University of Alberta
Department of Civil Engineering

Structural Engineering Report No. 15

Elastic Torsiona lAnalysis of Multi-Story Structures

by

H. J. Wynhoven

and

P. F. Adams

October, 1968

ELASTIC TORSIONAL ANALYSIS

OF MULTI-STORY STRUCTURES

by

J. H. WYNHOVEN

P.F. ADAMS

October, 1968

Department of Civil Engineering

University of Alberta

Edmonton, Canada

ABSTRACT

A computer program has been developed to perform a first order elastic analysis of a three-dimensional structure. The structure is assumed to be free to rotate about its longitudinal axis, and to translate in its principal directions.

The structure is considered to be composed of a series of planar bents. In each bent the frame and shear-wall elements are lumped into an analytical model composed of a single equivalent frame and single equivalent shear-wall. In each individual bent, frame and shear-wall elements may be coupled or uncoupled.

The structure is analyzed under lateral loads applied at each floor level. A stiffness approach is used to develop the equilibrium equations. These equations are then solved by an iterative procedure, which begins by assuming locations for the centres of rotation of the structure. These locations are then adjusted until the structure is in equilibrium.

The validity of the method is checked against other techniques. The effect of torsional action on the shear distribution within the structure is illustrated by a series of analyses of a ten story structure. The results are tabulated, and discussed in detail. The limitations of the analysis are indicated and possible extensions are discussed.

TABLE OF CONTENTS

		PAGE
Abstract	. . . .	i
Table of Contents	. . . .	ii
CHAPTER I	INTRODUCTION	1
CHAPTER II	PREVIOUS INVESTIGATIONS	3
CHAPTER III	ANALYTICAL MODEL	9
CHAPTER IV	METHOD OF ANALYSIS	17
CHAPTER V	RESULTS AND DISCUSSION	39
CHAPTER VI	SUMMARY AND CONCLUSIONS	57
NOMENCLATURE	. . . .	60
NOMENCLATURE	FOR FORTRAN IV PROGRAM	62
APPENDIX A	DERIVATION OF BENT STIFFNESS MATRIX	69
APPENDIX B	SUBROUTINE LISTING AND DATA CARDS	74
APPENDIX C	PRINT-OUT OF FORTRAN IV PROGRAM	79
BIBLIOGRAPHY	. . . .	106
ACKNOWLEDGEMENTS	. . . .	108

CHAPTER I

INTRODUCTION

Due to the complexity of many multi-story structures, it has been common practice to analyze the three-dimensional system as a series of braced and unbraced planar bents. Within each bent members are designed to carry the directly applied loads, with some modification for the interaction between adjacent bents.

The actual structure, however, deforms in a three dimensional manner in order to develop internal forces which are in equilibrium with the applied loads. The manner in which the structure reacts depends on the arrangement of the various stiffening elements, their relative stiffnesses, the interaction between adjacent elements, as well as the type and point of application of the loading. Within the individual bents, the normal shear-type of frame deformation is modified by, and must be compatible with, the cantilever deformation occurring in the shear-walls.

Computer solutions have been presented for determining the shear distribution between frame and shear-wall elements of planar bents (1, 2). These solutions are satisfactory when the arrangement of the stiffening elements within a structure is symmetric and the applied lateral load at each floor level passes through the centre of resistance. Under the above conditions the floor diaphragms do not rotate and the deflections of the stiffening elements are equal at each floor level.

If a torque is applied about the longitudinal axis of the structure;

or if the layout of the stiffening elements is asymmetric, the structure will rotate as well as translate (3, 4, 5). The interaction between shear-wall and frame elements in each bent is altered considerably by the torsional action of the structure (6). The shear distribution among individual bents, as well as between shear-wall and frame elements in each bent, may be quite different from that predicted when rotation of the structure is ignored.

The three dimensional aspect of structural behavior forms the basis of the present investigation. A first-order elastic analysis is developed which is used to investigate the behavior of structures free to rotate about a longitudinal axis, as well as translate under the action of lateral loads. The analysis is used to examine the shear distribution in various example structures for several arrangements of stiffening elements, and the results are presented in a systematic manner. Comparison is made between this and other methods of analysis. The limitations of the present method are discussed and modifications suggested to extend the application into the inelastic range.

CHAPTER II

PREVIOUS INVESTIGATIONS

It has been common practice to simplify the analysis of a multi-story structure by dividing it into a series of two-dimensional plane frames. The lateral loads were distributed to the bents in the structure on the basis of their tributary areas. The effect of the torsional deformations of the structure under the action of these lateral loads was neglected and only translational movements (in both principal directions) were considered.

If the arrangement of bents within a structure is not symmetrical, the above assumptions are erroneous. In this case the structure will deform so that certain bents are subjected to larger deflections than are others and must carry a correspondingly greater share of the lateral load.

In the last decade high intensity earthquakes have occurred in areas containing contemporary multi-story structures (7, 8, 9). Many of the structures failed in a torsional mode. The damage to these buildings has emphasized the necessity of considering the effect of torsion in design.

A completely general method of analysis is not available for asymmetric frame shear-wall structures. In Canada (10), however, torsional effects must be considered when designing for earthquake loading. Because of the uncertainties in the analysis, the eccentricities computed for asymmetric structures are increased by 50 per cent and, in fact, additional insurance factors added.

In Californian earthquake codes (11) provision is also made for an increase in shear due to torsion. The torque is computed as the product of the lateral earthquake loading and the distance separating the centre of mass and the centre of rigidity. It is recommended that negative torsional shears be neglected since the earthquake motion may have any direction of propagation. It is further stipulated that if the vertical elements depend on the diaphragm action of the floor system for shear distribution, the minimum torsional moment shall be the product of the story shear and an eccentricity equal to 5 per cent of the maximum building width at that level.

A design method proposed by the Portland Cement Association (12) provides for the possibility of torsional loading even when the structure is symmetrical. In this case a minimum design torque is specified. For asymmetric structures, the centre of rotation for each floor is assumed to be located at the centre of rigidity. A torsional moment is applied to the structure, which is equal to the product of the lateral load and the distance separating the centre of mass and the centre of rigidity.

The above design codes specify the loadings to be used but do not provide methods to determine the distribution of the resisting shears to the bents in a structure. The conservative nature of these provisions emphasizes the uncertainty surrounding the three-dimensional aspects of structural behavior.

Analyses of unsymmetric single story shear wall structures have been presented (4, 13). These methods take into consideration the shear contribution to the overall deflection of the structure. The analyses assume that the centre of rotation is at the centre of resistance of the structural elements. A torsional load is applied which is equal to the product of the lateral load and its eccentricity. The total load on any particular element is then obtained by superimposing the lateral and torsional load contributions. This approach is satisfactory for single story structures, where shear walls are not coupled to frames. Extension of the method to multi-story structures would be difficult because of the interaction of the various elements and the carry-over effects between adjacent stories.

Wilbur (3) presented equations, for determining the shear distribution to the individual bents of a structure. These equations allow for the torsional deformations which arise from the lack of coincidence of the point of load application and the centre of rigidity of the bents. The equations are based on the assumption that points of inflection occur at the mid points of all members and that all joint rotations are equal at a particular floor. The method is further limited to bents containing only uncoupled frames.

Blume, Newmark and Corning (12) suggest a method which is basically the same as that presented by Wilbur. In both cases the rotation of the beam to column joints are considered but no allowance is made for the interaction between frame and shear wall elements.

Khan and Sbarounis (14) have presented an analysis of planar bents which considers the interaction between frame and shear-wall elements. The method lumps the structure into an equivalent bent which is composed of two parts: a frame element and a shear wall element. The entire lateral load is applied to the wall element and its deflected position calculated. The loads necessary to make the frame element deform to the same position are then calculated. The load on the wall is modified until the frame and shear wall are compatible and in equilibrium under the applied lateral load. If the distribution of frame and shear wall elements is not symmetrical in the structure a torsional analysis is suggested. In this analysis the centre of rotation is to be located on the basis of the shear resisted by each element and its location in the structure. Since the analysis considers interaction effects, the centre of rotation, computed on this basis no longer coincides with the centre of rigidity computed simply on the basis of EI.

Winokur and Gluck (6) have formulated the analysis of asymmetric structures, containing frame and shear-wall elements, in matrix form. Three degrees of freedom are considered for each floor; translation in the X and Y direction and rotation about the vertical axis of the structure, θ. The analysis consists of the following three steps:

1. The overal lateral stiffness matrix for the structure is first evaluated. This is the sum of the lateral stiffness matrices for each of the stiffening elements. The overall lateral stiffness matrix for the structure, $|K|$, is a 3n by 3n square matrix, where n is the number of floors in the structure.

$$|K| = \begin{vmatrix} |Kxx| & |Kxy| & |Kx\theta| \\ |Kyx| & |Kyy| & |Ky\theta| \\ |K\theta x| & |K\theta y| & |K\theta\theta| \end{vmatrix}$$

where each of the submatrices represent the stiffness of the structure in the direction of the first subscript, due to a displacement in the direction of the second subscript.

2. Next, the three equations of equilibrium are formulated at each floor level. The solution of these equations involves the inversion of a 3n by 3n matrix and determines the deformations of the structure.
3. The member forces are obtained by multiplying the lateral stiffness submatrices for each element by the deformations obtained in step 2.

A method is not specified for calculating the stiffness matrix of the individual elements in the first step. Reference is made to the work of Khan and Sbarounis (14), and Clough, King and Wilson (2).

Weaver and Nelson (5) have developed an analysis which accounts for rotation of the floors as well as translation in the principal directions of the structure. The method is limited to framed structures and shear wall elements are not considered. The method consists of first determining member stiffness matrices. As both axial shortening and torsion are considered the member stiffness matrices consist of 6 by 6 arrays for beams and 12 by 12 arrays for columns. The geometric relations of the members within the structure are then used to transform the member stiffness matrices to a floor stiffness matrix. The equilibrium equations for the structure are formulated for each pair of adjacent floors. The equations contain joint rotations for both floors and floor translations and rotations for all floors in the structure, as unknowns. These unknowns are reduced by a forward elimination process starting at the top of the structure. Joint rotations and floor displacements are zero at the base, thus the first floor displacements are obtained by back substitution. Member forces are determined by multiplying the joint displacements by the member stiffness matrices.

As a summary of the above literature survey; it is apparent that, there is no completely general method for analysing multi-story frame shear-wall structures. Approximate design methods for framed structures have been developed based on simplifying assumptions to reduce the number of unknowns. These methods are approximations at best and do not make any allowance for the interaction between individual elements.

Complex exact analyses are available for analysing framed structures but these are not applicable to the large number of structures that incorporate shear walls. An analysis has been presented for considering planar bents incorporating frame and shear-wall elements, but this is not suitable for three dimensional structures subject to torsional loads. Even for symmetric structures not subjected to torsion, the techniques of lumping the structure into a planar bent introduces errors of unknown magnitude. A method is proposed for a three dimensional analysis of framed shear wall structures but this is not applicable to the case where the frame and shear-walls are coupled.

There is an immediate need for a method of analysis that can be applied to structures containing coupled frame shear-wall bents as well as uncoupled frame and shear-wall elements. This method must be applicable to large multi-story structures of varying geometric layouts.

CHAPTER III

ANALYTICAL MODEL

In the method of analysis discussed in this and the succeeding section, it will be assumed that the structure is composed of a linear elastic material and that the response of each member can be predicted by a linear analysis. The loads are lateral loads, concentrated at each floor level, and assumed to be applied statically. In addition, the diaphragms at each floor level are assumed to be infinitely rigid in their own plane.

The motion of a typical floor diaphragm is shown in FIGURE 3.1. The lateral loads cause translation as well as a rotation of the floor diaphragm, so that general point A moves to a new position A'. If it is assumed that the deformations are small relative to the overall dimensions of the structure, then bent k_x, which spans in the Y direction, will undergo a translation, v_k, in the Y direction, where

$$v_k = v_A + RX_k \times \theta \tag{3.1}$$

In Equation (3.1), v_k is the total deflection of bent k_x in the Y direction, v_A is the translation of the general point A in the Y direction, RX_k is the co-ordinate of bent k_x with respect to point A, measured perpendicular to the bent, and θ is the rotation of the floor diaphragm about the general point A. From Equation (3.1) the difference in deflection between adjacent bents is equal to the product of the angle of rotation and the perpendicular distance between the bents. Similarly for bent k_y, which spans in the X direction, the deflection in the X direction is given by

$$u_k = u_A - RY_k \times \theta \tag{3.2}$$

where u_k is the total deflection of bent k_y in the X direction, u_A is the translation of the general point A in the X direction, RY_k is the coordinate of bent k_x with respect to point A, measured perpendicular to the bent. In Equations (3.1) and (3.2), the rotation is assumed to be positive if clockwise and the distances from the general point A to the X and Y bents, RX and RY, are assumed to be positive as shown in FIGURE 3.1. Similar expressions may be developed for each bent, k, at each floor level, i.

If the torsional stiffness of the beams linking adjacent bents is neglected, the behavior of the structure will depend on that of the individual planar bents as shown in FIGURE 3.2. The deformation of a particular bent at each floor level differs from the deformation of adjacent bents due to their different locations relative to the general point A. Each bent in the system may contain frames coupled to one or more shear walls.

To obtain the analytical model used, the individual walls and frames must be lumped within each bent. The lumping technique has been used previously for the analysis of symmetrical structures consisting of shear walls and frames (1). In each story of the lumped model, each joint has one rotational degree of freedom and the story has one translational degree of freedom. Each degree of freedom requires one equilibrium equation in the solution. It is assumed that within a particular bent the beam to column connections undergo equal joint rotations and the beam to wall connections undergo equal joint rotations (but different from those at the beam to column connections); at a particular floor level. This reduces the number of unknowns to three per story for the case of a coupled frame shear-wall bent, and to two for an uncoupled frame bent. A typical coupled frame shear-wall bent is shown in FIGURE 3.3A and the equivalent model in FIGURE 3.3B . FIGURES 3.4A and 3.4B depict an uncoupled frame bent, and the equivalent model. In the model the wall stiffness, KW, is equal to the sum of stiffnesses of all the walls in a given story. The column stiffness, KC, in the model, is equal to the sum of stiffnesses of all the columns of the story. The beams are divided into two groups; those linking the shear walls to the columns are referred to as wall beams and those linking individual columns are referred to as frame beams. In the analytical model, the wall beam has a stiffness equal to the sum of the wall beam stiffnesses and the frame beam has a stiffness double that of the sum of the frame beam stiffnesses. One end of the frame beam is placed on a roller and the joint rotation of the roller end is considered to be equal to that at the column end. The distinction between wall beam and frame beam is necessary because of the finite width of the wall. This causes a vertical deflection of the wall beam, at the wall joint, due to the wall rotation. This effect increases the bending moment in the wall beam for a given wall joint rotation and is similar to an increased rotational restraint on the wall at each floor level.

The final stage in developing the analytical model is to reduce the number of degrees of freedom of each floor diaphragm, from three to one. This is achieved by assuming that each floor diaphragm rotates about a point in its plane as shown in FIGURE 3.5. This point, referred to as the centre of rotation, has a unique location, relative to the assumed general point A in FIGURE 3.1, such that the following geometric conditions are satisfied,

$$v_A = (X_o - X_A) \times \theta \tag{3.3}$$

$$u_A = (Y_o - Y_A) \times \theta \tag{3.4}$$

where v_A, u_A and θ have been previously defined, X_A and Y_A are the co-ordinates of point A and X_o and Y_o are the co-ordinates of the centre of rotation.

To initiate the analysis, the position of the centre of rotation must be assumed, relative to a reference point. The two unknowns, X_o and Y_o, are thus eliminated. This assumed location is varied until the angle of rotation selected results in a balance between the applied loads and the resisting forces, in both the X and Y directions; and a torque which is equal to zero about any point in space. This type of iterative solution requires a relatively small amount of computer storage space and thus more complex structures may be analyzed. The iteration process itself, however, is a complex portion of the program and requires a significant amount of computer calculation time.

