of the base.

4. Angle is input in degrees and decimal fractions e.g., \(15^\circ 30'\) input as 15.5.

Fig. A-4 - Typical Coordinate Systems.
A.5.2 Shear Stiffness Data for Three Dimensional Shear Building
(for ISEV = 1 only; skip this section if ISEV = 2 or 3)

USR.TXT Reference information; upto 80 characters of text.

A.5.2.1 Shear Stiffness - X, Y and Torsional Stiffness in \( \theta \) Direction

USR.TXT Reference information; upto 80 characters of text.

\( SX(I), I = 1, NF \)

\( SX(I) = \) Shear stiffness of story \( I \)
in the X direction.

\( SY(I), I = 1, NF \)

\( SY(I) = \) Shear stiffness of story \( I \)
in the Y direction.

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

\( ST(I) = \) Torsional stiffness of story \( I \)
in the \( \theta \) direction about
the center of mass of the floor.

Note: Input shear stiffness in the X and Y direction and torsional stiffness in the \( \theta \) direction of each individual story starting from the top story to the first story.

A.5.2.2 Eccentricity Data - X and Y Direction

USR.TXT Reference information; upto 80 characters of text.

\( EX(I), I = 1, NF \)

\( EX(I) = \) Eccentricity of center of resistance from the center of mass of the floor \( I \).

\( EY(I), I = 1, NF \)

\( EY(I) = \) Eccentricity of center of resistance from the center of mass of the floor \( I \).

Note: Input eccentricity at each individual story in the X and Y direction starting from the top story to the first story. If both the eccentricities are zero, a default value of 0.0001 is used to facilitate eigensolution.
A.5.3 Eigenvalues and Eigenvectors for Three Dimensional Building
(for ISEV = 3 only; skip this section if ISEV = 1 or 2)

USR_TXT Reference information; upto 80 characters of text

A.5.3.1 Eigenvalues

USR_TXT Reference information; upto 80 characters of text.

W(I),I = 1,NFQ  \( W(I) = \text{Eigenvalue of mode I} \)

Note: Input from the first mode to the NFQ mode given in section A.4.1.

A.5.3.2 Eigenvectors

USR_TXT Reference information; upto 80 characters of text.

E(3*NFI),I = 1,NFQ  \( E(3*NFI) = \text{Eigenvector of mode I} \)

Note: Input from the first mode to the NFQ mode given in section A.4.1.

A.5.4 Superstructure Translational Mass and Rotational Mass moment of Inertia (Skip this section if ISEV = 2)

USR_TXT Reference information; upto 80 characters of text.

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

CMR(I),I = 1,NF  \( \text{CMR(I) = Mass moment of inertia of floor I about the center of mass.} \)

Note: Input from the top floor to the first floor.
A.5.5 Superstructure Damping

USR.TXT Reference information; upto 80 characters of text.

DR(I), I = 1, NE

DR(I) = Damping ratio corresponding to mode I.

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

A.5.6 Eccentricities of center of mass

USR.TXT Reference information; upto 80 characters of text.

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: Input from the top floor to the first floor.

A.5.7 Height of Different Floors and the Base

USR.TXT Reference information; upto 80 characters of text.

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

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

Note: Input heights from the top floor to the base.
A.6 ISOLATION SYSTEM DATA

USR_TXT       Reference information; upto 80 characters of text.

A.6.1 Stiffness Data for Linear Elastic Isolation System

USR_TXT       Reference information; upto 80 characters of text.

SXE, SYE, STE, EXE, EYE

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

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

STE = Resultant torsional stiffness of the linear elastic isolation system in the 0 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: Data for linear elastic elements can also be input individually (refer to A.6.4.1).

A.6.2 Mass Data of the Base

USR.TXT Reference information; upto 80 characters of text.

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.

A.6.3 Global Damping Data of the Base

USR.TXT Reference information; upto 80 characters of text.

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 0 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 A.6.4.2).

A.6.4 Isolation Element Data

USR_TXT Reference information; upto 80 characters of text.

Notes for sections A.6.4.1 to A.6.4.4:


(ii). The indices INELEM(NP,2) are used in the subsequent sections A.6.4.1 to A.6.4.8 to identify the element types in the isolation system. Index INELEM(NP,2) is defined as follows:

INELEM(K,1:2) = Indices for the isolation element K indicating its type and whether it is a uniaxial or biaxial element.

INELEM(K,1) = 1 for a uniaxial element in the X direction, (or A direction)
INELEM(K,1) = 2 for a uniaxial element in the Y direction, (or B direction)
INELEM(K,1) = 3 for a biaxial element
INELEM(K,2) = 1 for linear elastic element.
INELEM(K,2) = 2 for linear viscous element.
INELEM(K,2) = 3 for hysteretic element
for elastomeric bearing steel damper.
INELEM(K,2) = 4 for element for flat sliding bearing
(friction force and \( f_{\text{max}} \) independent of instant changes in
normal force)
INELEM(K,2) = 5 for hysteretic element for flat sliding
bearing (friction force and \( f_{\text{max}} \) depend on instant change
in normal force)
INELEM(K,2) = 6 for FPS bearing element
INELEM(K,2) = 7 for hysteretic nonlinear stiffening element
(not available in the current Version)
INELEM(K,2) = 8 for nonlinear viscous element

A.6.4.1 Linear Elastic Element

\textbf{INELEM(K,1:2)}

\textbf{INELEM(K,1)} can be either 1, 2 or 3
\textbf{INELEM(K,2)} = 1
(Refer to A.6.4 for further details).

\textbf{PS(K,1), PS(K,2)}

\textbf{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).

\textbf{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: Biaxial element means elastic stiffness in both X and Y directions (no interaction between forces in the X and Y direction).

A.6.4.2 Linear Viscous Elements

![Diagram of Viscous Elements Cluster](image)

**Fig. A5 - Position of Viscous Elements Cluster**

\[
\text{INELEM}(K,1:2) \quad \text{INELEM}(K,1) \text{ can be either 1,2 or 3} \\
\text{INELEM}(K,2) = 2 \\
\text{(Refer to A.6.4 for further details).}
\]

CA, CB, THETAA, THETAB

\[
CA = C(K,3) = \text{Damping coefficient in the A direction for} \\
\text{biaxial element or uniaxial element in the A direction} \\
(\text{leave blank if the uniaxial element is in the B direction only}).
\]

\[
CB = PC(K,6) = \text{Damping coefficient in the B direction for} \\
\text{biaxial element or uniaxial element in the B direction} \\
(\text{leave blank if the uniaxial element is in the A direction only}).
\]
THETAA = PC(K,13) = Orientation angle \( \theta \) for damper A with X axis in degrees \((-180^\circ \leq \theta \leq 180^\circ)\) (leave blank if the uniaxial element is in the B direction only)

THETAB = PC(K,14) = Orientation angle \( \theta \) for damper B with X axis in degrees \((-180^\circ \leq \theta \leq 180^\circ)\) (leave blank if the uniaxial element is in the A direction only)

Note: Biaxial element means damping in both A and B directions (no interaction between forces in two directions).