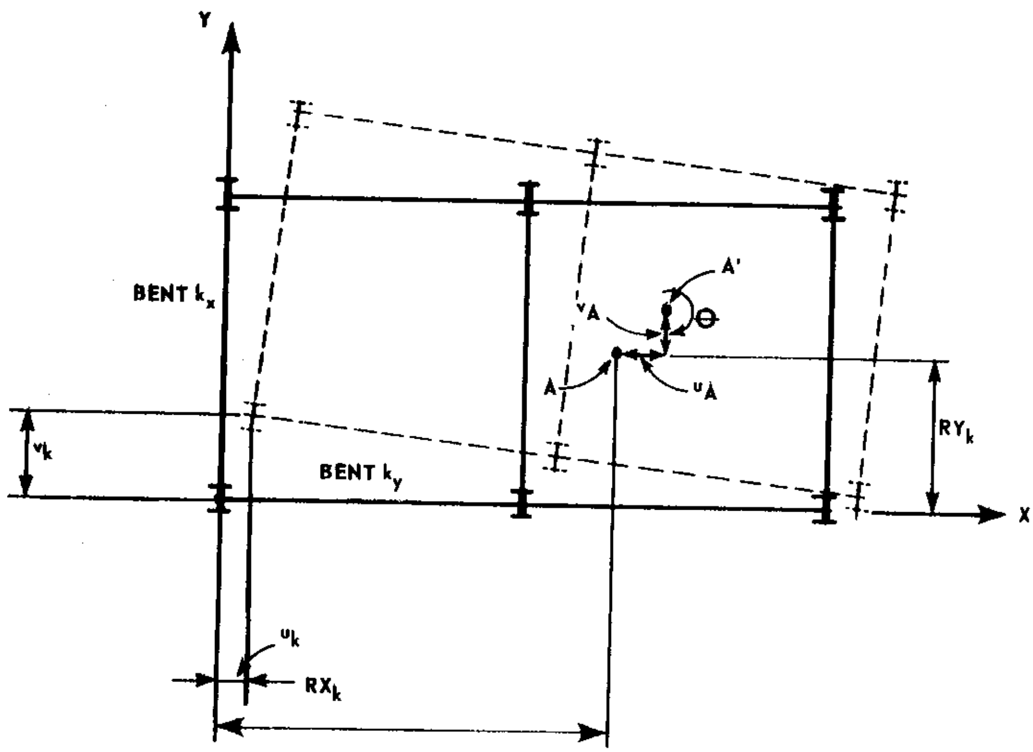

FIGURE 3.1 TYPICAL FLOOR DIAPHRAGM

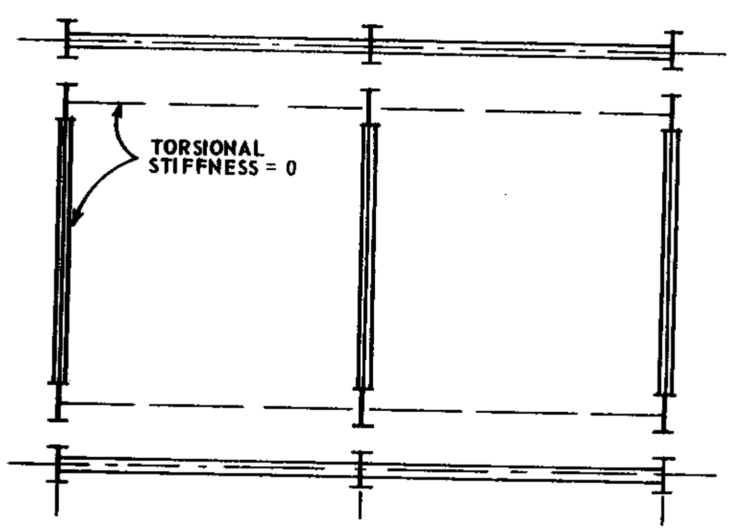

FIGURE 3.2 TWO DIRECTIONAL SYSTEM OF PLANAR BENTS

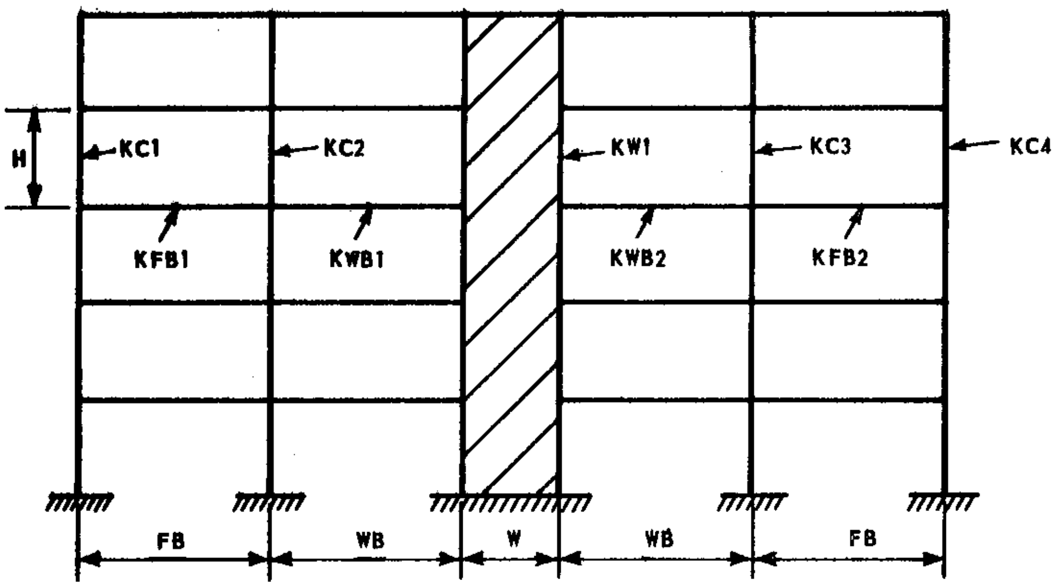

FIGURE 3.3A COUPLED BENT

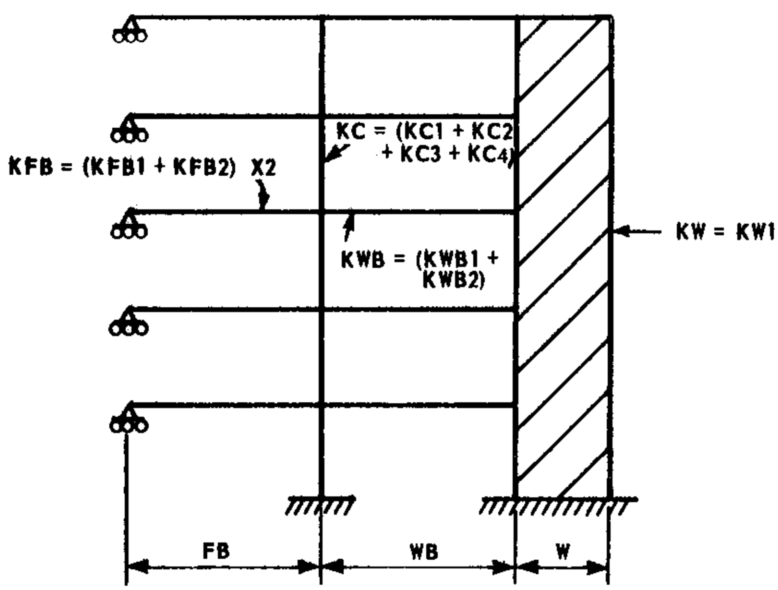

FIGURE 3.3B LUMPED COUPLED BENT

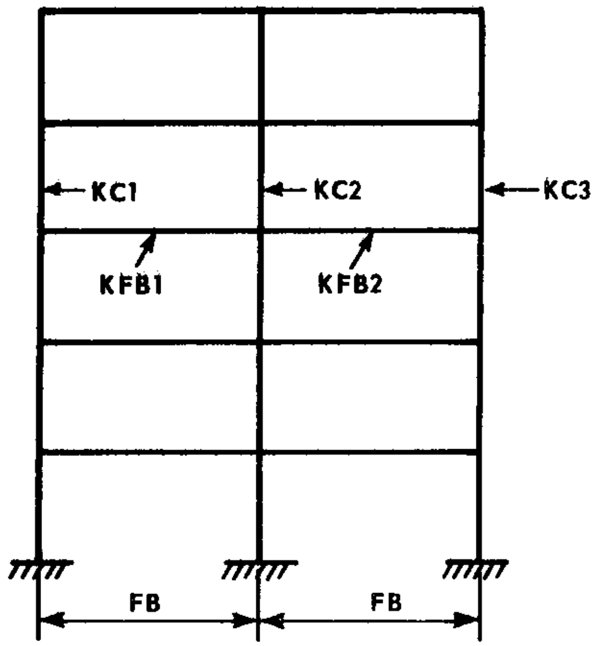

FIGURE 3.4A UNCOUPLED BENT

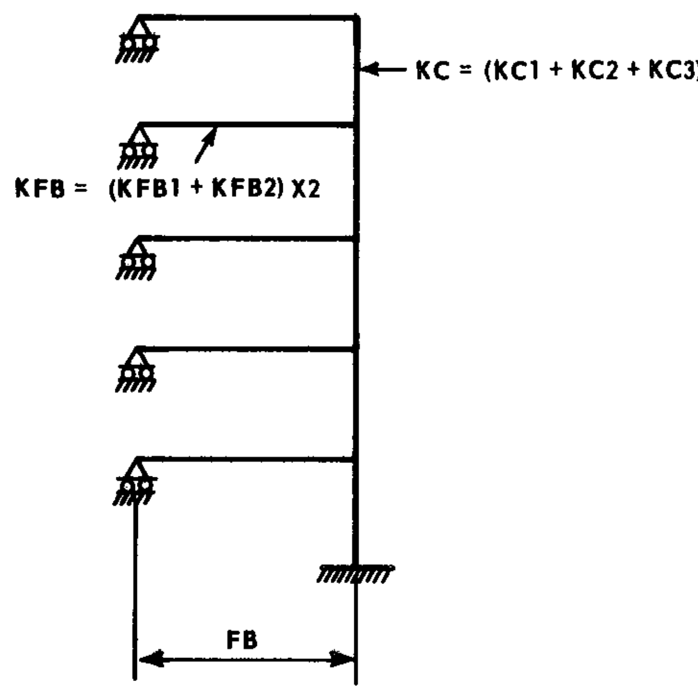

FIGURE 3.4B LUMPED UNCOUPLED BENT

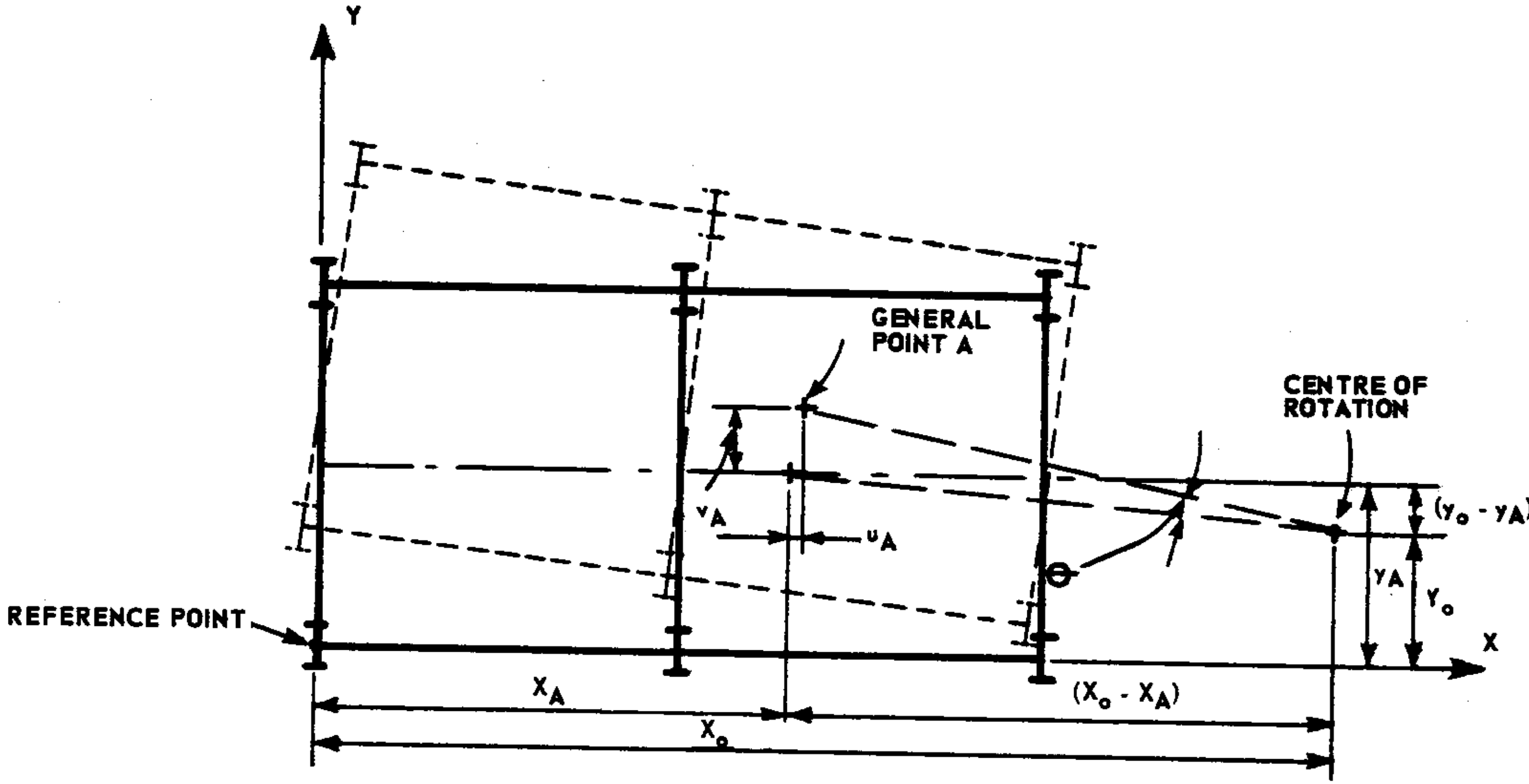

FIGURE 3.5 FLOOR DIAPHRAGM ROTATION

CHAPTER IV

METHOD OF ANALYSIS

The present analysis is based on the simplified model described in the previous chapter and involves two distinct steps; first a lateral stiffness matrix is developed, in terms of the story sway deformations, for each of the bents in the structure (in both the X and Y directions); secondly a rotational stiffness matrix is computed for the entire structure. This is possible because the story sway vectors of each bent are related, since the floor diaphragms are assumed to be infinitely rigid in their own planes. The rotational stiffness matrix is then inverted and multiplied by the applied torque to obtain the floor diaphragm rotation vector. By back substitution the resisting floor forces are calculated (in both the X and Y directions). If the resisting forces and applied loads are not in balance, an iterative process is used to relocate the assumed positions of the centres of rotation. This iterative procedure is repeated until the resisting floor forces are in balance with the applied loads and the moment about any point in space is equal to zero, for all floors in the structure.

The procedure used to determine the lateral stiffness matrix for each bent depends on whether the bent consists of a coupled frame and shear wall or an uncoupled frame. The case of a coupled frame and shear wall will be treated in detail and the modifications necessary for an uncoupled frame will be outlined briefly.

Consider the single bent shown in FIGURE 4.1. As lateral loads are applied, the bent deforms as shown in FIGURE 4.2. In each story the sway displacements of the frame and shear wall are equal. Because of the finite width of the shear wall, the wall beam undergoes a vertical displacement at the connection to the wall. The end rotations of each frame beam are assumed to be equal.

For each floor level there are three unknowns; Δ, θ_c and θ_w. The lateral stiffness matrix is developed by writing the equilibrium equations in terms of the slope deflection coefficients and expressing the joint rotations in terms of the story sway deformations. The elimination technique used to express joint rotations as story sway displacements is described in APPENDIX A. The resulting floor force and joint rotation vectors are as follows:

$$|V|_k = |K|_k^{\Delta} \times |\Delta|_k \tag{4.1a}$$

$$|\theta|_k^c = |K|_k^{\theta c} \times |\Delta|_k \tag{4.1b}$$

$$|\theta|_k^w = |K|_k^{\theta w} \times |\Delta|_k \tag{4.1c}$$

where $|K|_k^{\Delta}$, $|K|_k^{\theta c}$ and $|K|_k^{\theta w}$ are square matrices which depend only on the bent member properties and their geometry. The story sway vector, $|\Delta|_k$, contains unique values for each bent. These must be determined before the joint rotation vectors can be obtained by back substitution in Equations (4.1b) and (4.1c).

The next step in the analysis is to determine the story sway vector $|\Delta|_k$. The lateral displacement of a given floor in a particular bent is equal to the product of the floor diaphragm rotation and the perpendicular distance between the bent and the centre of rotation of the floor diaphragm.

For a bent spanning in the Y direction:

$$S_{k,i} = \theta_i \times (X_{o,i} - X_{k,i}) \tag{4.2a}$$

where $S_{k,i}$ is the displacement (from the undeformed position) of bent k at floor level i, θ_i is the rotation of floor diaphragm i about its centre of rotation and $(X_{o,i} - X_{k,i})$ is the co-ordinate distance of bent k from the centre of rotation of the i^{th} floor diaphragm. The sway deformation in the i^{th} story of bent k can then be expressed as,

$$\Delta_{k,i} = S_{k,i} - S_{k,i-1} \tag{4.2b}$$

therefore

$$\Delta_{k,i} = \theta_i \times (X_{o,i} - X_{k,i}) - \theta_{i-1} \times (X_{o,i-1} - X_{k,i-1}) \tag{4.2c}$$

where $\Delta_{k,i}$ is the sway deformation of the i^{th} story of bent k. This may be written in general matrix form as follows:

$$|\Delta|_k = |D|_k \times |\theta| \tag{4.2d}$$

where $|\Delta|_k$ is the story sway vector for bent k, $|D|_k$ is a two-diagonal square matrix in which each row, i, contains the perpendicular distances $(X_{o,i-1} - X_{k,i-1})$, $(X_{o,i} - X_{k,i})$, between the bent and the centres of rotation of two adjacent floor diaphragms, and $|\theta|$ is the floor diaphragm rotation vector. The floor force vector $|V|_k$ may now be written as,

$$|V|_k = |K|_k^D \times |\theta| \tag{4.3a}$$

where

$$|K|_k^D = |K|_k^\Delta \times |D|_k \tag{4.3b}$$

The next step in the analysis is to formulate the torsional equilibrium equation. A reference point is chosen at each floor level so that all reference points lie on a common vertical axis and all of the bents lie in the first quadrant of the co-ordinate system, as shown in FIGURE 4.3. The building is oriented so that the centre of rotation lies on the positive X side of the centre of resistance. This will result in positive rotations of the floor diaphragms and resisting floor forces which are in opposition to lateral loads applied in the positive X and Y directions. The resisting torques, about the reference point, developed by the bents spanning in both the X and Y directions are computed individually and then summated. Written in general matrix form,

$$|T|_X = \sum_{k=1}^{NX} (|K|_k^D \times |X|_k) \tag{4.4a}$$

$$|T|_Y = \sum_{k=1}^{NY} (|K|_k^D \times |Y|_k) \tag{4.4b}$$

where $|T|_X$ is a torsional stiffness matrix which includes all the bents in the X direction, and $|T|_Y$ is the torsional stiffness matrix for all the bents in the Y direction. $|X|_k$ is the vector representing the distance of bent k (in the X direction) from the reference point, $|Y|_k$ is the vector representing the distance of bent k (in the Y direction) from the reference point, NX is the number of bents spanning in the X direction and NY represents the number of bents spanning in the Y direction. The individual bents. If the resisting forces in the X and Y directions are equal to the applied loads then the initial assumed locations of the centres of rotation are correct. If the resisting forces do not balance the applied loads then a correction technique is applied which shifts the centres of rotation in both the X and Y directions until the structure is in equilibrium.

The correction is applied by first determining an influence coefficient matrix for the shift of the centres of rotation in the X direction. The Y co-ordinates of the centres of rotation are held constant. The influence coefficient matrix is obtained by increasing the distance from the reference point to the centre of rotation for the first floor by 1 inch, while maintaining the position of the centres of rotation for all other floors at the initial values. With this new arrangement of the centres of rotation, the torsional analysis described above is repeated and the resultant floor forces are calculated. The influence coefficient for the first floor is equal to the difference in total floor force between the initial value and that obtained for the shifted centre of rotation. This procedure is repeated for all floors; in each case the centres of rotation are held at the initial values except for the floor under consideration. The physical interpretation of the process is that if the centre of rotation of a particular floor is shifted by x inches, then the resisting floor force at any floor is changed by the product of x and the influence coefficient for that floor. Consequently, if the resisting floor forces for the initial trial differ from the applied loads it is possible to determine the corrections to the positions of the centres of rotation, in order for the resisting floor forces to approach the applied lateral loads.

This may be written in general matrix form as,

$$|\Delta X| = |C|_X^{-1} \times (-|F|_X - |V|_X^A) \qquad (4.8)$$

where $|\Delta X|$ is the vector representing the corrections to be applied to the positions of the centres of rotation (in the X direction), $|C|_X$ is the transpose of the influence coefficient matrix (for a shift of the centres of rotation in the X direction), and $|V|_X^A$ is the resisting floor force vector in the Y direction, for the initial position of the centres of rotation. Due to the manner in which the iterative solution is formulated, the influence coefficients are non-linear. The correction vector, $|\Delta X|$, in Equation 4.8 does not immediately lead to the correct position for the centres of rotation and several iteration cycles may be required. After each cycle the corrected position of the centres of rotation become the initial values for the next cycle. When the floor forces in the Y direction balance the applied loads within a specified limit, a similar correction technique is applied to shift the centres of rotation in the Y direction. In matrix form,

$$|\Delta Y| = |C|_Y^{-1} \times (-|F|_Y - |V|_Y^A) \qquad (4.9)$$

where $|\Delta Y|$ is the vector representing the corrections to be applied to the position of the centres of rotation (in the Y direction), $|C|_Y$ is the transpose of the influence coefficient matrix (for a shift of the centres of rotation in the Y direction) and $|V|_Y^A$ is the vector of the resisting floor forces in the X direction (for the initial position of the centres of rotation). The number of iteration cycles required to determine the correct position of the centres of rotation will depend on how correct the initial choices were. If the building is symmetrical about a centroidal axis and there are no applied loads in this direction then the centre of rotation will lie on this axis. This factor facilitates the choice of the initial position of the centres of rotation.

A computer program was written in Fortran IV language for use on an IBM 360/67 system in order to facilitate the analysis. A print-out of the program is included as APPENDIX C. In this particular program the structure size was limited to twenty stories, with a maximum of four bents in the X direction and three bents in the Y direction. The size of structure that may be analyzed, however, is limited only by the computer storage capacity.

The computer program has three distinct divisions. COMPAK reads in the member properties and computes the bent stiffness matrices. TORPAK performs the torsional analysis until an equilibrium condition is reached. CALPAK uses the story sway and joint rotation vectors calculated by TORPAK to compute the member forces for each bent. The procedure followed by the program is described in greater detail below.

The COMPAK stage of the program first determines whether the bent includes a shear wall. It then reads in the member properties and bent geometry. From these quantities the member stiffness submatrices are computed. If the bent consists solely of a frame, four submatrices are required but if the frame is coupled to a shear wall the number of submatrices increases to nine. A subroutine then calculates the bent stiffness matrix, $|K|_k^{\Delta}$, and matrices $|K|_k^{\theta c}$ and $|K|_k^{\theta w}$ in Equations (4.1b) and

(4.1c).