A.6.4.3 Hysteretic Element for Elastomeric Bearings/Steel Dampers

INELEM(K,1:2) INELEM(K,1) can be either 1,2 or 3
INELEM(K,2) = 3
(Refer to A.6.4 for further details).

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

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

ALP(K,2) = Post-to-preyielding stiffness ratio;
YF(K,2) = Yield force;
YD(K,2) = Yield displacement;
in the Y direction for biaxial element or uniaxial element in the Y direction
(leave blank if the uniaxial element is in the X direction only).
A.6.4.4 Biaxial Element for Sliding Bearings with (Friction Independent of Instantaneous Change of Normal Load)

INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 4 (Refer to C.6 for further details).

(FMAX(K,I),FMIN(K,I),PA(K,I),YD(K,1),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.

A.6.4.5 Biaxial Element for Sliding Bearings (with Friction Dependent on Instantaneous Change of Normal Load)

INELEM(K,1:2)  INELEM(K,1) can be either 1, 2, or 3
INELEM(K,2) = 5 (Refer to C.6 for further details).

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

FMAX(K,1) = Maximum coefficient of sliding friction at almost zero pressure (f_{max0} in Equation 2.24) (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 2.24) (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.

A.6.4.6 Element for Friction Pendulum Bearings (FPS)

INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 6 (Refer to C.6 for further details).

ALP(K3),(FMAX(K,1),FMIN(K,1),PA(K,1),YD(K,1),I = 1,2),FN(K)

ALP(K,3) = Radius 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 2.24) (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 2.24) (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 \( f_{\text{max}} \) to minimum \( f_{\text{min}} \) 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 \( f_{\text{max}} \) to minimum \( f_{\text{min}} \) 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.

A.6.4.7 Hysteretic Nonlinear Stiffening Elements (Not available in this version)

A.6.4.8 Nonlinear Viscous Element*

(see Fig. A5 for positioning definition)

INELEM(K,1:2) INELEM(K,1) can be either 1, 2 or 3
INELEM(K,2) = 8 (Refer to A.6.4 for further details).

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(PC(K,I), I = 1,14)

PC(K,1) = Force offset for dampers A or B in range 1 ($F_{o1}$ in Eq. (2.9)). (To be determined from operation data of damper. Leave blank if the uniaxial element is in the B direction only);

PC(K,2) = Force offset for dampers A or B in range 2 ($F_{o2}$ in Eq. (2.9)). (To be determined from operation data of damper. Leave blank if the uniaxial element is in the A direction only);

PC(K,3) = Nonlinear viscous constant for damper A in range 1 ($C_{1A}$ in Eq. (2.9)). (Leave blank if the uniaxial element is in the B direction only);

PC(K,4) = Nonlinear viscous constant for damper A in range 2 ($C_{2A}$ in Eq. (2.9)). (Leave blank if the uniaxial element is in the B direction only);

PC(K,5) = Limit velocity for transition from range 1 to 2 in A direction ($U_{12}^A$). (Leave blank if the uniaxial element is in the B direction only);

PC(K,6) = Nonlinear viscous constant for damper B in range 1 ($C_{1B}$ in Eq. (2.9)). (Leave blank if the uniaxial element is in the A direction only);

PC(K,7) = Nonlinear viscous constant for damper B in range 2 ($C_{2B}$ in Eq. (2.9)). (Leave blank if the uniaxial element is in the A direction only);

PC(K,8) = Limit velocity for transition from range 1 to 2 in B direction ($U_{12}^B$). (Leave blank if the uniaxial element is in the A direction only);

PC(K,9) = Power (integer or fractional) for the velocity in range 1 for either dampers A or B ($p_1$ in Eq. (2.9));

PC(K,10) = Power (integer or fractional) for the velocity in range 2 for either dampers A or B ($p_2$ in Eq. (2.9));
PC(K, 11) = Maximum damper force (operational limitation) for either one of dampers A or B ($F_{d_{max}}$ in Eq. (2.9)).

PC(K, 12) = Displacement limit for damper operation start at low velocities and displacements for either A or B.

PC(K, 13) = Orientation angle $\theta$ for damper A with x axis in degrees ($-180^\circ \leq \theta \leq 180^\circ$)

PC(K, 14) = Orientation angle $\theta$ for damper B with x axis in degrees ($-180^\circ \leq \theta \leq 180^\circ$)

*Note: This model is suitable for a cluster of two (horizontal) dampers A and B oriented at an arbitrary angle to each other and to the building. The dampers have different nonlinear properties, but same maximum and same offset constants).

A.6.5 Coordinates of Isolation Elements

USR_TXT Reference information; upto 80 characters of text.

XP(I), YP(I), 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.
A.7 OUTPUT INFORMATION DATA

A.7.1 Output Parameters

USR_TXT  Reference information; upto 80 characters of text.

LTMH,KPD,IP1,IP2,IP3,IP4,

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

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

IP1,IP2, IP3, IP4 = Bearing numbers of four bearings at which the peak response values and the force - displacement time history response is desired.

A.7.2 Interstory drift output

USR_TXT  Reference information; upto 80 characters of text.

CORDX(K), CORDY(K), K=1,6

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

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

Note: 1. The coordinates of the column lines are with respect to the reference axis at the center of mass of the base. Six column lines can be specified.
A.8 LOAD CASE DEFINITION:

USR.TXT Reference information; upto 80 characters of text.

[\(XM(1,L),XM(2,L),XM(3,L),XM(4,L), L = 1,NLD\)]

\(XM(1,L) = \) Multiplier for vertical load case I

\(XM(2,L) = \) Multiplier for vertical load case II

\(XM(3,L) = \) Multiplier for vertical load case III

\(XM(4,L) = \) Multiplier for earthquake response

Note: Load cases for the complete building are defined as a combination of vertical load conditions (I,II,III), and earthquake loading. One card must be entered in this section for each different building load case; the total number of building load cases is controlled by the control information in section A.4.2.

A.9 EARTHQUAKE DATA

This information has to be specified in additional files outside the main input data file (e.g., WAVEXP1.DAT and WAVEYP1.DAT).

A.9.1 Unidirectional or Bidirectional Earthquake Record

Note: the following data has to be specified in the file which the user defined at the start of the user manual in section A.1 e.g., in the file WAVEX.DAT

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

Note: 1. If INDGACC as specified in A.4.5 is 1, then the input will be assumed at an angle XTH specified in A.4.5. If INDGACC as specified in A.4.5 is 2, 3, or 4 then X(LOR) is considered to be the X component of the bidirectional or tridirectional earthquake.
A.9.2 Earthquake Record in the Y Direction for the Bidirectional Earthquake (Input only if INDGACC=2 or 4)

Note: the following data has to be specified in the file which the user defined at the start of the user manual in section A.1 e.g., in the file WAVEY.DAT

\[ Y(I,1), I=1, \text{LOR} \quad \text{Y(I,1)} = \text{Acceleration component in the Y direction.} \]

A.9.3 Earthquake Record in the Z Direction for the Bidirectional or tridirectional Earthquake (Input only if INDGACC=3 or 4)

Note: The following data has to be specified in the file which the user defined at the start of the user manual in section A.1 e.g., in the file WAVEZ.DAT

\[ Y(I,2), I=1, \text{LOR} \quad \text{Y(I,2)} = \text{Acceleration component in the Z direction.} \]

A.10 Execution Instructions

Check the README file in the distribution disk for details on execution of program.
APPENDIX B

EXAMPLE I

(1) FULL 3D-SUPERSTRUCTURE (BEAM-COLUMN)
(2) SLIDING ISOLATION SYSTEM
(3) UNIAXIAL EXCITATION
(4) OUTPUT OF PEAK RESPONSE AND MEMBER FORCES
<table>
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<td>6 7 3 60280508 0.37 0.42 0.31 11045024</td>
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<td>6 7 3 60280508 0.37 0.42 0.31 11045024</td>
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</table>
### OUTPUT FILE FOR EXAMPLE 1

**EXAMPLE FROM SECTION 4.1 - NCEER 93-0011**

---------------------------------------------------------------------------------------------------------------------------
**PROGRAM 3D-BASIS-TABS** ... A GENERAL PROGRAM FOR NONLINEAR DYNAMIC ANALYSIS OF THREE DIMENSIONAL FRAME STRUCTURES**
**BASE ISOLATED BUILDINGS**
**VERSION 2.0 FOR VAX/SUN/PC COMPUTERS, DEPT. 1984**
**DEVELOPED BY:**
**8. B. REINER, MICHAELIS LNEXTON**
**DEPT. OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**
**SATISH RAGARAJAIS, DEPT. OF CIVIL ENGINEERING**
**UNIVERSITY OF ULAS, AT COLUMBIA**
**RATIONAL CENTER FOR EARTHQUA E ENGINEERING RESEARCH, BURLINGTON, STATE UNIVERSITY OF NEW YORK AT BUFFALO**
**CONTRIBUTIONS:**
**KANIDOTIS TROUPEAS, CREP LI AND REINER LIA**
**DEPT. OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**

---------------------------------------------------------------------------------------------------------------------------
**PROGRAM 1.0 FOR VAX/PC COMPUTERS, AUGUST 1983**
**DEVELOPED BY... SATISH RAGARAJAIS**
**CREP LI**
**ANDREW M. REINER**
**AND MICHAELIS L. LXENTON**
**DEPARTMENT OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**
**RATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH**
**STATE UNIVERSITY OF NEW YORK AT BUFFALO**

---------------------------------------------------------------------------------------------------------------------------
**THIS PROGRAM HAS BEEN DEVELOPED USING:**
**(1) PROGRAM 3D BASIS**
**DEVELOPED BY... SATISH RAGARAJAIS**
**ANDREW M. REINER**
**AND MICHAELIS L. LXENTON**
**DEPARTMENT OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO, VAX VERSION, 1990**

**(2) PROGRAM STABS**
**DEVELOPED BY... E. L. WILSON**
**B. P. DONTY**
**AND J. P. ROLLIE**
**DEPARTMENT OF CIVIL ENGINEERING**
**UNIVERSITY OF CALIFORNIA, BERKELEY, SEPTMBEBE 1974, REVISED MARCH 1979**

---------------------------------------------------------------------------------------------------------------------------
**1**

**MIRROR OF INPUT DATA**

THREE STORY BUILDING IN ITALY
UNIT ID - 000-3-E
GENERAL, CONTROL INFORMATION
10.11.010.1700 0.8 0.6
INFRASTRUCTURE CONTROL INFORMATION
1.1 INTEGRATION CONTROL PARAMETERS
0.01 0.005 1000 20 1
BEHAVIOR METIC CONTROL PARAMETERS (DEFAULT VALUES: 0.3 AND 0.25)
1.02.E 0.0 0.0
INFRASTRUCTURE INFORMATION
THIRD STORY - GENERAL DATA

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<th>CENTROID</th>
<th>LOCATION</th>
<th>Z-TRANSFORMATION FACTOR</th>
<th>Z-TRANSLATION</th>
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SUPERSTRUCTURE DATA

0.10.0723.60.00025.292.85
FRAHES

INPUT

1.00

REPRESENTATION

D.0002:s.-

.....

OF

"3280000

BIDIRECTIONAL INPUT

BUILDING IN ITALY

2985.60 .00 .00 .00 .00
OF

U280000

DATA

0 1 0,07 23.6.
.

43280000

DATA

CONSTANT TIME STEP

43280000

OF

0.00025.

OF

0.01

6 10

SUPERSTRUCTURE STIFFNESS DATA -

OF

0.016

CASE
-

DATA

....

0.00025.

119.'0

FIR

•

0.00025 0.10.0723.6000025.0.10.0723.6

CONTROL

LOGIC

WITHIN

FRAHES

STEP OF

NO.

SHEAR BUILDING

0.00025.

E.lGEN DATA

0.016
"3280000

FOR

OF

0.00025.

119.

GLFCA.L

DNtPING

••

SUPERSTRUCTURE CONTROL INFORMATION

UNIT K-METER-SEC

TOTAL NUMBER OF STORIES

3

NUMBER OF U.SY FRAME

1

TOTAL NUMBER OF FRAMES

1

NUMBER OF LOAD CONDITIONS

1

NUMBER OF FREQUENCIES

9

NO. OF PLACEMENTS

BASE

3

NO. OF BEARINGS

10

NO. OF EIGEN VECTORS CONSIDERED

9

INDEX FOR SUPERSTRUCTURE STIFFNESS DATA

2

INDEX = 1 FOR NO SHEAR BUILDING. INDEX = 2 FOR FULL 3D REPRESENTATION

INDEX = 3 FOR REPRESENTATION USING EIGEN DATA

TIME STEP OF INTEGRATION (NEWTON) .0100

INDEX FOR TYPE OF TIME STEP

1

INDEX = 1 FOR CONSTANT TIME STEP

INDEX = 2 FOR VARIABLE TIME STEP

GAIN FOR MOMENTS METHOD

50

BETA FOR MOMENTS METHOD

23

TOLERANCE FOR FORCE COMPUTATION

.0050

REFERENCE INERTIA OF CONVERGENCE

1000.0

MAX NUMBER OF ITERATIONS T.S.