The torsional stiffness matrix, $|T|_R$ is calculated in the TORPAK stage. The location of bents within the structure, the magnitude of the applied lateral loads, their points of application, the location of the centre of resistance at each floor level, and the St. Venant torsional stiffness for each floor level are read in and used by TORPAK. TORPAK may next perform a torsional analysis or an analysis with rotation of the floor diaphragms suppressed.

If a torsional analysis is performed the torque about the reference point, due to the applied loads, is calculated. If the centre of resistance of the structure is within 5 per cent of the overall width of the structure, from the geometric centre, then a minimum torque is applied. TORPAK first computes $|T|_{SV}$, $|T|_X$, and $|T|_Y$; the latter two will differ for each change in the position of the centres of rotation. The initial position of the centres of rotation are assumed to be at,

$$X_{o,i} = 1.2 \times X_{c,i} \tag{4.10a}$$

$$Y_{o,i} = 1.2 \times Y_{c,i} \tag{4.10b}$$

if there is an applied lateral load in both the X and Y directions. If there is no applied load in one direction the initial positions of the corresponding centres of rotation are modified to,

$$X_{o,i} = X_{NX,i} \div 2.0 \tag{4.10c}$$

$$Y_{o,i} = Y_{NY,i} \div 2.0 \tag{4.10d}$$

In the above four equations $X_{o,i}$ is the distance between the reference point and the centre of rotation (in the X direction), $Y_{o,i}$ is the distance between the reference point and the centre of rotation (in the Y direction), $X_{c,i}$ is the distance between the reference point and the centre of resistance (in the X direction), $Y_{c,i}$ is the distance between the reference point and the centre of resistance (in the Y direction), all taken at the i^{th} floor level. The distance between the reference point and the X bent furthest away from the reference point is denoted as $X_{NX,i}$ and $Y_{NY,i}$ is the distance between the reference point and the Y bent furthest away from the reference point.

The floor diaphragm rotation vector $|\theta|$ is calculated by inverting the torsional stiffness matrix $|T|_R$. The resisting floor forces in both the X and Y directions are obtained by back substitution and summation. A check is performed to determine whether the resisting floor forces are within 1 per cent of the applied lateral loads. If so, TORPAK returns control to COMPAK, after calculating the story sway and joint rotation vectors $|\Delta|_k$, $|\theta|_k^c$ and $|\theta|_k^w$ for each bent.

If the resisting forces are not within 1 per cent of the applied loads, TORPAK calls up the subroutine which calculates the influence coefficients for correcting the centres of rotation in the X direction. The correction cycle is repeated until the resisting forces and applied loads balance in the Y direction. Then the subroutine for correcting the position of the centres of rotation in the Y direction takes over. After each correction cycle, if the forces and loads in the Y direction are not in balance, these are balanced first before correction in the X direction continues. The correction procedure is continued until either equilibrium

ERRATA

Mr. Barter reports the steel yield strength in terms of mill test results and has based all his computation on the mean yield strength from these tests. The four bars from column C2 were tested with yield strengths of 43,600, 44,500, 44,500 and 45,000 psi. Six other bars from the steel used in this test series have also been tested with yield strengths of 44,000 to 46,000 psi. Thus it would appear that a mean yield strength of 44,700 psi would better represent the steel in these tests. If this lower value of yield strength were used in computing the column strengths, the tension branches of the interaction curves in Figures 4-6, 4-7, 4-17 and 4-18 would be shifted inwards slightly to a position that would agree better with the test results. This also would affect the comparisons made for test series D in Chapter 7. This error in yield strengths should not appreciably affect the computations for test series A and C.

is reached or the number of cycles exceeds the program limit.

COMPAK then calls up CALPAK which calculates all of the member forces for each bent. These member forces are based on the last values of $|\Delta|_k$, $|\theta|_k^c$ and $|\theta|_k^w$ calculated by TORPAK. Unless the structure is in equilibrium, therefore, the member forces calculated by CALPAK are not necessarily the correct values. If the correction procedure is terminated by the program limit, the unbalance of forces and applied loads is indicated by a print statement in the output.

CALPAK also includes the write subroutine, which prints out the member forces, before returning to COMPAK and stopping. A flow diagram of the program is presented in FIGURES 4.4, 4.5 and 4.6. In APPENDIX B a list of all subroutines is presented together with an explanation of the tasks that each subroutine performs. Also included in APPENDIX B is a list of the input data cards and their formats.

Two additional variations are possible within the TORPAK stage of the analysis; a minimum torque may be applied to the structure or an in plane analysis may be performed on the structure. In the former case, if the structure is approximately symmetrical, the rotation of the floor diaphragms become very small and the centres of rotation are a great distance from the reference point. The solution requires many iteration cycles and results in floor deformations that are almost equal at all bents. In this case, it may be required by design codes that a minimum torque be applied to the structure. This is done automatically by TORPAK when the centre of resistance of the structure is within 5 per cent of the overall width of the structure from the geometric centre. TORPAK applies a minimum torque equal to the product of the applied loads and an eccentricity equal to 10 per cent of the overall width of the structure.

The second variation is initiated by the input data. If requested, TORPAK performs a symmetrical analysis on the structure, in which all bents in any one direction translate equal amounts. This is achieved by summing the lateral stiffness matrices of all bents in one direction. The total lateral stiffness matrix is then inverted and multiplied by the applied lateral loads (in that direction) to yield the story sway vectors (which will be the same for all bents in that direction). The subroutine that carries out the symmetrical analysis is called SYMPAK and after returning control back to COMPAK all the torsional analysis subroutines are bypassed except SWAY which calls up CALPAK as before.

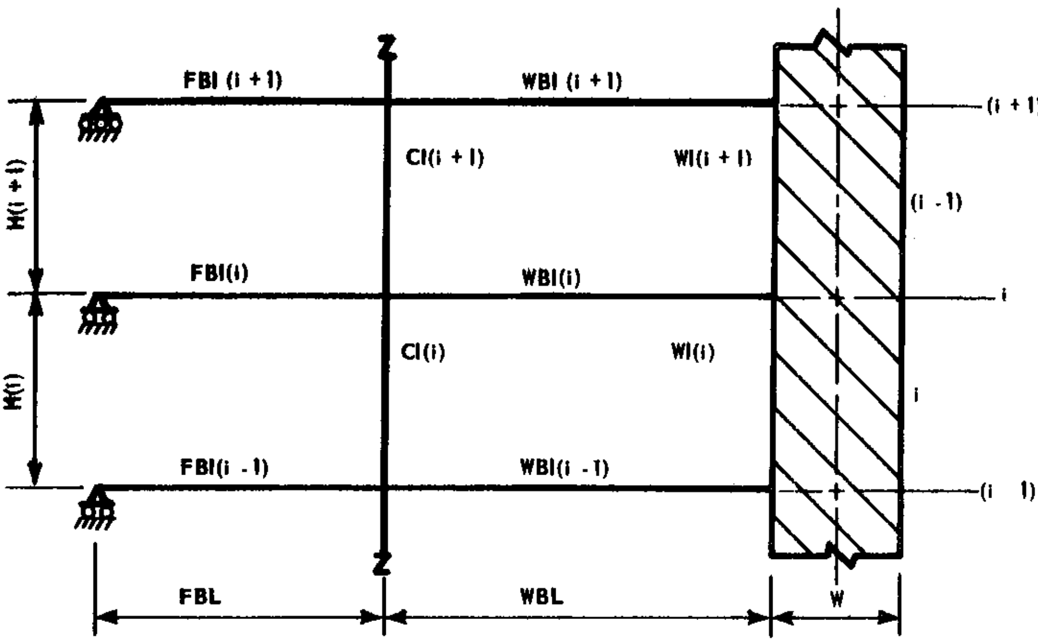

FIGURE 4.1 SECTION OF TYPICAL BENT

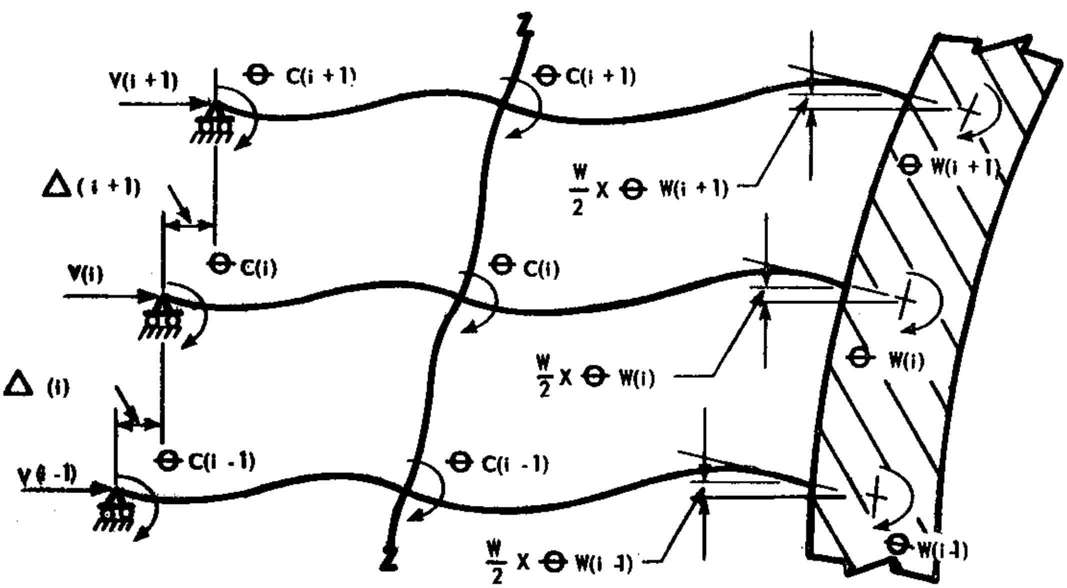

FIGURE 4.2 DEFORMED SECTION OF TYPICAL BENT

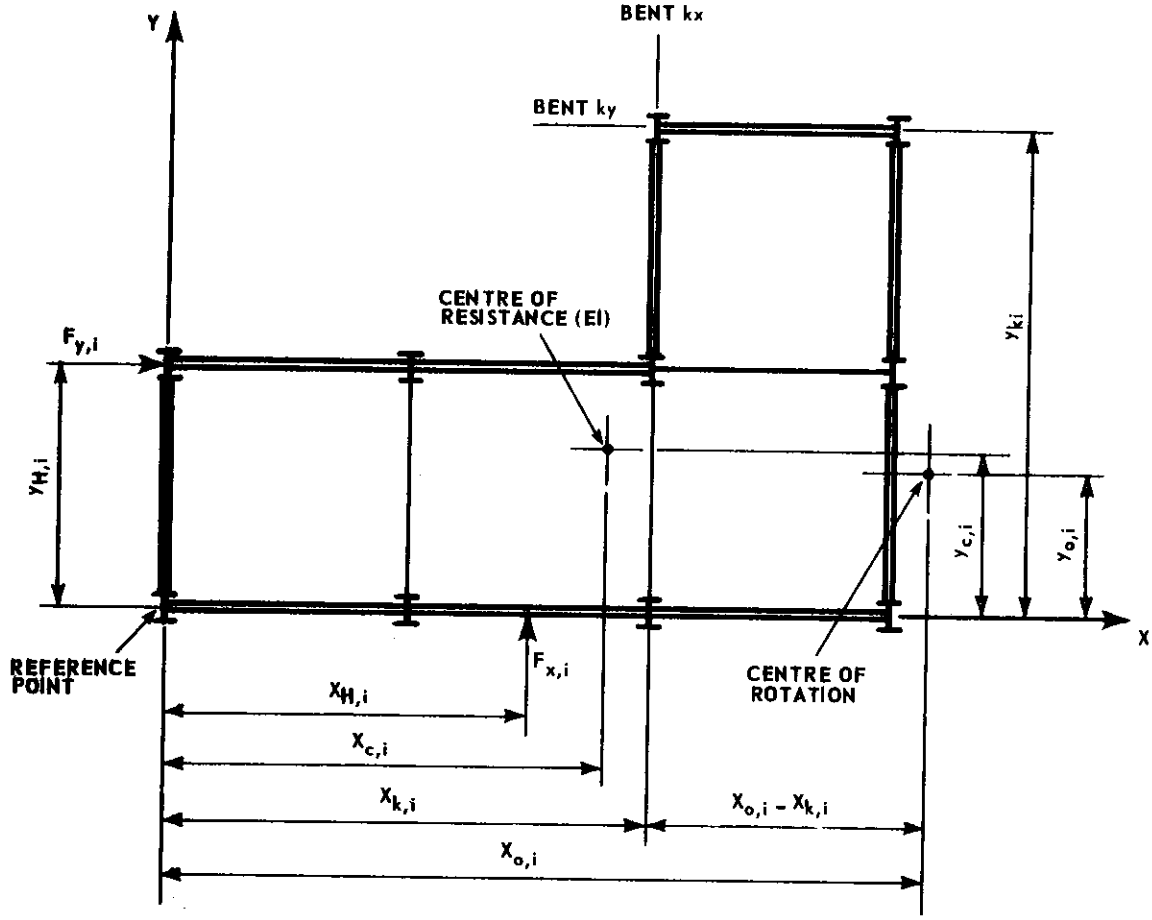

FIGURE 4.3 CO-ORDINATE AXES AND BUILDING ORIENTATION

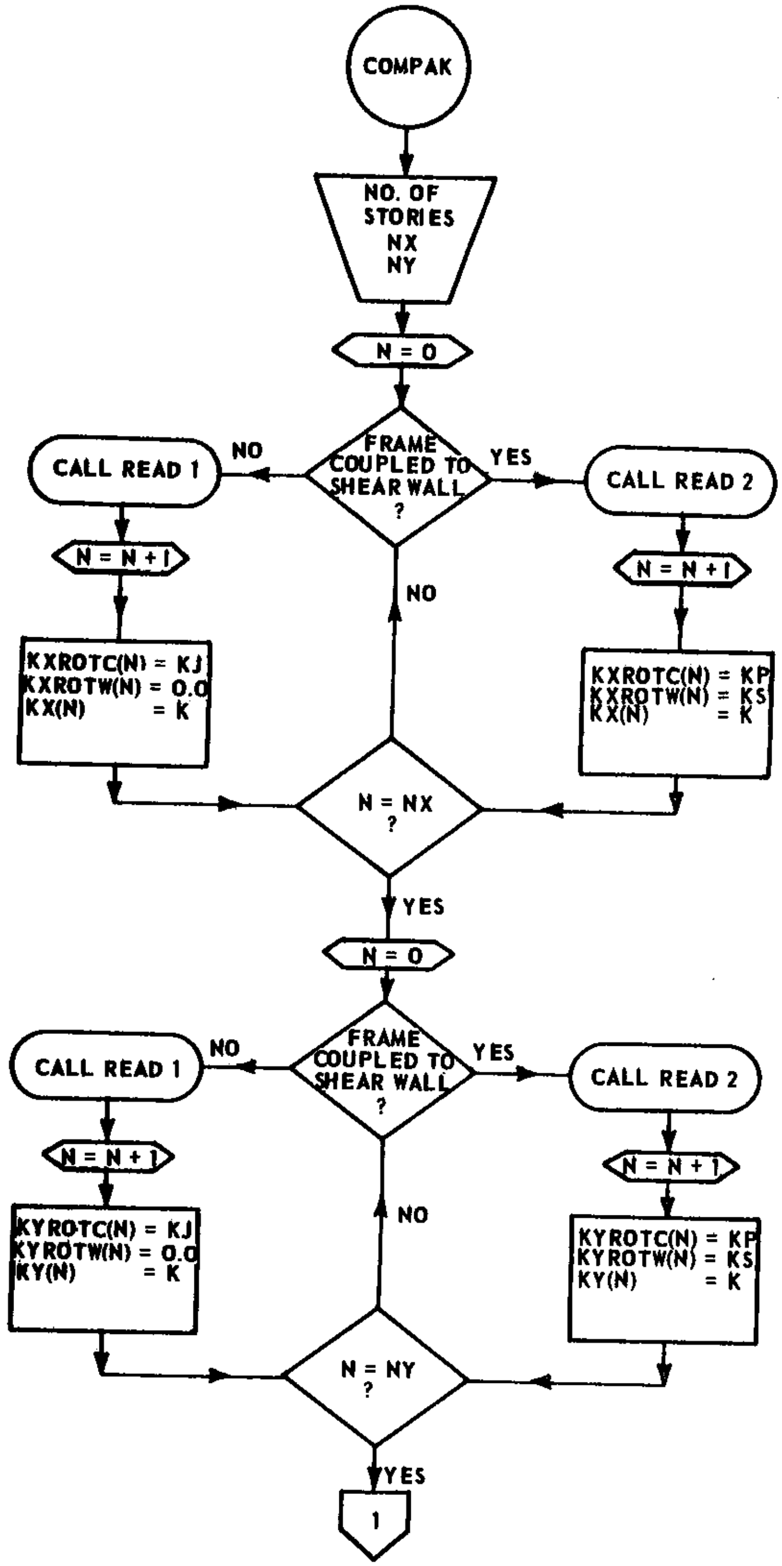

FIGURE 4.4 MAIN PROGRAM

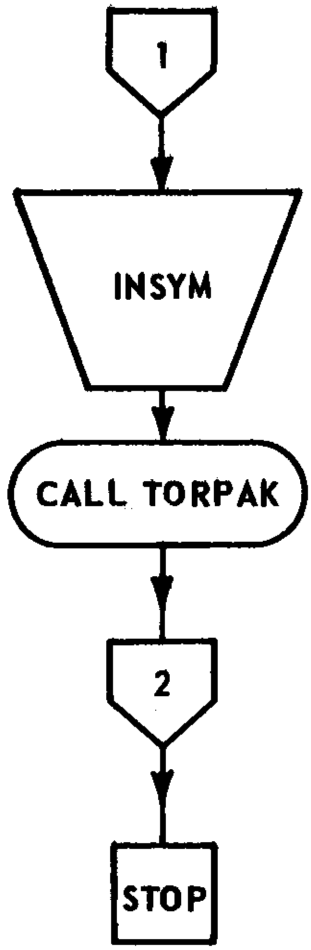

FIGURE 4.4 MAIN PROGRAM (CONTINUED)