20

INDEX FOR GROUND MOTION INPUT

1

INDEX = 1 FOR UNIDIRECTIONAL INPUT

INDEX = 2 FOR BIDIRECTIONAL INPUT

TIME STEP OF RECORD

.003

LENGTH OF RECORD

720

LOAD FACTOR

1.00

AMPLITUDE OF EARTHQUAKE INCIDENCE

0.00

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

STORY DATA

LEVEL NO. ID HEIGHT MASS(M) M*2 X(H) Y(H) X*2 Y*2

THIRD STORY-GENERAL DATA

3 3.50 110.40 2085.60 .00 .00 .00 .00

SECOND 2 3.50 110.40 2085.60 .00 .00 .00 .00

FIRST 1 3.50 110.40 2085.60 .00 .00 .00 .00

B - 6 B - 7
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### FIRST FRAME

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<th>NUMBER OF DIFF. COL PRO</th>
<th>NUMBER OF DIFF. BEAM PROP</th>
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<th>NUMBER OF COLUMN ELEMENTS</th>
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### PAREL CARDS

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<th>E</th>
<th>A</th>
<th>I</th>
<th>EA</th>
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### BRACING ELEMENT CARDS

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**OUTPUT PARAMETERS**

- **TIME HISTORY OPTION**: 1
  - **TIME STEP**: 1
  - **NO. OF TIME STEPS AT WHICH TIME HISTORY OUTPUT IS DESIRED**: 1
  - **FORCE-DEPLACEMENT TIME HISTORY DESIRED AT BEARINGS NUMBERED**: 1

**COORDINATES OF COLUMN LINES WHERE INTERSTORY DRIFTS ARE DESIRED**

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**OUTPUT**

**MAX. DRIFT**

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**MAX. ROTATION**

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**MAX. RESULTANT DRIFT**

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**MAX. RESULTANT ROLLED DRIFT**

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**MAX. ROLLED DISPLACEMENT**

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**MAX. DRIFT AT THE CENTER OF MASS OF BASE**

<table>
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<tr>
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**MAX. DRIFT AT THE CENTER OF MASS OF BASE**

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**MAX. DRIFT AT THE CENTER OF MASS OF BASE**

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**MAX. DRIFT AT THE CENTER OF MASS OF BASE**

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**MAX. DRIFT AT THE CENTER OF MASS OF BASE**

<table>
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<tr>
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<td>...</td>
<td>...</td>
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</tr>
<tr>
<td>Column</td>
<td>Top-Load Moment</td>
<td>Bottom-Load Moment</td>
<td>Axial-Load Force</td>
<td>Shear-Load Force</td>
<td>Major</td>
<td>Minor</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------</td>
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<td>------------------</td>
<td>------------------</td>
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<td>18.0404</td>
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**Member Forces**

1. Torcible columns, M = 1, M = 0.5, \( r = 1 \), \( r = 0.5 \)
2. Full-frame columns, M = 1, M = 0.5, \( r = 1 \), \( r = 0.5 \)
3. Partial-frame columns, M = 1, M = 0.5, \( r = 1 \), \( r = 0.5 \)

**Column Forces**

1. Level 2, Level 6, Level 8, Level 10
2. Load, Top-Moment, Bottom-Moment, Axial-Load Force, Shear-Load Force, Major, Minor
<table>
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<th>TOP MOMENT</th>
<th>BOT. MOMENT</th>
<th>AXIAL FORCE</th>
<th>TOP MINOR AXIS</th>
<th>BOT. MINOR AXIS</th>
<th>shear FORCE</th>
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**MEMBER FORCES** ...... FRAME ID F10 K IN ANE L EC A

**FRAME TYPES**

**LEVEL NO 1** .... **LEVEL NO 2**

**AXIAL LOAD** | **TORSIONAL MOMENT** | **MAJOR AXIS** | **TOP moment** | **BOT. moment** | **AXIAL FORCE** | **TOP MINOR AXIS** | **BOT. MINOR AXIS** | **MAJOR MOMENT** | **MINOR MOMENT** | **SHEAR FORCE**
<table>
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**DIAHARM ELEMENTS** - LISTED IN SAME SEQUENCE AS INPUT

**T-COL. LOAD**

| 7 | 1 MAX | 124.044 |
| 8 | 1 MAX | 124.044 |
| 9 | 1 MAX | 124.044 |
| 10 | 1 MAX | 124.044 |

**BEAM FORCES**

| 8 | 1 MAX | 0.000 | 14.798 | 13.755 | 1.2844 | 2.0232 | 2.5310 | 8.8232 | 1.7594 |
| 9 | 1 MAX | 0.000 | -14.798 | -13.755 | -1.2844 | -2.0232 | -2.5310 | -8.8232 | -1.7594 |
### FLEXURAL PANELS

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<td>.2031</td>
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<td>.2031</td>
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<td>.5934</td>
<td>.5934</td>
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### BRACING ELEMENTS - LISTED IN SAME SEQUENCE AS INPUT

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</table>

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#### END OF OUTPUT
APPENDIX C

EXAMPLE 2

EXAMPLE WITH

(1) 3D-SHEAR BUILDING (STORY STIFFNESS)
(2) ELASTOMERIC ISOLATION SYSTEM
(3) BIAXIAL EXCITATION
(4) OUTPUT OF PEAK RESPONSE

SINGLE STORY STRUCTURE WITH ELASTOMERIC ISOLATION SYSTEM (See Section 7.3 - NCEER 910005)

unitskip in

general control information
1 3 4 760 368.2 0
integration control parameters
0.01 0.001 10000 20 1
nonlinear parameters
0.5 0.25
earthquake control parameters
2 0.02 0.56 0.62
superstructure information
shear stiffness
272.58
272.58
38142202
acceleration
15
15
superstructure mass
0.0214
22367
superstructure damping
0.02 0.02 0.02
acceleration of mass
0.9
height
100

isolation system data
stiffness of linear elastic isolation system
0 0 0 0
base mass
0.0214
12367
global damping
0 0 0 0
elastomeric isolators
3 3
0.059 0.065 0.076 0.081 0.086 0.091 0.096 0.096
3 3
0.059 0.065 0.076 0.081 0.086 0.091 0.096 0.096
3 3
0.059 0.065 0.076 0.081 0.086 0.091 0.096 0.096
coordinates of isolation elements
240 280
240 280
coordinates for interstory drift
0 0
0 0
0 0
0 0
0 0
load case
0 0 0 1

C-1
OUTPUT FILE FOR EXAMPLE 2
(EXAMPLE FROM SECTION 7.3 - NCEER 91-0005)

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

PROGRAM 3D-BASIS-TASK ... A GENERAL PROGRAM FOR NONLINEAR
DYNAMIC ANALYSIS OF THREE DIMENSIONAL
BASE ISOLATED BUILDINGS

VERSION 2.0 FOR VAX/SUN/PC COMPUTERS, SEPT. 1994

DEVELOPED BY:
ANDREI REINHORN, MICHAILAIS KONSTANTINOU
DEPT. OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

SATISH NAGARAJAIAH, DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF MISSOURI AT COLUMBIA

CONTRIBUTIONS:
PANAGIOTIS TROYRAS, CHEE LI AND KOOT LI
DEPT. OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

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

VERSION 1.0 FOR VAX/PC COMPUTERS, AUGUST 1993

DEVELOPED BY ... SATISH NAGARAJAIAH
CHEE LI AND KOOT LI
DEPARTMENT OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

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

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

THIS PROGRAM HAS BEEN DEVELOPED USING:
(1) PROGRAM 3D-BASIS
DEVELOPED BY ... SATISH NAGARAJAIAH
ANDREI M. REINHORN
AND MICHAILAIS C. KONSTANTINOU
DEPARTMENT OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

(2) PROGRAM 3D-CHEN
DEVELOPED BY ... E. L. WILSON
H. R. DOWY
AND J. P. KOLLM
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY

VAX VERSION, 1990

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

1

******* END OF MIRROR OF INPUT *******

SINGLE STORY STRUCTURE WITH ELASTOMERIC ISOLATION SYSTEM (SEE SECTION 7.3 - NCEER 91-0005)

general control information

unit kip in

TOTAL NUMBER OF STOREYS .............. 1
NUMBER OF DIFF. FRAMES .............. 0
TOTAL NUMBER OF FRAMES .............. 1
NUMBER OF LOAD CONDITIONS ........... 0
NUMBER OF FREQUENCIES .............. 1

NO. OF槍LOUS (EXCL. BASE) ......... 1
NO. OF BASES ............. 0
NO. OF EIGEN VECTORS CONSIDERED .... 3
INDEX FOR SUPERSTRUCTURE STIFFNESS DATA ........ 1
INDEX = 1 FOR 2D SHEAR BUILDING REPRESENTATION
INDEX = 2 FOR FULL 3D REPRESENTATION
INDEX = 3 FOR REPRESENTATION USING EIGEN DATA

TIME STEP OF INTEGRATION (NORMAL) = 0.001
INDEX FOR TYPE OF TIME STEP ......... 1
INDEX = 1 FOR CONSTANT TIME STEP
INDEX = 2 FOR VARIABLE TIME STEP

GAMMA FOR NEWMARKS METHOD ........ 50
BETA FOR NEWMARKS METHOD ........ 25
TOLERANCE FOR FORCE COMPUTATION = .0005
REFERENCE有點 CONVERGENCE = 10000
MAX NUMBER OF ITERATIONS WITHIN T.S. = 20
INDEX FOR CONVERGENCE = 2
INDEX = 1 FOR UNIDIRECTIONAL INPUT
INDEX = 2 FOR BIDIRECTIONAL INPUT

TIME STEP OF RECORD = .020
LENGTH OF RECORD = 750
LOAD FACTOR = 36.62

ANGLE OF EARTHQUAKE INCIDENCE = .00

REFERENCE IDENT OF CONVERGENCE.

INDEX FOR UNIDIRECTIONAL INPUT
INDEX = 1 FOR BIDIRECTIONAL INPUT

INDEX 0 FOR TIME HISTORY OUTPUT
INDEX = 1 FOR NO TIME HISTORY OUTPUT
NO. OF TIME STEPS AT WHICH TIME HISTORY OUTPUT IS DESIRED = 50
FORCE DISPLACEMENT TIME HISTORY DESIRED AT BEARINGS NUMBERED = 1 2 3 4

COORDINATES OF COLUMN LINES AT WHICH INTERSTORY DRIFTS ARE DESIRED
COL. LINE X CORD Y CORD.
1 2 000 000
2 2 000 000
3 3 000 000
4 4 000 000
5 5 000 000
6 6 000 000

TIME HISTORY OPTION
INDEX = 1

BASE ISOLATION DATA.
OPTION ONE: EQUIVALENT GLOBAL DEVICE PROPERTIES
GLOBAL ISOLATION DEVICE AT THE CENTER OF MASS OF THE BASE...
BASE ISOLATION DATA.

HEIGHT OF THE FLOOR = 100000

BASE MASSES.

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

BASE MASSES AT THE CENTER OF MASS OF THE BASE...
TRANS. MASS ROTATIONAL MASS

SUPERSTRUCTURE STIFFNESS DATA
STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING)...
FLOOR STIFF X STIFF Y STIFF X STIFF Y EXCENT X EXCENT Y
1 272.580 272.580 38184320.000 48.000 48.000

SUPERSTRUCTURE MASS
FLOOR TRANS. MASS ROTATIONAL MASS
1 .67 22867 000 000 000

SUPERSTRUCTURE DAMPING
MODE SHAPE DAMPING RATIO (
1 2 000 2 2 000

HEIGHT OF THE FLOOR = 100000

BASE MASSES.

********** EIGENVALUES AND EIGEN VECTORS FOR THREE DIMENSIONAL SHEAR BUILDING REPRESENTATION **********

EIGENVALUES
COLUMN 1
ROW 1 1.12 0.0
ROW 2 0.00 0.0
ROW 3 1.10 5.7

EIGENVECTORS
COLUMN 1
ROW 1 .30516 .89701
ROW 2 -.88116 .51600
ROW 3 .88116 .51600

********** MAX. RESPONSE **********

MAX. REL. DISP. AT THE CENTER OF MASS OF FLOORS... (WITH RESPECT TO THE BASE)
1 1 22 1 1197 000

1 1 00 00 5.56 22 07 07
1 1 00 00 5.56 22 07 07
1 1 00 00 5.56 22 07 07
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<th>00</th>
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<th>5.34</th>
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**Max. Disp. at the Center of Mass of Base**

<table>
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<tr>
<th>X Disp.</th>
<th>Y Disp.</th>
<th>North</th>
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<tr>
<td>3.42</td>
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**Max Resultant Disp. at the Center of Mass of Base**

<table>
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<tr>
<th>Time</th>
<th>X Comp.</th>
<th>Y Comp.</th>
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<tbody>
<tr>
<td>3.240</td>
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**Max Resultant Bearing Disp**

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<td>5.520</td>
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<tr>
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<td>5.580</td>
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**Max Bearing Disp in X**

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<td>3.560</td>
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**Max Bearing Disp in Y**