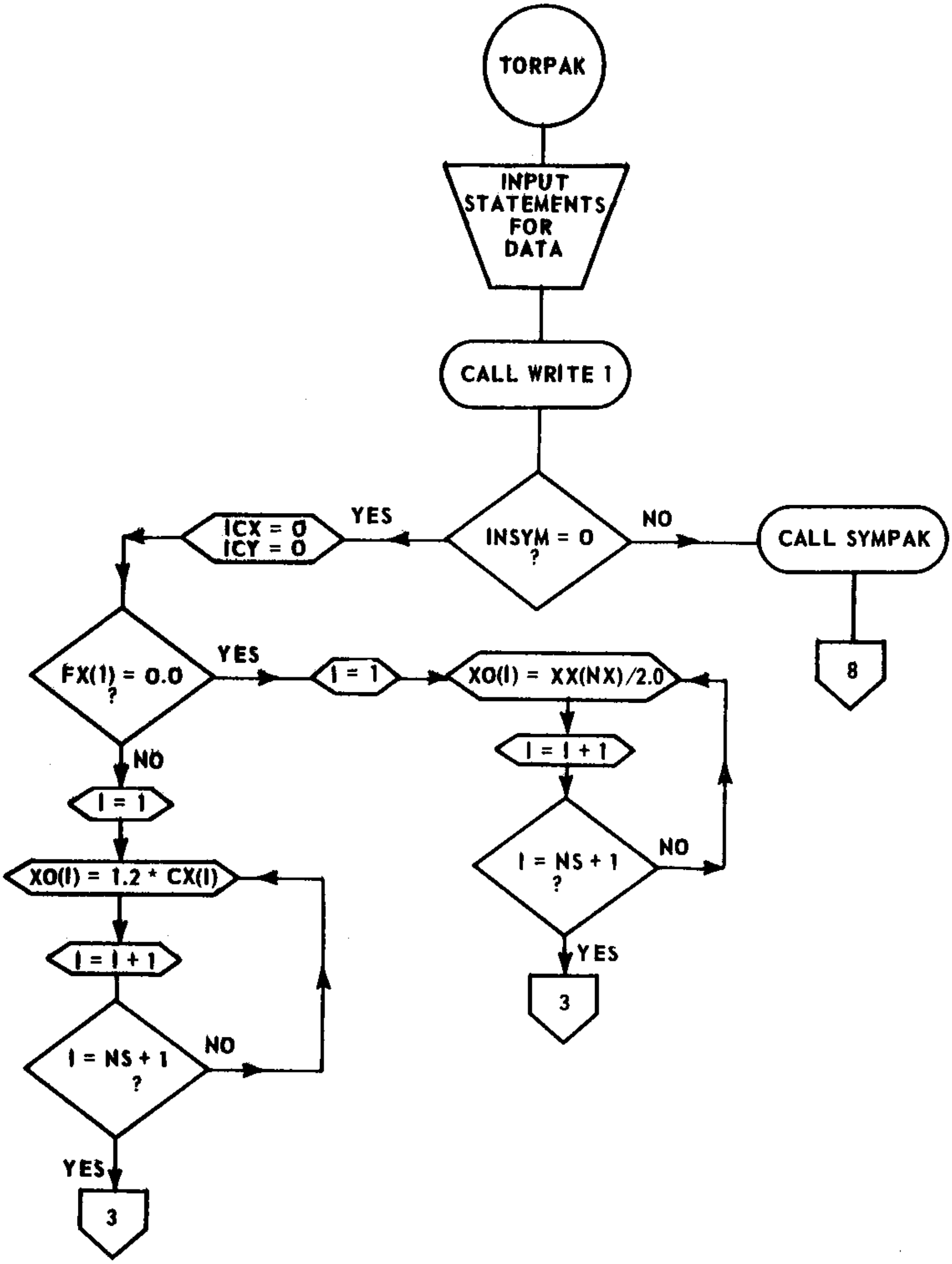

FIGURE 4.5 SUBROUTINE TORPAK

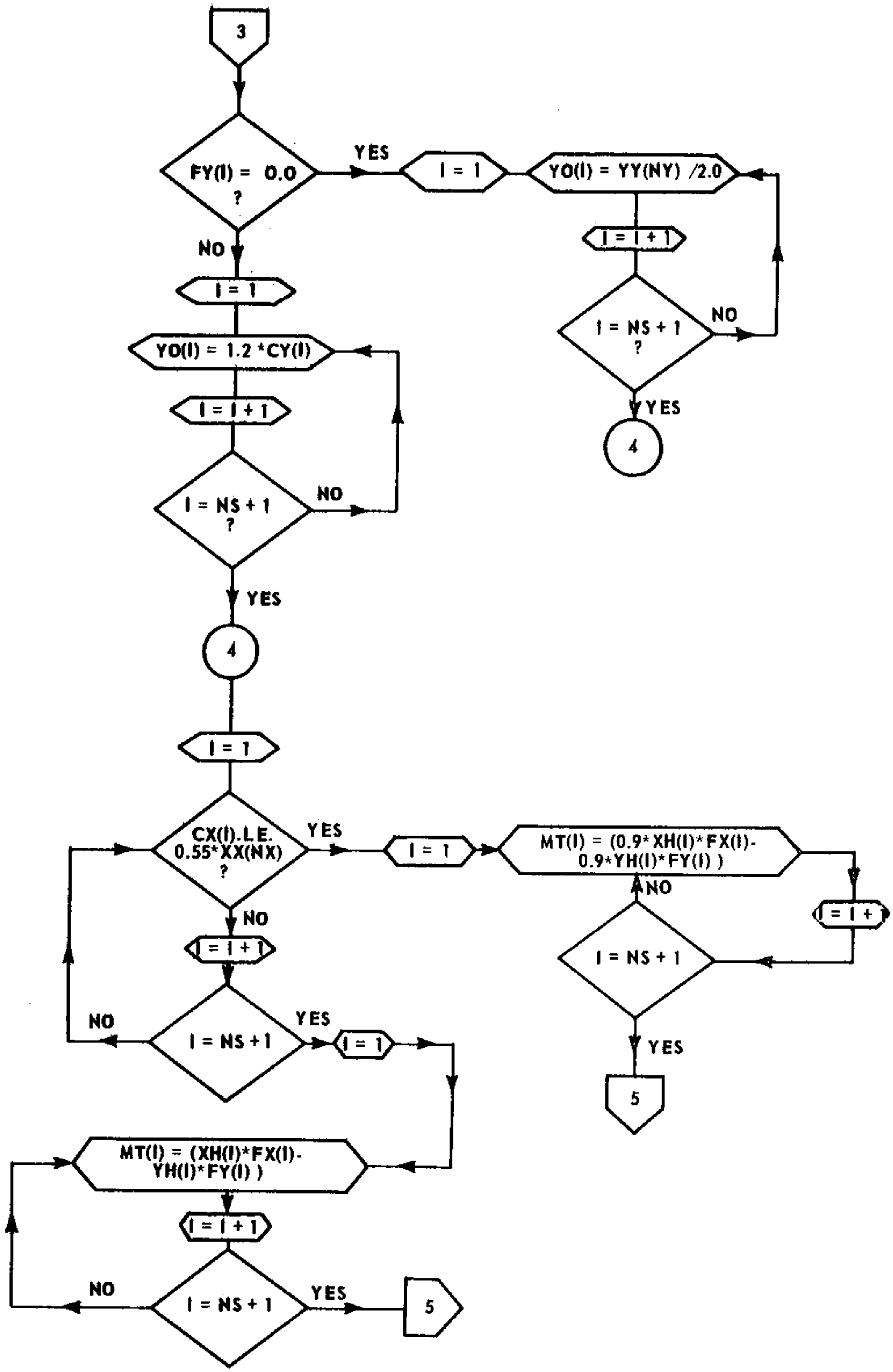

FIGURE 4.5 SUBROUTINE TORPAK (CONTINUED)

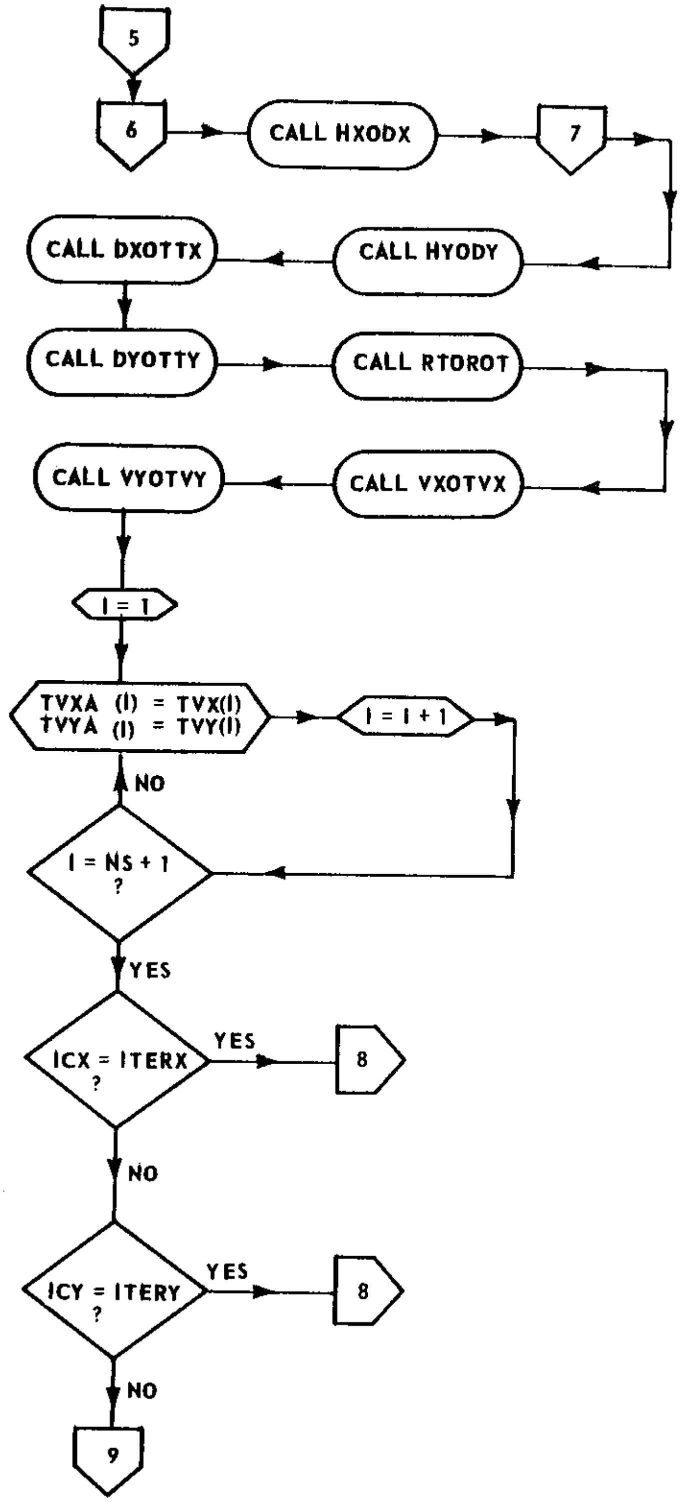

FIGURE 4.5 SUBROUTINE TORPAK (CONTINUED)

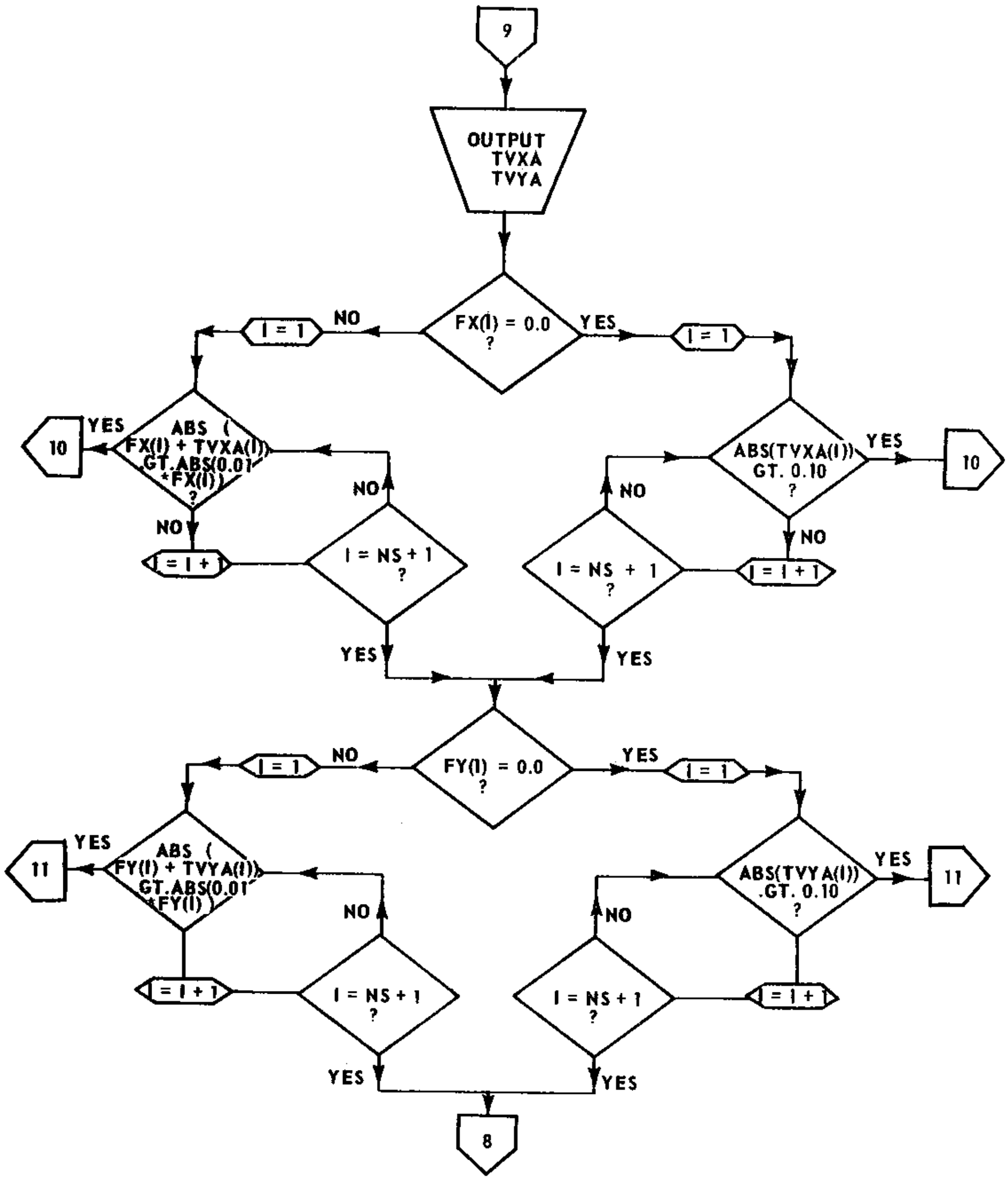

FIGURE 4.5 SUBROUTINE TORPAK (CONTINUED)

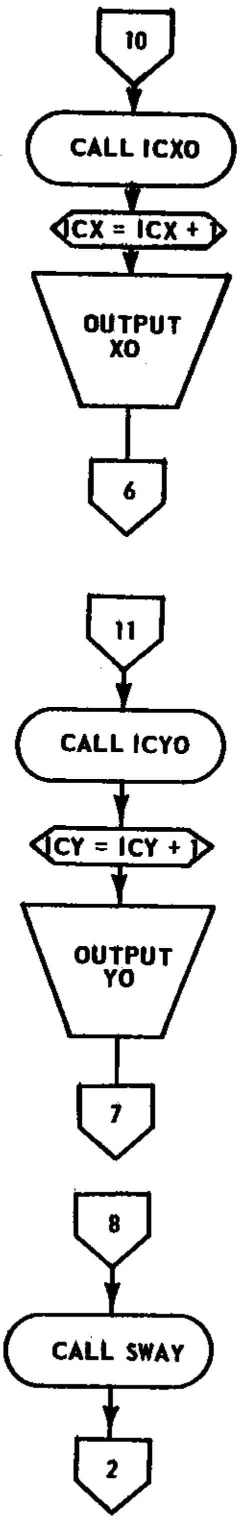

FIGURE 4.5 SUBROUTINE TORPAK (CONTINUED)

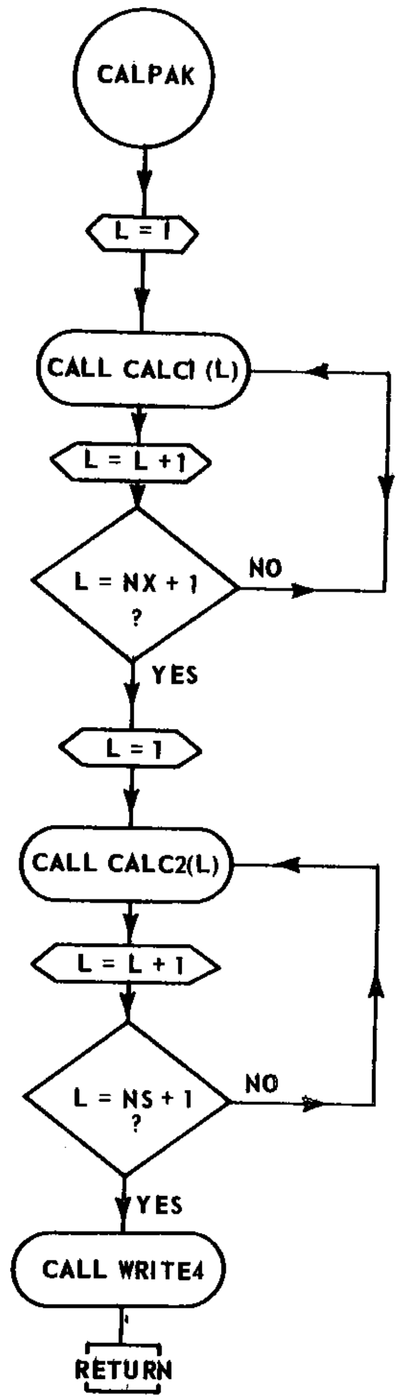

FIGURE 4.6 SUBROUTINE CALPAK

CHAPTER V

RESULTS AND DISCUSSION

As a check on the validity of the assumptions used in the analysis, several structures were analyzed and the results compared with those obtained by other methods. Although a method does not exist for performing a general analysis of a three dimensional frame shear-wall structure, it was possible to check the various sections of the analysis individually.

The calculation of the stiffness matrix for an uncoupled frame was checked by analyzing the twenty story structure shown in elevation in FIGURE 5.1A. A structure containing this bent was used by Weaver and Nelson (5) to illustrate the rigorous analysis of three-dimensional framed structures. The members were of structural steel having a modulus of elasticity of 30,000 k.s.i. and were assumed to be coated with one inch of concrete fireproofing. The moments of inertia were computed on the basis of the transformed section using a modular ratio of nine. The lateral load on the structure consists of a wind pressure of 20 p.s.f., concentrated at each floor level and applied to the south face as shown on the plan of the structure, FIGURE 5.1B.

The first stage of the comparison consisted of performing an in-plane analysis using the present method. Then, the one-bay bent, X1, was isolated as shown in FIGURE 5.2 and subjected to the lateral loads resisted by the bent in the in-plane analysis of the entire structure. This analysis was performed using STRUDL (15). The column moments, joint rotations and floor deflections obtained by the two analyses show excellent agreement and are tabulated in TABLE 5.1. The discrepancies occur only in the third decimal place. The bents used for the comparison were chosen to eliminate errors due to the lumping technique employed in the analysis.

The calculation of the stiffness matrix for a coupled frame shear-wall bent was checked by analyzing the ten-story structure shown in FIGURE 5.3. The moment of inertia of the shear-wall was taken as 443,000 inches^4 and that of the frame members was based on the CISC handbook properties for the sections used (16). The lateral load consists of a wind pressure of 16 p.s.f. on the long side of the structure. This was applied as an equivalent concentrated load at each floor level. The columns were of constant cross section for the bottom five stories then changed at the sixth story and were again constant for the top five stories. All column sections in a given story are the same. The beam sections were the same for all floors in a particular bent. The shear wall dimensions were 8'-0" x 0'-6" and its modulus of elasticity was 3,160 k.s.i. The modulus of elasticity of the steel was taken as 29,000 k.s.i.

An in-plane analysis was performed on this structure using the present method. Bent X1 was then isolated as shown in FIGURE 5.4 and subjected to the lateral loads resisted by this bent in the in-plane analysis of the entire structure. This planar bent was then analyzed using an approximate procedure, developed by Guhamajumdar et al (1), for two-dimensional frame shear-wall structures. The column shears, wall shears and floor deflections obtained by the two methods are presented in TABLE 5.2. The agreement was again excellent. If the bents, in the above two comparisons, had consisted of more than one bay, the lumping technique would introduce errors in the stiffness matrix calculation.