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**Max Total Accel. at Center of Mass of Floors**

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**Max Story Shear**

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<td>11.800</td>
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<td>11.800</td>
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**Max Structure Shear (Top of Base)**

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**Max Base Shear (Bearing Level)**

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****** End of Output ******

C-6
APPENDIX D

EXAMPLE 3

EXAMPLE WITH
(1) FULL 3D-SUPERSTRUCTURE (BEAM-COLUMN)
(2) ELASTOMERIC ISOLATION SYSTEM
(3) UNIAXIAL EXCITATION
(4) OUTPUT OF PEAK RESPONSE
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<th>Beam Properties</th>
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Panel Info

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D - 2

D - 3
### OUTPUT FILE FOR EXAMPLE 3

**EXAMPLE FROM SECTION 8 - NCEER 91-0005**

******************************************************************************
**PROGRAM 3D-BASIS-TABS ... A GENERAL PROGRAM FOR NONLINEAR**
**DYNAMIC ANALYSIS OF THREE DIMENSIONAL**
**BASE ISOLATED BUILDINGS**
**VERSION 2.0 FOR VAX/SUN/PC COMPUTERS, SEPT. 1994**
**DEVELOPED BY:**
**ANDREI REZMER, MICHALAKIS COSTANTINOU**
**DEPT. OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**

**SATHI RAMAGAJAIN, DEPT. OF CIVIL ENGINEERING**
**UNIVERSITY OF SOUTHERN CALIFORNIA**

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

**CONTRIBUTIONS:**
**PANAGIOTIS TROPOGLOWIS, CHEE LI AND ROBERT LI**
**DEPT. OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**

******************************************************************************
**VERSION 1.0 FOR VAX/PC COMPUTERS, AUGUST 1993**
**DEVELOPED BY ... SATHI RAMAGAJAIN**
**ANDREI M. REZMER**
**AND MICHALAKIS C. COSTANTINOU**
**DEPARTMENT OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO**

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

******************************************************************************
**THIS PROGRAM HAS BEEN DEVELOPED USING:**
**(1) PROGRAM 3D-BASIS**
**DEVELOPED BY ... SATHI RAMAGAJAIN**
**ANDREI M. REZMER**
**AND MICHALAKIS C. COSTANTINOU**
**DEPARTMENT OF CIVIL ENGINEERING**
**STATE UNIV. OF NEW YORK AT BUFFALO,**
**VAX VERSION, 1990**

**(2) PROGRAM 3D-BASIS**
**DEVELOPED BY ... E L. WILSON**
**R. H. DOWY**
**AND J. F. DOLLIN,**
**DEPARTMENT OF CIVIL ENGINEERING**
**UNIVERSITY OF CALIFORNIA, BERKELEY,**
**SEPTEMBER 1979, REVISED MARCH 1980**

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

****** MESH OF INPUT DATA ******

**SIX STORY R. C. STRUCTURE WITH LEAD-BEARING ISOLATION SYSTEM (SEE SECTION 8 - NCEER**

(Unit loads) meters

<table>
<thead>
<tr>
<th>Story</th>
<th>General Control Information</th>
<th>Substructure Information</th>
<th>Integration Control Parameters</th>
<th>Moment Method</th>
<th>Compatibility Control Parameters</th>
<th>Supplementary Information</th>
<th>6 Story Info</th>
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|       | 2 6 22 1000 0 81 8 | 1 1 1 | 0.01 0.001 1000 20 1 | 10 0.095 | 0.5 0.25 | 1 0.02 | 0.81 |

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

**2 35.665 1561.3 0.15 6.0**
**3 35.665 1561.3 0.15 6.0**
**4 35.665 1561.3 0.15 6.0**
**3 35.665 1561.3 0.15 6.0**
**2 8 39.175 0.15 6.0**
**3 35.665 1561.3 0.15 6.0**
**1 37.271 1851.0 0.15 6.0**

**frame data**

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### Superstructure Data

#### Structure Data

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#### Structure Lateral Loads - Cases A and B

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D - 12
### GENERATED COLUMN LOCATIONS

| STORY | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|-------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|

### PANEL CARDS


### BEAM PROPERTIES AND LOADS

#### BAY NUMBERS 1


#### BAY NUMBERS 2


#### BAY NUMBERS 3


#### BAY NUMBERS 4


#### BAY NUMBERS 5


#### BAY NUMBERS 6


#### BAY NUMBERS 7


#### BAY NUMBERS 8


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D - 16

D - 17
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**FRAME LOCATION**

**FRAME IDENTIFICATION CODE**

**SUPERSTRUCTURE DAMPING**

**MODE SHAPE DAMPING RATIO (S)**

**FLOOR DEGREE**

**BASEMAY MASS AT THE CENTER OF MASS OF THE BASE**

**BASE ISOLATION DATA**

**GLOBAL ISOLATION DEVICE AT THE CENTER OF MASS**
### Maximum Shear at the Center of Mass of Base

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### Maximum Structure Shear (Top of Base)

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### Maximum Base Shear (Bearing Level)

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### Maximum Acceleration at Center of Mass of Bearing

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**LOAD CONDITION DEFINITION CARDS**

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**** END OF OUTPUT ****
APPENDIX E

EXAMPLE 4

EXAMPLE WITH

(1) 3-D SUPERSTRUCTURE
(EIGENVALUES AND EIGENVECTORS)

(2) ELASTOMERIC ISOLATION SYSTEM

(3) UNIAXIAL EXCITATION

(4) OUTPUT OF PEAK RESPONSE AND TIME HISTORIES
PROGRAM 3D-BASIS-TABS: A GENERAL PROGRAM FOR NONLINEAR
DYNAMIC ANALYSIS OF THREE DIMENSIONAL
BASE ISOLATED BUILDINGS

VERSION 1.0 FOR VAX/SUN/PC COMPUTERS, SEPT. 1994

DEVELOPED BY:

ANDREI REINHORN, MICHALAKIS CONSTANTINOU
DEPT. OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO

SATISH MAGARAJAN, DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF MISSOURI AT COLUMBIA

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

CONTRIBUTIONS:

PANAGIOTIS TSOPelas, CHEN LI AND RENFEN LI
DEPT. OF CIVIL ENGINEERING
STATE UNIVERSITY OF NEW YORK AT BUFFALO

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

VERSION 1.0 FOR VAX/PC COMPUTERS, AUGUST 1993

DEVELOPED BY... SATISH MAGARAJAN
CHEN LI AND RENFEN LI
DEPT. OF CIVIL ENGINEERING
STATE UNIVERSITY OF NEW YORK AT BUFFALO

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

THIS PROGRAM HAS BEEN DEVELOPED USING
(1) PROGRAM 3D-BASIS
DEVELOPED BY... SATISH MAGARAJAN
ANDREI M. REINHORN
AND MICHALAKIS C. CONSTANTINOU
DEPT. OF CIVIL ENGINEERING
STATE UNIV. OF NEW YORK AT BUFFALO.

RATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
STATE UNIVERSITY OF NEW YORK AT BUFFALO

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

(2) PROGRAM ETABS
DEVELOPED BY... E. L. WILSON
R. H. BOVEY
AND J. P. HOLLIN
DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF CALIFORNIA, BERKELEY,
SEPTEMBER 1974, REVISED MARCH 1978

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

1

******* MIRROR OF INPUT DATA *******

SIX STORY R C. STRUCTURE WITH LEAD-RUBBER SLAB ISOLATING SYSTEM
(SECTION 8 - NCEE)

Units tons/ft

96.0 000 1000 9.81 0

Integration control parameters
0.00 0 000 10000 20 1

normal method
0.0 0.239

earthquake control parameters
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Eigen vectors
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### Absolute Accel. at Floor Degree of Freedom

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### Structure Break at Top of Ball

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<tr>
<td>Velc X</td>
<td>1300E-10</td>
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<tr>
<td>Force Y</td>
<td>21.21E-18</td>
</tr>
<tr>
<td>Disp Y</td>
<td>5130E-15</td>
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<tr>
<td>Velc Y</td>
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<tr>
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<td>Y DISP</td>
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<th>Y DST.</th>
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<th>MAX. DISP. Y</th>
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<td>13.630</td>
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<td>9.180</td>
<td>13.630</td>
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<table>
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<tr>
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<th>FORCE Y</th>
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<td>MAX BASE SHEAR (BEARING LEVEL)</td>
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******** END OF OUTPUT ********
APPENDIX F

EXAMPLE 5

EXAMPLE WITH

(1) SINGLE STORY STRUCTURE
(2) SLIDING BEARINGS
(3) UNIAXIAL EXCITATION
(4) OUTPUT OF PEAK RESPONSE

VERIFICATION OF HYSTERETIC ELEMENT
UNIT IS KIPS-SEC
GENERAL CONTROL INFORMATION
1 1 1 8 100 360.2
INTERACTION CONTROL PARAMETERS
0.021 0.001 1800 20 3
REMARK METHOD CONTROL PARAMETERS (DEFAULT VALUES: 0.5 AND 0.25)
0 0
EARTHQUAKE CONTROL PARAMETERS
0.03 0.0 360.2
SUPERSTRUCTURE INFORMATION
ONE STORY-GENERAL DATA
0.1
0.1
2000.00
MASSES
0.01
2000.00
SUPERSTRUCTURE DAMPING
0.0
0.0
0.0
MOMENT ROTATIONS
0.0 0.0
BASE ISOULATION SYSTEM DATA
STIFFNESS DATA FOR LINEAR ELASTIC BEARING
0.0 0.0
0.0 0.0
BASIS OF BASE
101.32 200000000.0
GLOBAL DAMPING
0.0 0.0
0.0 0.0
LOAD CASE DATA
0 0 0 0
COORDINATES OF BEARING
1000 0 1000 0
-1000 0 1000 0
-1000 0 -1000 0
1000 0 -1000 0
-1000 0 0 1000 0
1000 0 -1000 0
OUTPUT CONTROL PARAMETERS
1 2 3 4
COORDINATES OF DESIRED INTERSTORY DRIFT
0.0
0.0
0.0
0.0
LOAD CASE DATA
0 0 1
### OUTPUT FILE FOR EXAMPLE 5

---

**PROGRAM 3D-BASIS-TABS - A GENERAL PROGRAM FOR NON-LINEAR UMPACT ANALYSIS OF THREE DIMENSIONAL BASE ISOLATED BUILDINGS**

**VERSION 2.0 FOR VAX/SUN/PC COMPUTERS, SEPT. 1994**

**DEVELOPED BY:**

ANDREI REINIRC, MICHALAKIS CONSTANTINOU
DEPT. OF CIVIL ENGINEERING
STATE UNIVERSITY OF NEW YORK AT BUFFALO

SATISH MAGARAJAN, DEPT. OF CIVIL ENGINEERING
UNIVERSITY OF MONTREAL AT MONTREAL

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

**CONTRIBUTIONS:**

PANAGIOTIS TRAPPOULAS, CHEP LI AND REYNOLD LI
DEPT. OF CIVIL ENGINEERING
STATE UNIVERSITY OF NEW YORK AT BUFFALO

---

**VERSION 1.0 FOR VAX/PC COMPUTERS, AUG 1993**

**DEVELOPED BY ... SATISH MAGARAJAN**

CHEP LI
ANDREI H. REINIRCK.

NATIONAL CENTER FOR EARTHQUAKE ENGINEERING RESEARCH
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**DEVELOPED BY ... SATISH MAGARAJAN**

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

---

**THIS PROGRAM HAS BEEN DEVELOPED USING:**

1. PROGRAM 3D-BASIS
2. SATISH MAGARAJAN
3. ANDREI H. REINIRCK.
4. MICHALAKIS C. CONSTANTINOU

**DEPT. OF CIVIL ENGINEERING**
STATE UNIVERSITY OF NEW YORK AT BUFFALO

**DEPT. OF CIVIL ENGINEERING**
UNIVERSITY OF MONTREAL AT MONTREAL

---

**VERIFICATION OF HYPOTHETICAL ELEMENT**

UNIT (IN-KIPS-SEC)

**GENERAL CONTROL INFORMATION**

- 1 1 1 1 1 1 1 1 1 1 1 1 1
- 1 1 1 1 1 1 1 1 1 1 1 1 1
- 1 1 1 1 1 1 1 1 1 1 1 1 1

**INTEGRATION CONTROL PARAMETERS**

0.001 0.001 1000 20 1

**HYPOTHEUTICAL CONTROL PARAMETERS (DEFAULT VALUES: 0.5 AND 0.25)**

**EARTHQUAKE CONTROL PARAMETERS**

- 1 0 0 0 0 0 0 0 0 0 0 0

**SUPERSTRUCTURE INFORMATION**

- 1 0 0 0 0 0 0 0 0 0 0 0

---

**COORDINATES OF BEARING**

- 1 0 0 0 0 0 0 0 0 0 0 0

---

**LOAD CASE DATA**

- 1 1 0 0 0 0 0 0 0 0 0 0

---

**TOTAL NUMBER OF STORIES**

- 1

**TOTAL NUMBER OF DIFF FRAMES**

- 0

**TOTAL NUMBER OF LOAD CONDITIONS**

- 0

**TOTAL NUMBER OF ELEMENTS**

- 0

**TOTAL NUMBER OF TRANSFORMATIONS**

- 0

**NO. OF FLOORLEVEL BASES**

- 1

---

**GENERAL CONTROL INFORMATION**

**PROGRAM ETABS**

**GENERAL INFORMATION**

**UNIT (IN-KIPS-SEC)**

**TOTAL NUMBER OF STORIES**

- 1

**TOTAL NUMBER OF DIFF FRAMES**

- 0

**TOTAL NUMBER OF LOAD CONDITIONS**

- 0

**TOTAL NUMBER OF TRANSFORMATIONS**

- 0

**NO. OF FLOORLEVEL BASES**

- 1
**SUPERSTRUCTURE STIFFNESS DATA**

**STIFFNESS (THREE DIMENSIONAL SHEAR BUILDING)**

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<tr>
<th>FLOOR</th>
<th>STIFF X</th>
<th>STIFF Y</th>
<th>STIFF B</th>
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<th>EXCEPT Y</th>
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**SUPERSTRUCTURE MASS**