To provide a check on the torsional portion of the analysis the example structure in FIGURE 5.1 was again used. A torsional analysis was performed using the present method and the results were compared with a "Space Frame" analysis performed using STRUDL. For the latter analysis the cross-sectional areas of all members were set at an artificially large value (99999.0 square inches) so as to suppress the effect of axial deformations. Pin-ended diagonal members were introduced between adjacent bents, in a horizontal plane, to simulate the action of floor diaphragms having large rigidities in their own planes. The floor deflections of bents X1 and X4, and the floor diaphragm rotations, as computed by the two analyses, have been presented in TABLE 5.3. The values in all cases agree remarkably well. This structure contains several multi-bay bents which will result in errors in the stiffness matrix calculation, for the present analysis. The maximum discrepancy, however, is less than 4 per cent which is acceptable for a structure of this size. The maximum floor deflections and floor diaphragm rotations obtained agree very well with results quoted by Weaver and Nelson (5).

Several structures have been analyzed by the present method to determine the effect of varying degrees of asymmetry on the structure. The results of the analysis of one such structure will be presented in detail.

The ten story structure in FIGURE 5.3 was analyzed for four different positions of bent X3. For simplicity, bent X3 is considered to have zero stiffness in the X direction. The stiffnesses of bents Y1 and Y2 are computed by ignoring the contribution of the columns of bent X3 and thus have the same properties for all positions of X3. The shear-wall has a constant section for the full height of the structure. Since the column sizes change at the sixth story, the ratio of rigidity of shear-wall to rigidity of all the columns is 83 for the first five stories and 172 for the top five stories.

The position of bent X3 is defined by the dimension X, and analyses were performed for values of; 0, 90, 180, 270 and 360 inches. TABLE 5.4 contains the story shears developed by the columns in bent X1 and the shear-wall in bent X3; for the various values of X. In TABLE 5.5 the story shears, V_X, for X = 180 and 360 inches have been expressed as ratios of the corresponding shears, V_{SYM}, obtained from the in-plane analysis (X = 0). To show the effect of the increasing asymmetry, FIGURE 5.5 plots the deflection at the top floor of each bent for values of X from 0 to 360 inches.

The change in the interaction between shear-wall and frame elements, for increasing asymmetry of the shear-wall bent, is clearly shown in TABLES 5.4 and 5.5. For a symmetric structure, the interaction between the cantilever-type of deformation of the wall and the shear-type deformation of the frame, results in the shear-wall carrying almost all of the lateral load at the base of the structure. Due to the large deflections of the wall in the upper stories of the structure the frame must act as a restraining member. Consequently the frame carries a larger part of the overall lateral load in the upper stories and, as shown in TABLE 5.4, may actually carry more than the externally applied lateral load, due to the negative load imposed on the frame by the wall.

In TABLE 5.4 as the value of X increases, more and more of the load formerly carried by the wall has to be resisted by the frame of bent X1.

As the shear ratios (V_X/V_{SYM}) show, this change may be very large. The change is greatest for the lower stories of the structure and decreases towards the top. The discontinuity at the sixth floor is due to the abrupt change in the column moment of inertia at this level. It is a general observation that the effect of any abrupt change in member properties serves to attract load to the immediate area.

FIGURE 5.5 shows the same effect for bent X2, but on a reduced scale of magnitude. As the eccentricity increases, the increase in deflection at the top of bent X1 is of the order of 300 per cent while the increase for bent X2 is less than 200 per cent. The deflection characteristic of bent X4 is explained by the fact that the torsional behavior of a bent is influenced by its location in relation to the centre of rotation, as well as its stiffness. Up to an X value of approximately 200 inches the centre of rotation of the structure lies inside the structure, so that as the floor diaphragms rotate the net deflection of bent X4 is reduced. Beyond this point the deflections tend to increase once again.

To observe the effect of a reduction in shear wall rigidity, relative to the sum of the column rigidities, in a structure, the shear-wall moment of inertia in the structure of FIGURE 5.3 was reduced from 443,000 to 80,000 inches^4. The results obtained from a series of torsional analyses for various positions of the shear wall bent indicated the same trends as those of TABLES 5.4, 5.5 and FIGURE 5.5. The only difference was in the proportion of total lateral load carried by the shear-wall at any one time.

These trends were confirmed by the results of a series of analyses on a three story structure with a plan similar to that of the ten story structures mentioned above.

The symmetrical structure, of FIGURE 5.3, with bent X3 at X = 0 inches, was also analyzed under a torque equal to the product of the applied lateral load and an eccentricity of 10 per cent of the overall width of the structure. As bents X2 and X3 are at the centre of resistance of the structure, the floor deflections and story shears for these two bents are the same as those obtained from an in-plane analysis. For this reason TABLE 5.6 contains the story shears, floor deflections and the ratios of the story shears to the shears obtained from an in-plane analysis; for bents X1 and X4 only.

The results in TABLE 5.6 illustrate the large change in shears that can occur in certain bents of a symmetric structure if the structure is subjected to a torque about its longitudinal axis. The increase in shear in bent X1 is greatest for the bottom stories and gradually reduces with height. Because of symmetry the decrease in shear in bent X4 is equal to the increase in shear in bent X1. This decrease in shear was sufficient to cause a sign reversal for the bottom story. Because bents X2 and X3 are located at the centre of rotation of the structure there is no net change in floor deflections or story shears for these bents.

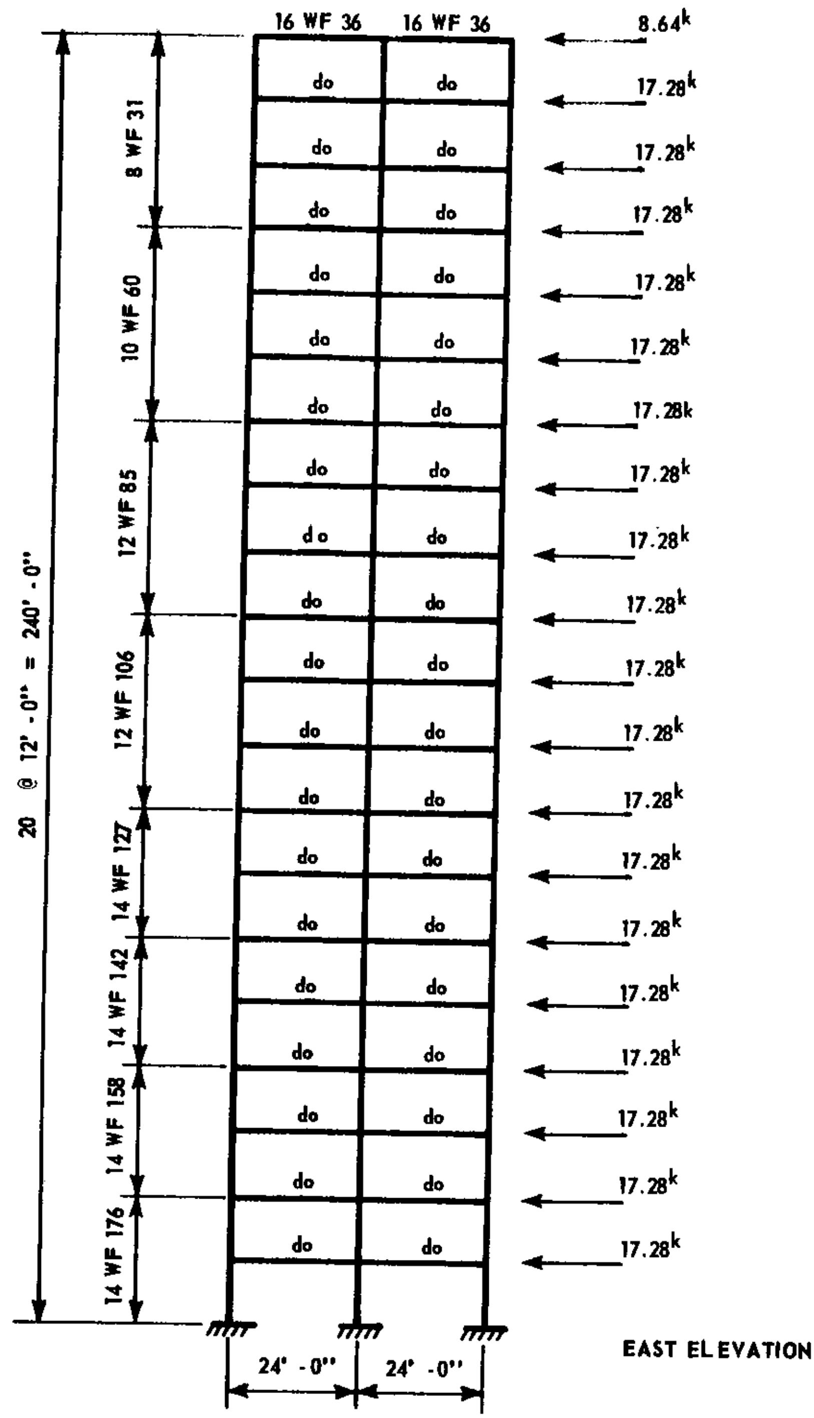

FIGURE 5.1A EXAMPLE STRUCTURE ELEVATION (TWENTY STORIES)

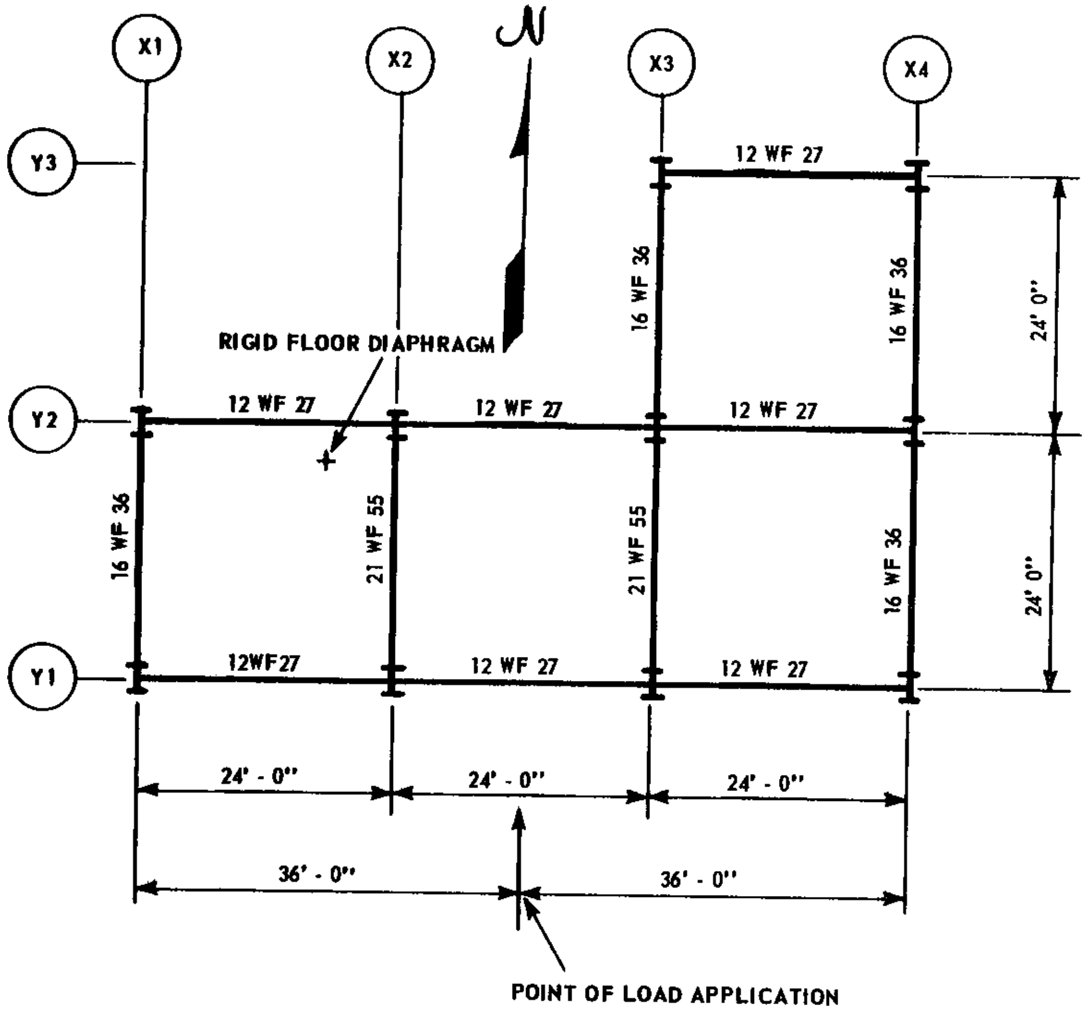

FIGURE 5.1B EXAMPLE STRUCTURE PLAN (TWENTY STORIES)

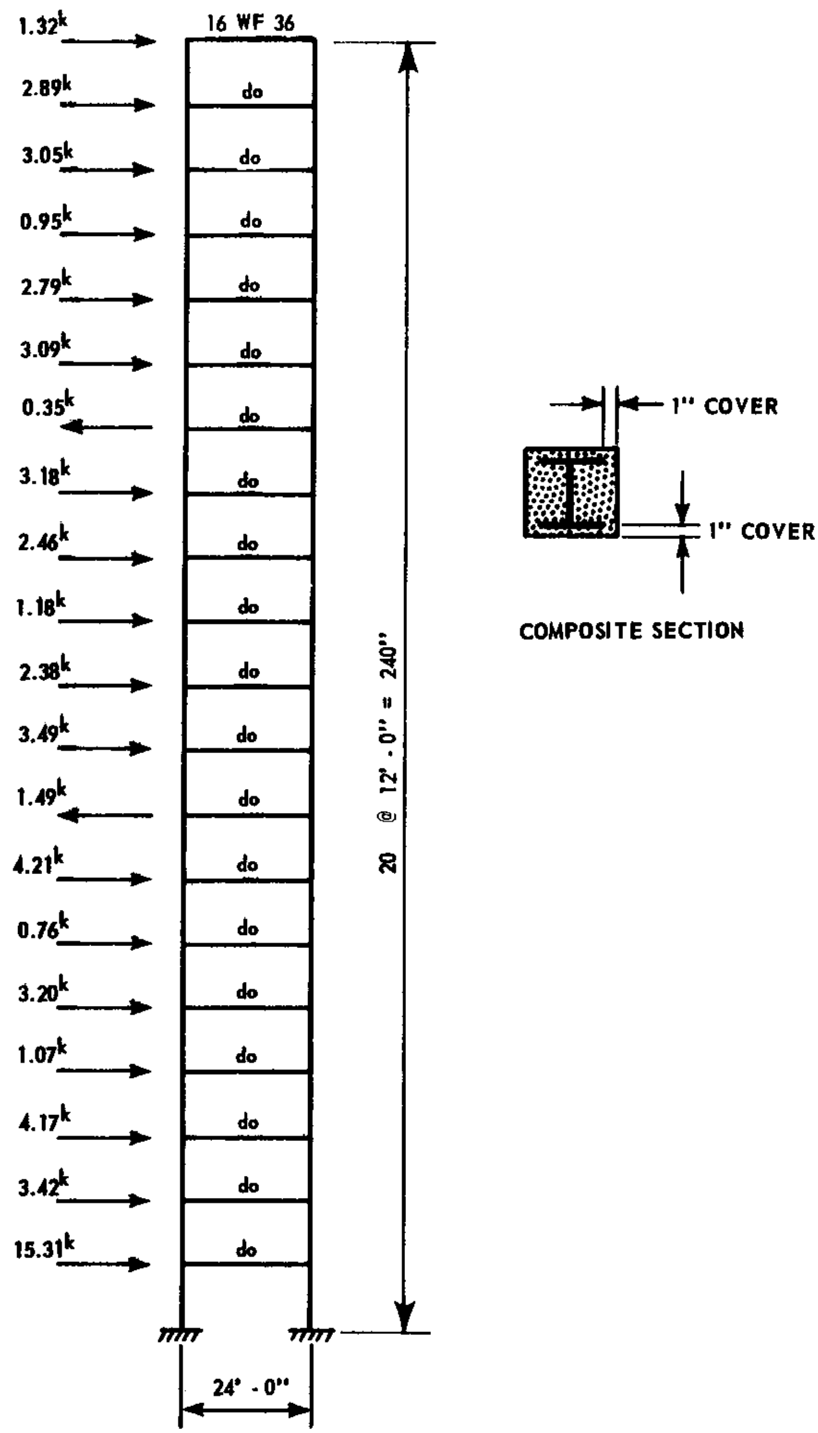

FIGURE 5.2 ISOLATED BENT X1 (TWENTY STORIES)

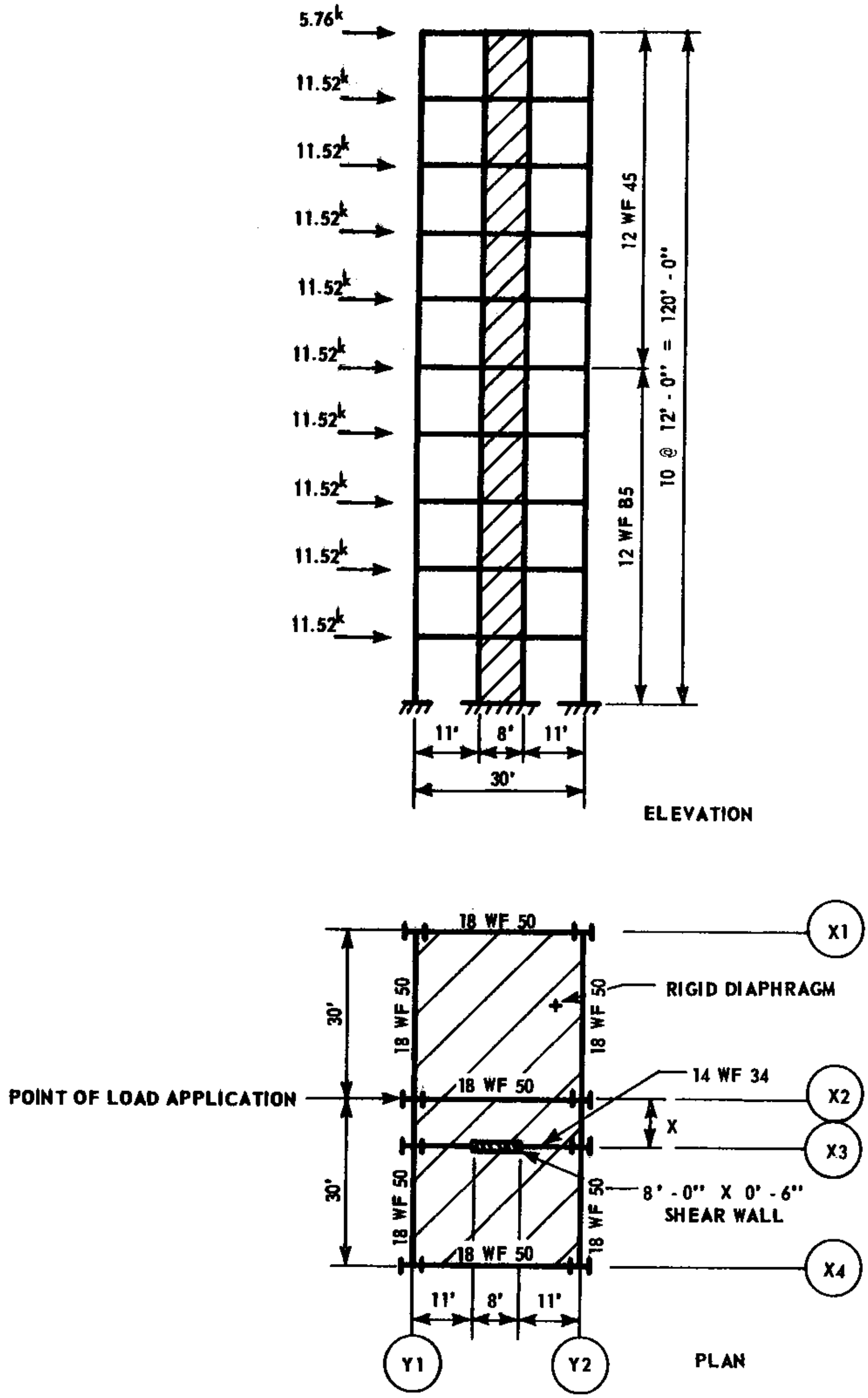

FIGURE 5.3 EXAMPLE STRUCTURE (TEN STORIES)