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**HEIGHT**

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**BASEMEN MASS AT THE CENTER OF MASS OF THE BASE**

| MASS | 201.320 | 200000000.000 |

**BASE ISOLATION DATA**

**GLOBAL ISOLATION DEVICE AT THE CENTER OF MASS**

**EIGENVALUES AND EIGEN VECTORS (FOR THREE DIMENSIONAL SHEAR BUILDING REPRESENTATION)**

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**EIGENVALUES**

- **F - 4**
- **F - 5**
COLUMN: 1  2  3
ROW 1  .00000 10.000 .00000
ROW 2  .00000 .00000 10.000
ROW 3  .00000 .00000 .00000

************ MAX. RESPONSE ************

MAX. REL. DISP. AT THE CENTER OF MASS OF FLOORS
(WITH RESPECT TO THE BASE)
FLOOR  X DISP.  Y DISP.  ROTN. (rad)
1   .30166   .00000   .00000

MAX INTERSTORY DRIFT
STORY  X DIST.  Y DIST.  TIME  X DRIFT/FL. BT.(s)  TIME  Y DRIFT/FL. BT.(s)
1   .00000   .00000 1.84   3.02   .00000
1   .00000   .00000 1.84   3.02   .00000
1   .00000   .00000 1.84   3.02   .00000
1   .00000   .00000 1.84   3.02   .00000
1   .00000   .00000 1.84   3.02   .00000

MAX. DISP. AT THE CENTER OF MASS OF BASE
X DISP.  Y DISP.  ROTN. (rad)
-1.816   .00000   .00000

MAX RESULTANT DISP. AT THE CENTER OF MASS OF BASE
TIME  REL. DISP.  X COMP.  Y COMP
1.720   1.676   -1.676   .000

MAX RESULTANT BEARING DISPLACEMENT
BEARING  TIME  MAX. DISP. ANG. WITH X AXIS
1  1.720   1.676   -1.676   .000
3  1.720   1.676   -1.676   .000
3  1.720   1.676   -1.676   .000
4  1.720   1.676   -1.676   .000

MAX. BEARING DISP. IN X
BEARING  TIME  MAX. DISP. X
1  1.720   -1.676
3  1.720   -1.676
3  1.720   -1.676
4  1.720   -1.676

MAX. BEARING DISP. IN Y
BEARING  TIME  MAX. DISP. Y
1  .000   .000
4  .000   .000

F - 6
F - 7
APPENDIX G

EXAMPLE 6

EXAMPLE WITH (1) 3D-SUPERSTRUCTURE (EIGENVALUES AND EIGENVECTORS)
(2) ELASTOMERIC ISOLATION SYSTEM
(3) NONLINEAR VISCOS ISOALATION SYSTEM
(4) OUTPUT OF PEAK RESPONSE AND TIME HISTORIES

SIX STORY R.C. STRUCTURE WITH LEAF-SHAPED BEARING ISOLATION SYSTEM (SEE SECTION 8 - NCEER 01-0065)
Units: Ton/sec/ft superstructure information
2.5 28 1008 8.9 0
0.0 28 1008 8.9 0
integration control parameters
0.0 4 1 1000 78 1
earthquake control parameters
1 0.9 80 0 0
******** superstructure info**********
6 story info
3 2 35.65 351 2 9 15 6 9
3 story info
3 2 35.65 351 3 9 15 6 9
3 story info
3 2 35.65 351 3 9 15 6 9
3 story info
3 2 35.65 351 3 9 15 6 9
3 story info
3 2 35.65 351 3 9 15 6 9
frame data
frame control parameters
1 1 34 12 8 8 4 0
column info
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
column properties
1 2
2 3
3 4
4 5
5 6
6 7
7 8
8 9
9 10
10 11
11 12
12 13
13 14
14 15
15 16
16 17
17 18
18 19
19 20
20 21
21 22
22 23
23 24
24 25
25 26
26 27
27 28
28 29
29 30
30 31
31 32
32 33
33 34
34 35
35 36
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G - 21
**BASE ISOLATION DATA**

**GLOBAL ISOLATION DEVICE AT THE CENTER OF MASS**

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**TIME HISTORY OPTION**

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

**Mode Shapes**

**Mode 1**

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**Max M. Response**

**Max Rel. Disp. At the Center of Mass of Floors**

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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).


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<td>NCEER-87-0016</td>
<td>&quot;Pipeline Experiment at Parkfield, California,&quot;</td>
<td>J. Isenberg and E. Richardson</td>
<td>9/15/87</td>
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<td>NCEER-87-0017</td>
<td>&quot;Digital Simulation of Seismic Ground Motion,&quot;</td>
<td>M. Shinozuka, G. Deodatis and T. Harada</td>
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<td>NCEER-87-0022</td>
<td>&quot;Seismic Damage Assessment of Reinforced Concrete Members,&quot;</td>
<td>Y.S. Chung, C. Meyer and M. Shinozuka</td>
<td>10/9/87</td>
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<td>&quot;Design of a Modular Program for Transient Nonlinear Analysis of Large 3-D Building Structures,&quot;</td>
<td>S. Srivastav and J.F. Abel</td>
<td>12/30/87</td>
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<td>NCEER-87-0028</td>
<td>&quot;Second-Year Program in Research, Education and Technology Transfer,&quot;</td>
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<td>&quot;Optimal Control of Nonlinear Flexible Structures,&quot;</td>
<td>J.N. Yang, F.X. Long and D. Wong</td>
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<td>NCEER-88-0006</td>
<td>&quot;Combining Structural Optimization and Structural Control,&quot;</td>
<td>F.Y. Cheng and C.P. Pantelides</td>
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<td>NCEER-93-0012</td>
<td>&quot;Effects of Hydrocarbon Spills from an Oil Pipeline Break on Ground Water,&quot; by O.J. Helweg and H.H.M. Hwang</td>
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