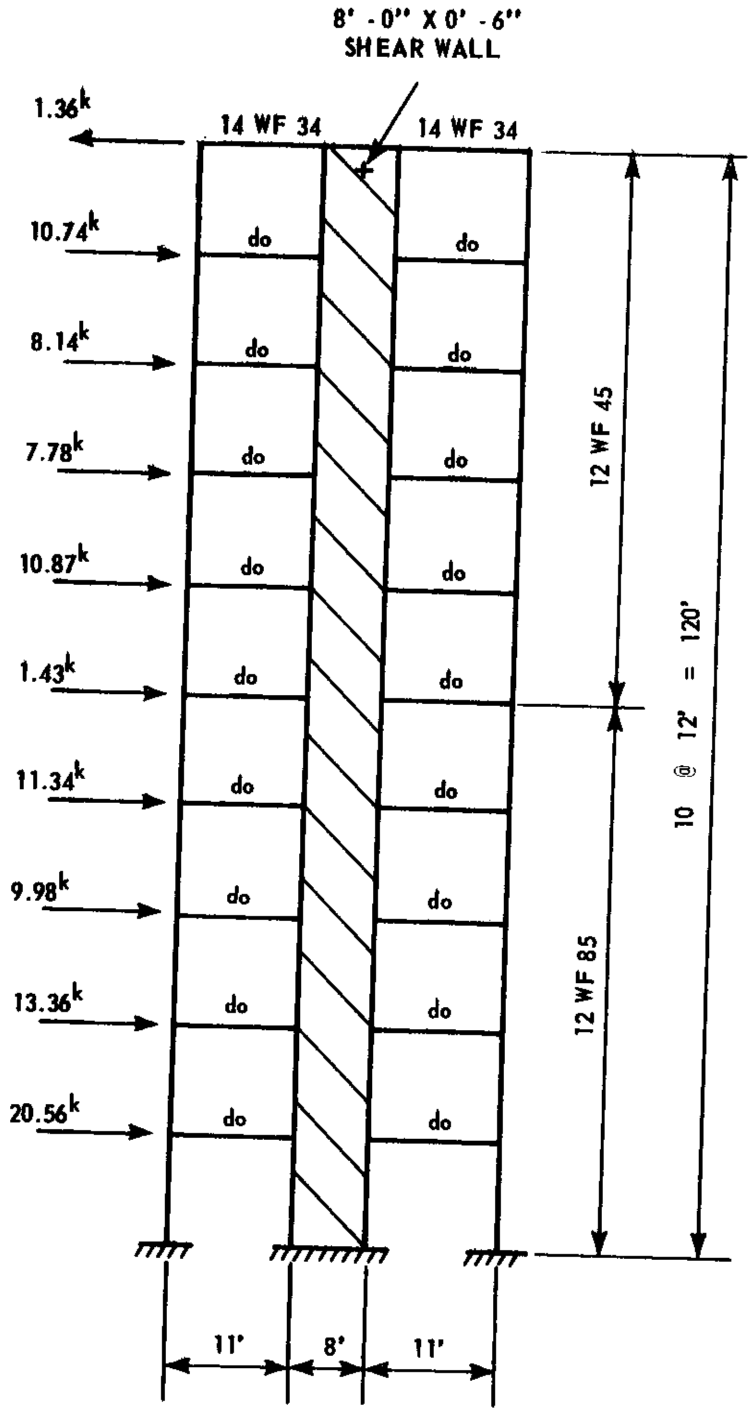

FIGURE 5.4 ISOLATED BENT X3 (TEN STORIES)

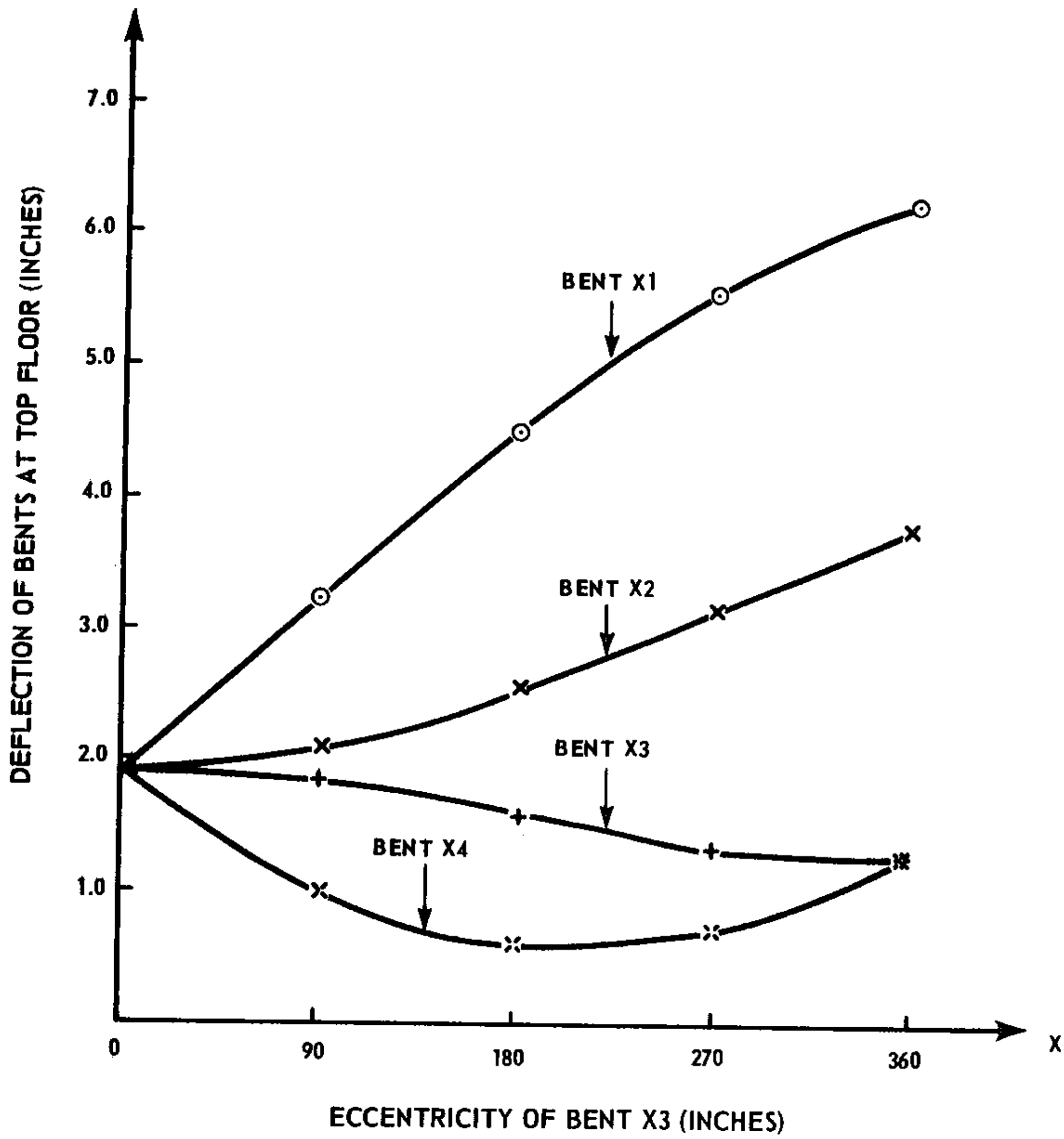

FIGURE 5.5 BENT DEFLECTIONS AT TOP FLOOR

Story or Floor No.	PRESENT ANALYSIS: Column Moments Bottom Kip Inch	PRESENT ANALYSIS: Column Moments Top Kip Inch	PRESENT ANALYSIS: Joint Rotation $X10^{-3}$Rad.	PRESENT ANALYSIS: Floor Deflection Inches	STRUDL: Column Moments Bottom Kip Inch	STRUDL: Column Moments Top Kip Inch	STRUDL: Joint Rotation $X10^{-3}$Rad	STRUDL: Floor Deflection Inches
1	4172	-62	3.4031	0.324	4172	-62	3.4030	0.324
2	2015	992	4.2252	0.932	2015	992	4.2251	0.931
3	1432	1329	4.3167	1.605	1432	1329	4.3165	1.605
4	1147	1313	4.1691	2.269	1147	1313	4.1688	2.269
5	1078	1305	3.9448	2.910	1078	1305	3.9444	2.910
6	957	1196	3.7096	3.512	957	1195	3.7090	3.512
7	932	1167	3.4522	4.083	932	1166	3.4513	4.082
8	813	982	3.2670	4.614	813	982	3.2660	4.613
9	891	1011	3.0563	5.150	891	1011	3.0551	5.149
10	742	910	2.7593	5.638	741	910	2.7583	5.637
11	672	808	2.5206	6.081	672	807	2.5196	6.080
12	638	758	2.2633	6.497	637	757	2.2623	6.496
13	540	678	1.9681	6.864	540	678	1.9671	6.863
14	450	539	1.7793	7.185	450	538	1.7782	7.183
15	481	533	1.5548	7.531	481	533	1.5536	7.529
16	358	434	1.2262	7.815	358	434	1.2252	7.812
17	269	322	0.9965	8.037	269	322	0.9958	8.034
18	250	273	0.7146	8.308	249	273	0.7140	8.306
19	136	167	0.3551	8.471	136	167	0.3548	8.469
20	37	58	0.1016	8.531	37	58	0.1015	8.528

TABLE 5.1 STIFFNESS MATRIX CHECK (UNCOUPLED BENT)

Story or Floor No.	PRESENT ANALYSIS			GUHAMAJUMDAR		
	Column Shear Kips	Wall Shear Kips	Floor Deflection Inches	Column Shear Kips	Wall Shear Kips	Floor Deflection Inches
1	7.63	85.21	0.110	7.62	85.22	0.110
2	13.27	59.01	0.347	13.27	59.01	0.347
3	14.60	44.33	0.626	14.60	44.32	0.626
4	13.88	35.06	0.903	13.88	35.06	0.903
5	14.11	23.49	1.160	14.11	23.49	1.160
6	8.72	27.45	1.389	8.72	27.45	1.389
7	8.45	16.85	1.579	8.45	16.85	1.579
8	6.35	11.17	1.727	6.34	11.18	1.726
9	4.44	4.93	1.836	4.43	4.95	1.834
10	4.25	-5.60	1.916	4.25	-5.61	1.913

TABLE 5.2 STIFFNESS MATRIX CHECK (COUPLED BENT)

	PRESENT ANALYSIS			STRUDL		
Floor Number	Floor Deflection Inches Bent X1	Floor Deflection Inches Bent X4	Floor Rotation Rad. $X10^{-2}$	Floor Deflection Inches Bent X1	Floor Deflection Inches Bent X4	Floor Rotation Rad. $X10^{-2}$
1	0.421	0.252	0.020	0.422	0.256	0.019
2	1.226	0.712	0.059	1.229	0.726	0.058
3	2.129	1.216	0.106	2.136	1.241	0.103
4	3.025	1.708	0.152	3.035	1.746	0.149
5	3.891	2.182	0.198	3.905	2.232	0.194
6	4.708	2.625	0.241	4.725	2.689	0.236
7	5.483	3.046	0.282	5.502	3.123	0.275
8	6.203	3.438	0.320	6.226	3.527	0.312
9	6.925	3.835	0.358	6.953	3.939	0.348
10	7.584	4.198	0.392	7.616	4.317	0.382
11	8.182	4.526	0.423	8.217	4.659	0.412
12	8.742	4.837	0.452	8.780	4.983	0.439
13	9.236	5.110	0.478	9.277	5.270	0.464
14	9.671	5.347	0.500	9.713	5.521	0.485
15	10.130	5.611	0.523	10.175	5.799	0.506
16	10.504	5.826	0.541	10.553	6.027	0.524
17	10.796	5.997	0.555	10.851	6.207	0.537
18	11.148	6.209	0.572	11.202	6.433	0.552
19	11.357	6.338	0.581	11.414	6.571	0.561
20	11.443	6.379	0.586	11.518	6.618	0.567

TABLE 5.3 TORSIONAL ANALYSIS CHECK (FRAMED STRUCTURE)

Floor Number	EFFECT OF INCREASING ASYMMETRY									
	Story Shear in Bent XI Kips					Story Shear in Shear Wall Kips				
X	0	90	180	270	360	0	90	180	270	360
1	5.53	16.68	27.35	35.31	40.22	85.21	79.88	67.01	52.94	40.94
2	8.55	16.31	24.12	30.35	34.54	59.01	56.09	48.74	39.98	31.93
3	9.16	15.43	21.62	26.76	30.28	44.33	42.40	37.29	31.08	25.17
4	8.65	13.80	18.97	23.24	26.21	35.06	33.59	29.74	24.97	20.36
5	8.59	12.30	16.05	19.35	21.84	23.49	22.89	20.98	18.23	15.27
6	5.22	9.76	14.04	17.34	19.32	27.45	25.83	21.84	17.45	13.67
7	5.01	8.05	10.99	13.28	14.87	16.85	16.02	13.92	11.42	9.13
8	3.76	5.86	7.94	9.56	10.60	11.17	10.60	9.25	7.62	6.11
9	2.63	3.78	4.84	5.74	6.33	4.93	4.76	4.21	3.55	2.91
10	2.37	2.12	1.92	1.89	1.97	-5.61	-5.10	-3.96	-2.80	-1.94

TABLE 5.4 SHEAR TABULATION FOR BENT X1 AND SHEAR-WALL

Floor Number	SHEAR RATIOS VX/V_{SYM}			
	Bent X1		Shear Wall	
X	180	360	180	360
1	4.95	7.28	0.79	0.48
2	2.82	4.04	0.82	0.54
3	2.36	3.31	0.84	0.57
4	2.19	3.03	0.85	0.58
5	1.87	2.55	0.89	0.65
6	2.69	3.70	0.80	0.50
7	2.20	2.97	0.83	0.54
8	2.11	2.82	0.83	0.55
9	1.84	2.41	0.85	0.59
10	0.81	0.83	0.71	0.35

TABLE 5.5 SHEAR RATIOS BENT X1 AND SHEAR-WALL

Floor Number	BENT X1			BENT X4		
	Shear Min. Torque Kips	Deflection Inches	Ratio of Shears	Shear Min. Torque Kips	Deflection Inches	Ratio of Shears
1	14.38	0.241	2.60	-3.32	-0.021	-0.60
2	15.60	0.683	1.83	1.49	0.011	0.17
3	15.34	1.158	1.68	2.97	0.093	0.32
4	13.92	1.609	1.61	3.35	0.198	0.39
5	12.88	2.015	1.50	4.29	0.304	0.50
6	9.62	2.408	1.84	0.83	0.369	0.16
7	8.34	2.729	1.67	1.67	0.429	0.33
8	6.14	2.970	1.63	1.37	0.483	0.36
9	4.09	3.135	1.56	1.18	0.535	0.45
10	2.83	3.239	1.19	1.92	0.592	0.81

TABLE 5.6 COMPARISON OF IN-PLANE AND MINIMUM TORQUE ANALYSES

CHAPTER VI

SUMMARY AND CONCLUSIONS

A method of analysis has been presented which determines the distribution of resisting shears among the various bents in asymmetric three-dimensional structures. The analysis neglects second order effects and assumes that the material is ideally elastic. The bents of the structure may contain either coupled or independent shear-wall and frame elements.

The actual structure has been simplified to a system of two-dimensional bents. A lumping technique has been used to reduce the individual bents to single equivalent frame and shear-wall elements. Each floor diaphragm is free to rotate about a vertical axis, and to translate in the X and Y directions.

The computer program developed for the analysis, performs a torsional analysis if the structure is asymmetric but when the degree of asymmetry is minor a specified torque is applied to the structure. The program also performs an in-plane analysis if required. A list of the subroutines used in the computer program, and the required input data is presented in APPENDIX B. A print-out of the computer program is included in APPENDIX C.

The various steps in the analysis were verified by performing analyses on segments of the structure for which other methods were available. The present method was then used to analyze several structures containing coupled frame and shear-wall bents. The results of these analyses clearly show the important effect that the rotation of the structure has on the shear distribution. With increasing asymmetry of the structure the interaction between shear-wall and frame elements is changed dramatically. Even for small eccentricities the increased shears imposed on certain bents near the perimeter of the structure are significant and must be considered.

For the series of ten story structures used to illustrate the effect of torsion, the number of iteration cycles required for convergence varied between ten and twenty. The corresponding computer time amounted to approximately 0.8 minutes. For the twenty story structure convergence was considerably slower. This was because the structure does not have an axis of symmetry, so that both the X and Y co-ordinates of the centre of rotation must be determined by iteration. Each iterative cycle requires the inversion of more than twenty matrices. To alleviate this problem it is suggested that the program be modified to a more rigorous solution, in which the three equilibrium equations, for each floor, will be solved at the one time. This approach will lead to reduced computer time, at the expense of increased computer storage space.

The next stage to be considered is the inelastic response of the structure. The greatest increase in shear due to torsional action occurs in the bents located furthest from the centre of rotation. The formation of plastic hinges in these bents reduces the bent stiffness and would result in a shift of the centre of resistance as the structure is loaded into the inelastic range. In future extensions of the program the structure will be analyzed as described until a plastic hinge forms. The stiffness matrix for the particular bent involved will then be modified by the insertion of a plastic hinge in the member. The structure will be analyzed with the modified stiffness matrix until a second hinge forms. The process is then repeated. At each load increment, iteration will be used to obtain a balance between the applied loads and the resisting floor forces using the actual stiffness matrix for each bent.

Additional effects that must be investigated are primarily due to the axial loads; the influence of axial shortening, the P-Δ effect caused by the vertical loads and the change in carry-over and stiffness coefficients due to the presence of axial load.

NOMENCLATURE

u	Displacement in the X direction.
v	Displacement in the Y direction.
X, Y	General co-ordinates.
X_A, Y_A	Co-ordinates of general point A.
X_o, Y_o	Co-ordinates of the centre of rotation.
X_c, Y_c	Co-ordinates of the centre of resistance.
NX, NY	Number of bents.
F	Applied lateral load.
V	Resisting floor force.
Δ	Story sway deformation.
S	Displacement from the undeformed position.
θ	Floor diaphragm rotation.
D	Two-diagonal matrix.
T	Torsional stiffness matrix.
C	Transpose of influence coefficient matrix.
ΔX	Centre of rotation correction in the X direction.
ΔY	Centre of rotation correction in the Y direction.
E	Modulus of elasticity of frame.
EW	Modulus of elasticity of wall.
h	Story height.
CI	Moment of inertia of equivalent column.
WI	Moment of inertia of equivalent wall.
θC	Beam to column joint rotation.

θW	Beam to wall joint rotation.
MC	Resultant moment at beam to column joint.
MW	Resultant moment at beam to wall joint.
FBI	Moment of inertia of equivalent frame beam.
FBL	Length of equivalent frame beam.
WBI	Moment of inertia of equivalent wall beam.
WBL	Length of equivalent wall beam.

NOMENCLATURE FOR FORTRAN IV PROGRAM

In the following nomenclature, X and Y in any of the terms refer to the direction of the perpendicular to the plane of the bent.

KJ	Matrix relating column joint rotation to the story sway for an uncoupled frame.
KP	Matrix relating column joint rotation to the story sway for a coupled frame.
KS	Matrix relating wall joint rotation to the story sway for a coupled frame and shear-wall bent.
KX	Bent stiffness matrix in terms of story sway.
KY	Bent stiffness matrix in terms of story sway.
KV	St. Venant torsional stiffness matrix.
K	Bent stiffness matrix term used in subroutines MACAL1 and MACAL2.
NS	Number of stories.
NX, NY	Number of bents.
ICX	Dummy term representing the number of iteration cycles.
ICY	Dummy term representing the number of iteration cycles.
XO	Distance between reference point and centre of rotation.
YO	Distance between reference point and centre of rotation.
KXROTC	Matrix relating column joint rotation to the story sway.
KXROTW	Matrix relating wall joint rotation to the story sway.
KYROTC	Matrix relating column joint rotation to the story sway.
KYROTW	Matrix relating wall joint rotation to the story sway.

H	Story height.
CI	Equivalent column moment of inertia.
WI	Equivalent wall moment of inertia.
WBL	Wall beam length.
W	Wall width.
FBL	Frame beam length.
FBI	Frame beam moment of inertia.
WBI	Wall beam moment of inertia.
E	Modulus of elasticity of frame.
EW	Modulus of elasticity of wall.
EGC	Rotational stiffness of foundation under column.
EGW	Rotational stiffness of foundation under wall.
FX	Applied lateral load in the Y direction.
FY	Applied lateral load in the X direction.
XX	Distance between reference point and particular bent.
YY	Distance between reference point and particular bent.
CX	Distance between reference point and centre of resistance (EI).
CY	Distance between reference point and centre of resistance (EI).
RX	Distance between a particular bent and the centre of rotation.
DX	Relative distance between top and bottom of each story and their respective centres of rotation.
KDX	Stiffness matrix in terms of unit rotation about the centres of rotation.
TTX	Torsional stiffness contribution, computed about the reference point.

ROT	Floor diaphragm rotation vector.
VX	Floor forces developed by a particular bent.
TVX	Sums of the floor forces.
RY	Distance between a particular bent and the centres of rotation.
DY	Relative distance between top and bottom of each story and their respective centres of rotation.
KDY	Stiffness matrix in terms of unit rotation about the centres of rotation.
TTY	Torsional stiffness contribution, computed about the reference point.
VY	Floor forces developed by a particular bent.
TVY	Sum of the floor forces.
MT	Torsional moment, about the reference point, due to the applied lateral loads.
TVXA	Sum of the floor forces for the initially assumed position of the centres of rotation.
TVYA	Sum of the floor forces for the initially assumed position of the centres of rotation.
XH	Distance between reference point and FX.
YH	Distance between reference point and FY.
INDICX	Dummy term indicating whether frame is coupled or not.
INDICY	Dummy term indicating whether frame is coupled or not.
HX	Story height.
CIX	Equivalent column moment of inertia.
WIX	Equivalent wall moment of inertia.
WBLX	Wall beam length.

WX	Wall width.
FBLX	Frame beam length.
WBIX	Wall beam moment of inertia.
FBIX	Frame beam moment of inertia.
HY	Story height.
CIY	Equivalent column moment of inertia.
WIY	Equivalent wall moment of inertia.
WBLY	Wall beam length.
WY	Wall width.
FBLY	Frame beam length.
WBIY	Wall beam moment of inertia.
FBIY	Frame beam moment of inertia.
KA	Bent stiffness submatrix.
KB	Bent stiffness submatrix.
KC	Bent stiffness submatrix.
KD	Bent stiffness submatrix.
KE	Bent stiffness submatrix.
KF	Bent stiffness submatrix.
KG	Bent stiffness submatrix.
KH	Bent stiffness submatrix.
KI	Bent stiffness submatrix.
KK	Work matrix.
KL	Work matrix.
KM	Work matrix.
KN	Work matrix.
KO	Work matrix.

KQ	Work matrix.
KR	Work matrix.
KT	Work matrix.
KW	Work matrix.
TX	Torsional stiffness contribution, computed about the reference point.
TY	Torsional stiffness contribution, computed about the reference point.
RT	Torsional stiffness matrix about the reference point.
SX	Story sway vector.
SY	Story sway vector.
ROTXC	Column joint rotation vector.
ROTXW	Wall joint rotation vector.
ROTYC	Column joint rotation vector.
ROTYW	Wall joint rotation vector.
TVXC	Influence coefficient matrix.
TTVXC	Transpose of TVXC.
TVYC	Influence coefficient matrix.
TTVYC	Transpose of TVYC.
CMXB	Moment at bottom of column.
CMXT	Moment at top of column.
WMXB	Moment at bottom of wall.
WMXT	Moment at top of wall.
FBMX	Moment at the ends of frame beam.
WBMXC	Moment at column end of wall beam.
WBMXW	Moment at wall end of wall beam.

CMYB	Moment at bottom of column.
CMYT	Moment at top of column.
WMYB	Moment at bottom of wall.
WMYT	Moment at top of wall.
FBMY	Moment at the end of frame beam.
WBMYC	Moment at column end of wall beam.
WBMYW	Moment at wall end of wall beam.
CSX	Column shear.
WSX	Wall shear.
FBSX	Frame beam shear.
WBSX	Wall beam shear.
CSY	Column shear.
WSY	Wall shear.
FBSY	Frame beam shear.
WBSY	Wall beam shear.
CFX	Column axial load.
WFX	Wall axial load.
FBFX	Frame beam axial load.
WBFX	Wall beam axial load.
CFY	Column axial load.
WFY	Wall axial load.
FBFY	Frame beam axial load.
WBFY	Wall beam axial load.
DEX	Floor deflection.
DEY	Floor deflection.
INSYM	Dummy term indicating whether a rotational analysis is to

be performed.

ITERX	Dummy term that limits the number of iteration cycles.
ITERY	Dummy term that limits the number of iteration cycles.
IX	Dummy term indicating the number of resets.
IY	Dummy term indicating the number of resets.

APPENDIX A

DERIVATION OF BENT STIFFNESS MATRIX

For the section of the bent shown in FIGURE 4.1, three equilibrium equation may be written in terms of slopes and deflections.

$$V(i) = \Delta(i) \times \left| \frac{-12 \times E \times CI(i)}{(h(i))^3} - \frac{12 \times EW \times WI(i)}{(h(i))^3} \right| +$$

$$\Delta(i+1) \times \left| \frac{12 \times E \times CI(i+1)}{(h(i+1))^3} + \frac{12 \times EW \times WI(i+1)}{(h(i+1))^3} \right| +$$

$$\theta C(i-1) \times \left| \frac{6 \times E \times CI(i)}{(h(i))^2} \right| + \theta C(i) \times \left| \frac{6 \times E \times CI(i)}{(h(i))^2} - \frac{6 \times E \times CI_{(i+1)}}{(h(i+1))^2} \right|$$

$$+ \theta C(i+1) \times \left| \frac{-6 \times E \times CI_{(i+1)}}{(h(i+1))^2} \right| + \theta W_{(i-1)} \times \left| \frac{6 \times EW \times WI(i)}{(h(i))^2} \right| +$$

$$\theta W(i) \times \left| \frac{6 \times EW \times WI(i)}{(h(i))^2} - \frac{6 \times EW \times WI(i+1)}{(h(i+1))^2} \right| +$$

$$\theta W(i+1) \times \left| \frac{-6 \times EW \times WI(i+1)}{(h(i+1))^2} \right| \tag{A.1}$$

$$MC(i) = \Delta(i) \times \left| \frac{-6 \times E \times CI(i)}{(h(i))^2} \right| + \Delta(i+1) \times \left| \frac{-6 \times E \times CI(i+1)}{(h(i+1))^2} \right| +$$

$$\theta C(i-1) \times \left| \frac{2 \times E \times CI(i)}{h(i)} \right| + \theta C(i) \times \left| \frac{4 \times E \times CI(i)}{h(i)} \right. +$$

$$\frac{4 \times E \times CI(i+1)}{h(i+1)} + \frac{12 \times E \times FBI(i)}{FBL(i)} + \frac{4 \times E \times WBI(i)}{WBL(i)} \Bigg| +$$

$$\theta C(i+1) \times \left| \frac{2 \times E \times CI(i+1)}{h(i+1)} \right| +$$

$$\theta W(i) \times \left| \frac{2 \times E \times WBI(i)}{WBL(i)} + \frac{3 \times W(i) \times E \times WBI(i)}{(WBL(i))^2} \right| \qquad (A.2)$$

$$MW(i) = \Delta(i) \times \left| \frac{-6 \times EW \times WI(i)}{(h(i))^2} \right| + \Delta(i+1) \times \left| \frac{-6 \times EW \times WI(i+1)}{(h(i+1))^2} \right| +$$

$$\theta C(i) \times \left| \frac{3 \times E \times WBI(i) \times W(i)}{(WBL(i))^2} + \frac{2 \times E \times WBI(i)}{WBL(i)} \right| +$$

$$\theta W(i-1) \times \left| \frac{2 \times EW \times WI(i)}{h(i)} \right| + \theta W(i) \times \Bigg| \frac{4 \times EW \times WI(i)}{h(i)} +$$

$$\frac{4 \times EW \times WI(i+1)}{h(i+1)} + \frac{6 \times E \times WBI(i) \times W(i)}{(WBL(i))^2} + \frac{3 \times E \times WBI(i) \times (W(i))^2}{(WBL(i))^3}$$

$$+ \frac{4 \times E \times WBI(i)}{WBL(i)} \Bigg| + \theta W(i+1) \times \left| \frac{2 \times EW \times WI(i+1)}{h(i+1)} \right| \qquad (A.3)$$

Where V(i) is the force exerted on the bent by floor diaphragm i, MC(i) is the resultant moment at the beam to column joint of floor level i and MW(i) is the resultant moment at the shear wall to beam joint of floor level i. The remaining terms are defined in the nomenclature. The above three equations may be written for each of the n floors in the bent.

This procedure results in 3 × n equations for 3 × n unknowns which may be expressed in matrix form as follows.

$$\begin{vmatrix} |V| \\ |M|^{c} \\ |M|^{w} \end{vmatrix} = \begin{vmatrix} |KA| & |KB| & |KC| \\ |KD| & |KE| & |KF| \\ |KG| & |KH| & |KI| \end{vmatrix} \times \begin{vmatrix} |\Delta| \\ |\theta|^{c} \\ |\theta|^{w} \end{vmatrix} \qquad (A.4)$$

where KA, KB, KC, KD, KE, KF, KG, KH and KI are square submatrices containing n × n elements, most of which are zero terms. The elements of the submatrices consist of the member stiffness terms expressed in Equations (A.1) to (A.3) above. As an example the i^{th} row of submatrix KE expresses the resultant moment at the beam to column joint on the i^{th} floor due to unit rotation of $\theta C(i-1)$, $\theta C(i)$ and $\theta C(i+1)$. All columns of row i would contain zeros except for the following;

$$\text{column } (i-1) \equiv \frac{2 \times E \times CI(i)}{h(i)}$$

$$\text{column } (i) \equiv \frac{4 \times E \times CI(i)}{h(i)} + \frac{4 \times E \times CI(i+1)}{h(i+1)} + \frac{12 \times E \times FBI(i)}{FBL(i)} + \frac{4 \times E \times WBI(i)}{WBL(i)}$$

$$\text{column } (i+1) \equiv \frac{2 \times E \times CI(i+1)}{h(i+1)}$$

The matrix Equation (A.4) may be expanded into the following;

$$|V| = |KA| \times |\Delta| + |KB| \times |\theta|^{c} + |KC| \times |\theta|^{W} \quad (A.5a)$$

$$|M|^{c} = |KD| \times |\Delta| + |KE| \times |\theta|^{c} + |KF| \times |\theta|^{W} \quad (A.5b)$$

$$|M|^{W} = |KC| \times |\Delta| + |KH| \times |\theta|^{c} + |KI| \times |\theta|^{W} \quad (A.5c)$$

In order to satisfy equilibrium the resultant moments at the beam to column joints and at the beam to wall joints must be equal to zero. It is therefore possible to eliminate the joint rotation vectors $|\theta|^{c}$ and $|\theta|^{W}$ from Equation (A.5a). Transposing Equations (A.5b) and (A.5c) yields,

$$|\theta|^{c} = - |KE|^{-1} \times (|KD| \times |\Delta| + |KF| \times |\theta|^{W}) \quad (A.6)$$

$$|\theta|^{W} = - |KI|^{-1} \times (|KG| \times |\Delta| + |KH| \times |\theta|^{c}) \quad (A.7)$$

and substituting for $|\theta|^{W}$ in Equation (A.6),

$$|\theta|^{c} = [(|KF| \times |KI|^{-1} \times |KH|) - |KE|]^{-1} \times [|KD| - |KF| \times |KI|^{-1} \times |KG|] \times |\Delta| \quad (A.6a)$$

or $$|\theta|^{c} = |K|^{\theta c} \times |\Delta| \quad (A.6b)$$

Substituting for $|\theta|^{c}$ in Equation (A.7),

$$|\theta|^{W} = - |KI|^{-1} \times [|KG| \times |\Delta| + |KH| \times |KP| \times |\Delta|] \quad (A.7a)$$

or $$|\theta|^{W} = |K|^{\theta W} \times |\Delta| \quad (A.7b)$$

and substituting for $|\theta|^{c}$ and $|\theta|^{W}$ in Equation (A.5a) yields,

$$|V| = |KA| \times |\Delta| + |KB| \times |K|^{\theta c} \times |\Delta| + |KC| \times |K|^{\theta w} \times |\Delta| \qquad (A.5d)$$

or $$|V| = |K|^{\Delta} \times |\Delta| \qquad (A.5e)$$

where $|K|^{\Delta}$ is the bent stiffness matrix in terms of the story sway deformations.

When the bent is composed of an uncoupled frame all terms containing WI(i) are eliminated in Equation (A.1); in Equation (A.2), all terms containing WBI(i) are eliminated and Equation (A.3) is eliminated entirely. Equation (A.4) is then written as,

$$\begin{vmatrix} |V| \\ |M|^{c} \end{vmatrix} = \begin{vmatrix} |KA'| & |KB| \\ |KD| & |KE'| \end{vmatrix} \times \begin{vmatrix} |\Delta| \\ |\theta|^{c} \end{vmatrix} \qquad (A.8)$$

where the submatrices have the same significance as in Equation (A.4) except for $|KA'|$ and $|KE'|$, which have been modified as described above. Furthermore, for an uncoupled frame Equations (A.5c), (A.7), (A.7a) and (A.7b) are eliminated and Equation (A.5d) now reads,

$$|V| = |KA'| \times |\Delta| + |KB| \times |K|^{\theta c} \times |\Delta| \qquad (A.9)$$

where $|KA'|$ and $|K'|^{\theta c}$ have been modified due to the absence of the shear wall.

APPENDIX B

SUBROUTINE LISTING AND DATA CARDS

In the following subroutines, X and Y (where they occur) denote the directions of a line constructed perpendicular to the plane of a bent.

1. COMPAK: - Calls up subroutines to read in the member properties and calculate the bent stiffness matrix.
2. READ1: - Reads in the member properties for an uncoupled bent.
3. READ2: - Reads in the member properties for a coupled bent.
4. MACAL1: - Calculates the bent stiffness matrix using the submatrices calculated by READ1.
5. MACAL2: - Calculates the bent stiffness matrix using the submatrices calculated by READ2.
6. TOKYO: - Matrix inversion subroutine.
7. TORPAK: - Calls up subroutines to develop the rotational stiffness matrix for the structure, and also tests for equilibrium of resisting floor forces and applied loads. If there is an unbalance, subroutines are called which carry out the correction technique.
8. SYMPAK: - When called up by TORPAK this performs an in-plane analysis on the structure.
9. WRITE1: - Prints out member properties, loads, number of stories and bent location within the structure.
10. HXODX: - Computes the two-diagonal geometric matrix, which relates the bent location to the centres of rotation of successive floors.
11. DXOTTX: - Computes the torsional stiffness matrix contribution.

12. VXOTVX: - After the floor rotations have been calculated this subroutine calculates the resisting floor forces.

13. HYODY: - Computes the two-diagonal geometric matrix, which relates the bent location to the centres of rotation of successive floors.

14. DYOTTY: - Computes the torsional stiffness matrix contribution.

15. VYOTVY: - After the floor rotations have been calculated this subroutine calculates the resisting floor forces.

16. RTOROT: - Adds up the three contributions to the rotational stiffness matrix then inverts the total and calculates the rotation vector.

17. SWAY: - When the story sway vectors have been calculated, this subroutine calculates the joint rotation vectors for all bents.

18. WRITE3: - Prints out the resisting floor forces, location of the centres of rotation, rotation vector, the number of iteration cycles in the X and Y directions, and whether there is an unbalance in the resisting floor forces and applied loads after the last iteration cycle.

19. ICXO: - This subroutine corrects the positions of the assumed centres of rotation, in the X direction.

20. ICYO: - This subroutine corrects the positions of the assumed centres of rotation, in the Y direction.

21. CALPAK: - Calls up subroutines to calculate the member forces.

22. CALC1: - Calculates the member forces and bent deformations for the bents located in the X plane.

23. CALC2: - Calculates the member forces and bent deformations for the bents located in the Y plane.

24. WRITE4: - Prints out the member forces and bent deformations for all the bents in the structure.

Data is transmitted to the program by means of punched cards. The contents of each card is explained below and the order of cards must be the same as the numeric order in which they are listed.

1. NS, NX, NY; Format (3I10). Where NS is the number of stories, NX the number of bents in the X plane and NY the number of bents in the Y plane. (A bent in the X plane has a perpendicular which is parallel to the X axis.)
2. E, EW; Format (2F10.2). Where E is the modulus of elasticity for the frame and EW is the modulus of elasticity for the shear wall. The units of both constants are kips per square inch.
3. INDICX or INDICY; Format (I10). Where INDIC is the indicator that tells whether the bent consists of a coupled frame and shear wall or an uncoupled frame. The numeral, 1, in column 10 indicates a coupled frame shear wall bent while the numeral, 0, in column 10 indicates an uncoupled frame. This particular card must be repeated for each bent and precedes each bent member property card group as defined below.
4. H, CI, WI, W, WBL, FBL, WBI, FBI; Format (F8.2, 2F12.2, F8.2, 4F10.2). Where for each story or floor level H is the story height, CI is the lumped column moment of inertia, WI is the lumped shear wall moment of inertia, W is the shear wall width (in the plane of the bent), WBL is the wall beam length, FBL is the frame beam length, WBI is the wall beam moment of inertia and FBI is the frame beam moment of inertia. The units for all of the above are inches. For each bent

there must be firstly an INDIC card followed by a member property card for each floor in the bent. Then an INDIC card for the next bent and so on. For the case where the bent consists of an uncoupled frame; WI and WBI are left blank but W and WBL must still have non zero values. This is necessary so that the computer will not divide by zero which would cause a program interrupt.

5. INSYM; Format (I10). INSYM indicates whether a torsional analysis is required. If the numeral, 1, is placed in column 10 then TORPAK calls up SYMPAK and the torsional analysis is suppressed. When a torsional analysis is required the card is left blank.

6. FX; Format (10F8.2). FX is the applied lateral load in the Y direction. The loads are read in starting with the bottom story and moving to the top. If the number of stories is greater than 10, additional cards must be used.

7. FY; Format (10F8.2). FY is the applied lateral load in the X direction. Both FX and FY are in kips.

8. XH; Format (10F8.2). XH is the distance from the reference point to load FX.

9. YH; Format (10F8.2). YH is the distance from the reference point to load FY.

10. ITERX, ITERY; Format (2I10). ITER is the number of iteration cycles to which the correction technique is limited. X and Y refer to the direction in which the correction technique is to be applied. After the number of iterations in either direction has reached the limit then TORPAK calls up CALPAK which calculates the member forces on the basis of the last analysis.

11. GKT; Format (5F16.6). GKT is the sum, for each story, of the St. Venant torsion constants. The units are kip square inches.
12. XX; Format (10F8.2). XX is the perpendicular distance between each bent and the reference point. In this and the following card names the X and Y refer to the direction in which the measurement is taken.
13. YY; Format (10F8.2). YY is the perpendicular distance between each bent and the reference point.
14. CX; Format (10F8.2). CX is the distance between the reference point and the centre of resistance (EI) for each story.
15. CY; Format (10F8.2). CY is the distance between the reference point and the centre of resistance (EI) for each story.

APPENDIX C

PRINT-OUT OF FORTRAN IV PROGRAM

```
C
C
C     COMPAK        MAIN PROGRAM
C
C
C
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
C
C     THIS SECTION READS IN THE BENT MEMBER PROPERTIES AND THEN
C     CALCULATES THE BENT  STIFFNESS MATRICES (IN TERMS OF STORY SWAY)
C
      READ(5,100)NS,NX,NY
  100 FORMAT(3I10)
      READ(5,99)E,EW,EGC,EGW
   99 FORMAT(2F10.2,2E12.5)
      DO 101 N=1,NX
      READ(5,117)INDICX(N)
  117 FORMAT(I10)
      IF(INDICX(N).EQ.1)GO TO 116
  115 CALL READ1
      DO 120 I=1,NS
      DO 121 J=1,NS
      KXROTC(N,I,J)=KJ(I,J)
      KXROTW(N,I,J)=0.0
  121 CONTINUE
  120 CONTINUE
  102 CONTINUE
      IF(INDICX(N).EQ.0)GO TO 103
  116 CALL READ 2
      DO 122 I=1,NS
      DO 123 J=1,NS
      KXROTC(N,I,J)=KP(I,J)
      KXROTW(N,I,J)=KS(I,J)
  123 CONTINUE
  122 CONTINUE
  103 CONTINUE
```

```
      DO 104 I=1,NS
      DO 105 J=1,NS
      KX(N,I,J)=K(I,J)
  105 CONTINUE
  104 CONTINUE
      DO 130 I=1,NS
      HX(N,I)=H(I)
      CIX(N,I)=CI(I)
      WIX(N,I)=WI(I)
      WBLX(N,I)=WBL(I)
      WX(N,I)=W(I)
      FBLX(N,I)=FBL(I)
      WBIX(N,I)=WBI(I)
      FBIX(N,I)=FBI(I)
  130 CONTINUE
  101 CONTINUE
      DO 106 N=1,NY
      READ(5,117)INDICY(N)
      IF(INDICY(N).EQ.1)GO TO 119
  118 CALL READ1
      DO 124 I=1,NS
      DO 125 J=1,NS
      KYROTC(N,I,J)=KJ(I,J)
      KYROTW(N,I,J)=0.0
  125 CONTINUE
  124 CONTINUE
  107 CONTINUE
      IF(INDICY(N).EQ.0)GO TO 108
  119 CALL READ 2
      DO 126 I=1,NS
      DO 127 J=1,NS
      KYROTC(N,I,J)=KP(I,J)
      KYROTW(N,I,J)=KS(I,J)
  127 CONTINUE
  126 CONTINUF
  108 CONTINUE
      DO 109 I=1,NS
      DO 110 J=1,NS
      KY(N,I,J)=K(I,J)
  110 CONTINUE
  109 CONTINUE
      DO 131 I=1,NS
      HY(N,I)=H(I)
      CIY(N,I)=CI(I)
      WIY(N,I)=WI(I)
      WBLY(N,I)=WBL(I)
      WY(N,I)=W(I)
      FBLY(N,I)=FBL(I)
      WBIY(N,I)=WBI(I)
      FBIY(N,I)=FBI(I)
  131 CONTINUE
  106 CONTINUE
      READ(5,117)INSYM
      CALL TORPAK
  132 CONTINUE
      STOP
      END

      SUBROUTINE   READ1
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
```

```
      7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
      8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
      9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
       COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
      1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
      2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
      3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
      4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
      5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
      6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
      7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
      8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
      94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
       COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
       REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
       REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
       DO 101 I=1,NS
       READ(5,102)H(I),CI(I),WI(I),W(I),WBL(I),FBL(I),WBI(I),FBI(I)
  102 FORMAT(F8.2,2F12.2,F8.2,4F10.2)
  101 CONTINUE
      DO 103 I=1,NS
      DO 104 J=1,NS
      KA(I,J)=0.0
      KB(I,J)=0.0
      KD(I,J)=0.0
      KE(I,J)=0.0
  104 CONTINUE
  103 CONTINUE
      DO 105 I=1,NS
      KA(I,I)=-((12.0*E*CI(I))/(H(I)*H(I)*H(I)))
      IF(I.EQ.NS)GO TO 105
      N=I+1
      KA(I,N)=((12.0*E*CI(N))/(H(N)*H(N)*H(N)))
  105 CONTINUE
      L=NS-1
      DO 106 I=1,L
      N=I+1
      KB(I,I)=6.0*E*((CI(I)/(H(I)*H(I)))-(CI(N)/(H(N)*H(N))))
      KB(I,N)=-((6.0*E*CI(N))/(H(N)*H(N)))
      KB(N,I)=((6.0*E*CI(N))/(H(N)*H(N)))
  106 CONTINUE
      KB(NS,NS)=((6.0*E*CI(NS))/(H(NS)*H(NS)))
      DO 107 I=1,NS
      KD(I,I)=-((6.0*E*CI(I))/(H(I)*H(I)))
      IF(I.EQ.NS)GO TO 107
      N=I+1
      KD(I,N)=-((6.0*E*CI(N))/(H(N)*H(N)))
  107 CONTINUE
      L=NS-I
      DO 108 I=1,L
      N=I+1
      KE(I,I)=E*((4.0*CI(I)/H(I))+(4.0*CI(N)/H(N))+(12.0*FBI(I)/FBL(I)))
      KE(I,N)=(2.0*E*CI(N))/H(N)
      KE(N,I)=(2.0*E*CI(N))/H(N)
  108 CONTINUE
      KE(NS,NS)=E*((4.0*CI(NS)/H(NS))+(12.0*FBI(NS)/FBL(NS)))
      CALL MACAL1
      RETURN
      END

      SUBROUTINE   READ2
       COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
      1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
      2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
      30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
      4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
```

```
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 101 I=1,NS
      READ(5,102)H(I),CI(I),WI(I),W(I),WBL(I),FBL(I),WBI(I),FBI(I)
  102 FORMAT(F8.2,2F12.2,F8.2,4F10.2)
  101 CONTINUE
      DO 103 I=1,NS
      DO 104 J=1,NS
      KA(I,J)=0.0
      KB(I,J)=0.0
      KC(I,J)=0.0
      KD(I,J)=0.0
      KE(I,J)=0.0
      KF(I,J)=0.0
      KG(I,J)=0.0
      KH(I,J)=0.0
      KI(I,J)=0.0
  104 CONTINUE
  103 CONTINUE
      DO 105 I=1,NS
      KA(I,I)=-((12.0)/(H(I)*H(I)*H(I)))*((E*CI(I))+(EW*WI(I)))
      IF(I.EQ.NS)GO TO 105
      N=I+1
      KA(I,N)=((12.0)/(H(N)*H(N)*H(N)))*((E*CI(N))+(EW*WI(N)))
  105 CONTINUE
      L=NS-1
      DO 106 I=1,L
      N=I+1
      KB(I,I)=6.0*E*((CI(I)/(H(I)*H(I)))-(CI(N)/(H(N)*H(N))))
      KB(I,N)=-((6.0)/(H(N)*H(N)))*(E*CI(N))
      KB(N,I)=((6.0)/(H(N)*H(N)))*(E*CI(N))
  106 CONTINUE
      KB(NS,NS)=((6.0)/(H(NS)*H(NS)))*(E*CI(NS))
  107 CONTINUE
      L=NS-1
      DO 108 I=1,L
      N=I+1
      KC(I,I)=6.0*EW*((WI(I)/(H(I)*H(I)))-(WI(N)/(H(N)*H(N))))
      KC(I,N)=-((6.0)/(H(N)*H(N)))*(EW*WI(N))
      KC(N,I)=((6.0)/(H(N)*H(N)))*(EW*WI(N))
  108 CONTINUE
      KC(NS,NS)=((6.0)/(H(NS)*H(NS)))*(EW*WI(NS))
      DO 110 I=1,NS
      KD(I,I)=-((6.0)/(H(I)*H(I)))*(E*CI(I))
      KG(I,I)=-(6.0*EW*WI(I))/(H(I)*H(I))
      IF(I.EQ.NS)GO TO 110
      N=I+1
      KD(I,N)=-((6.0)/(H(N)*H(N)))*(E*CI(N))
      KG(I,N)=-(6.0*EW*WI(N))/(H(N)*H(N))
  110 CONTINUE
```

```
      L=NS-1
      DO 111 I=1,L
      N=I+1
      KE(I,I)=E*((4.0*(CI(I)/H(I)))+(4.0*(CI(N)/H(N)))+(12.0*(FBI(I)/FBL
     1(I)))+(4.0*(WBI(I)/WBL(I))))
      KE(I,N)=E*((2.0*CI(N))/H(N))
      KE(N,I)=E*((2.0*CI(N))/H(N))
  111 CONTINUE
      KE(NS,NS)=E*((4.0*(CI(NS)/H(NS)))+(12.0*(FBI(NS)/FBL(NS)))+(4.0*
     1(WBI(NS)/WBL(NS))))
      DO 113 I=1,NS
      KF(I,I)=((E*WBI(I))/WBL(I))*((2.0)+(3.0*W(I)/WBL(I)))
      KH(I,I)=((E*WBI(I))/WBL(I))*((2.0)+(3.0*W(I)/WBL(I)))
  113 CONTINUE
      L=NS-1
      DO 114 I=1,L
      N=I+1
      KI(I,I)=(((E*WBI(I))/WBL(I))*((4.0)+(6.0*W(I)/WBL(I))+(3.0*W(I)
     1*W(I)/(WBL(I)*WBL(I)))))+((4.0*EW*WI(I))/H(I))+((4.0*EW*WI(N))/H(N
     2))
      KI(I,N)=EW*((2.0*WI(N))/H(N))
      KI(N,I)=EW*((2.0*WI(N))/H(N))
  114 CONTINUE
      KI(NS,NS)=(((E*WBI(NS))/WBL(NS))*((4.0)+(6.0*W(NS)/WBL(NS))+(3.0*
     1W(NS)*W(NS)/(WBL(NS)*WBL(NS)))))+((4.0*EW*WI(NS))/H(NS))
      CALL MACAL2
      RETURN
      END

      SUBROUTINE    MACAL1
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      CALL TOKYO(NS,KE)
  100 CONTINUE
      DO 101 I=1,NS
      DO 102 J=1,NS
      KJ(I,J)=0.0
      DO 103 L=1,NS
      KJ(I,J)=KJ(I,J)-KE(I,L)*KD(L,J)
  103 CONTINUE
  102 CONTINUE
  101 CONTINUE
      DO 104 I=1,NS
      DO 105 J=1,NS
      KK(I,J)=0.0
```

```
      DO 106 L=1,NS
      KK(I,J)=KK(I,J)+KB(I,L)*KJ(L,J)
  106 CONTINUE
  105 CONTINUE
  104 CONTINUE
      DO 107 I=1,NS
      DO 108 J=1,NS
      K(I,J)=KA(I,J)+KK(I,J)
  108 CONTINUE
  107 CONTINUE
      RETURN
      END

      SUBROUTINE   MACAL2
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      CALL TOKYO (NS,KI)
  100 CONTINUE
      DO 101 I=1,NS
      DO 102 J=1,NS
      KJ(I,J)=0.0
      DO 103 L=1,NS
      KJ(I,J)=KJ(I,J)+KI(I,L)*KG(L,J)
  103 CONTINUE
  102 CONTINUE
  101 CONTINUE
      DO 104 I=1,NS
      DO 105 J=1,NS
      KK(I,J)=0.0
      DO 106 L=1,NS
      KK(I,J)=KK(I,J)+KF(I,L)*KJ(L,J)
  106 CONTINUE
  105 CONTINUE.
  104 CONTINUE
      DO 107 I=1,NS
      DO 108 J=1,NS
      KL(I,J)=KD(I,J)-KK(I,J)
  108 CONTINUE
  107 CONTINUE
      DO 109 I=1,NS
      DO 110 J=1,NS
      KM(I,J)=0.0
      DO 111 L=1,NS
      KM(I,J)=KM(I,J)+KI(I,L)*KH(L,J)
  111 CONTINUE
```

```
110 CONTINUE
109 CONTINUE
    DO 112 I=1,NS
    DO 113 J=1,NS
    KN(I,J)=0.0
    DO 114 L=1,NS
    KN(I,J)=KN(I,J)+KF(I,L)*KM(L,J)
114 CONTINUE
113 CONTINUE
112 CONTINUE
    DO 115 I=1,NS
    DO 116 J=1,NS
    KO(I,J)=KN(I,J)-KE(I,J)
116 CONTINUE
115 CONTINUE
    CALL TOKYO (NS,KO)
    DO 117 I=1,NS
    DO 118 J=1,NS
    KP(I,J)=0.0
    DO 119 L=1,NS
    KP(I,J)=KP(I,J)+KO(I,L)*KL(L,J)
119 CONTINUE
118 CONTINUE
117 CONTINUE
    DO 120 I=1,NS
    DO 121 J=1,NS
    KQ(I,J)=0.0
    DO 122 L=1,NS
    KQ(I,J)=KQ(I,J)+KH(I,L)*KP(L,J)
122 CONTINUE
121 CONTINUE
120 CONTINUE
    DO 123 I=1,NS
    DO 124 J=1,NS
    KR(I,J)=KG(I,J)+KQ(I,J)
124 CONTINUE
123 CONTINUE
    DO 125 I=1,NS
    DO 126 J=1,NS
    KS(I,J)=0.0
    DO 127 L=1,NS
    KS(I,J)=KS(I,J)-(KI(I,L)*KR(L,J))
127 CONTINUE
126 CONTINUE
125 CONTINUE
    DO 128 I=1,NS
    DO 129 J=1,NS
    KT(I,J)=0.0
    DO 130 L=1,NS
    KT(I,J)=KT(I,J)+KB(I,L)*KP(L,J)
130 CONTINUE
129 CONTINUE
128 CONTINUE
    DO 131 I=1,NS
    DO 132 J=1,NS
    KW(I,J)=0.0
    DO 133 L=1,NS
    KW(I,J)=KW(I,J)+KC(I,L)*KS(L,J)
133 CONTINUE
132 CONTINUE
131 CONTINUE
    DO 134 I=1,NS
    DO 135 J=1,NS
    K(I,J)=KA(I,J)+KT(I,J)+KW(I,J)
135 CONTINUE
134 CONTINUE
```

```
      RETURN
      END

      SUBROUTINE TOKYO (NO,A)
      DIMENSION AC(20),AB(20),A(20,20)
      NO1=NO-1
      A(1,1)=1.0/A(1,1)
      DO 80 N=1, NO1
      DO 50 I=1,N
      AB(I)=0.0
      AC(I)=0.0
      DO 50 J=1,N
      AB(I)=AB(I)+A(I,J)*A(J,N+1)
      AC(I)=AC(I)+A(N+1,J)*A(J,I)
   50 CONTINUE
      ACB=0.0
      DO 60 I=1,N
      ACB=ACB+AC(I)*A(I,N+1)
   60 CONTINUE
      A(N+1,N+1)=1.0/(A(N+1,N+1)-ACB)
      DO 70 I=1,N
      A(N+1,I)=-A(N+1,N+1)*AC(I)
      A(I,N+1)=-AB(I)*A(N+1,N+1)
   70 CONTINUE
      DO 80 I=1,N
      DO 80 J=1,N
      A(I,J)=A(I,J)-A(I,N+1)*AC(J)
   80 CONTINUE
      RETURN
      END

      SUBROUTINE   TORPAK
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DIMENSION GKT(20)
      READ(5,201)(FX(I),I=1,NS)
      READ(5,201)(FY(I),I=1,NS)
      READ(5,201)(XH(I),I=1,NS)
      READ(5,201)(YH(I),I=1,NS)
  201 FORMAT(10F8.2)
      READ(5,212)ITERX,ITERY
  212 FORMAT(2I10)
      READ(5,203)(GKT(I),I=1,NS)
  203 FORMAT(5F16.6)
      DO 210 I=1,NS
```

```
      DO 211 J=1,NS
      KV(I,J)=0.0
  211 CONTINUE
  210 CONTINUE
      L=NS-1
      DO 202 I=1,L
      N=I+1
      KV(I,I)=+((GKT(I)/H(I))+(GKT(N)/H(N)))
      KV(N,I)=-GKT(N)/H(N)
      KV(I,N)=-GKT(N)/H(N)
  202 CONTINUE
      KV(NS,NS)=+(GKT(NS)/H(NS))
      READ(5,201)(XX(I),I=1,NX)
      READ(5,201)(YY(I),I=1,NY)
      READ(5,201)(CX(I),I=1,NS)
      READ(5,201)(CY(I),I=1,NS)
      CALL WRITE1
      WRITE(6,100)(GKT(I),I=1,NS)
  100 FORMAT(1H1,(2X,'ST.VENANT CONSTANT = ',7E13.6))
      WRITE(6,101)(E,EW)
  101 FORMAT(1H0/,2X,'MODULUS OF ELASTICITY FOR FRAME = ',F10.2,2X,'MODU
     1LUS OF ELASTICITY FOR WALL = ',F10.2)
  223 CONTINUE
      IF(INSYM.EQ.0)GO TO 254
      CALL SYMPAK
  254 CONTINUE
      IF(INSYM.EQ.1)GO TO 252
      ICX=0
      ICY=0
      IX=0
      IY=0
      IF(FX(1).EQ.0.)GO TO 501
      DO 502 I=1,NS
      XO(I)=CX(I)*1.2
  502 CONTINUE
      GO TO 503
  501 DO 503 I=1,NS
      XO(I)=XX(NX)/2.
  503 CONTINUE
      IF(FY(1).EQ.0.)GO TO 601
      DO 602 I=1,NS
      YO(I)=CY(I)*1.2
  602 CONTINUE
      GO TO 603
  601 DO 603 I=1,NS
      YO(I)=YY(NY)/2.
  603 CONTINUE
      DO 604 I=1,NS
      IF(CX(I).LE.(0.55*XX(NX)))GO TO 605
  604 CONTINUE
      GO TO 606
  605 CONTINUE
      DO 607 I=1,NS
      MT(I)=(FX(I)*0.8*XH(I))-(FY(I)*0.8*YH(I))
  607 CONTINUE
      GO TO 224
  606 CONTINUE
      DO 229 I=1,NS
      MT(I)=(FX(I)*XH(I))-(FY(I)*YH(I))
  229 CONTINUE
  224 CONTINUE
      CALL HXODX
  225 CONTINUE
      CALL HYODY
  226 CONTINUE
      CALL DXOTTX
```

```
  227 CONTINUE
      CALL DYOTTY
  228 CONTINUE
      CALL RTOROT
  232 CONTINUE
      CALL VXOTVX
  233 CONTINUE
      CALL VYOTVY
  234 CONTINUE
      DO 235 I=1,NS
      TVXA(I)=TVX(I)
      TVYA(I)=TVY(I)
  235 CONTINUE
      IF(ICX.EQ.ITERX)GO TO 255
  213 CONTINUE
      IF(ICY.EQ.ITERY)GO TO 255
  214 CONTINUE
      WRITE(6,215)(TVXA(I),I=1,NS)
  215 FORMAT(1H0,2X,'TVXA=',9E13.6)
C
C     THIS SECTION TESTS FOR EQUILIBRIUM OF LOADS AND RESISTANCE
C
      IF(FX(1).EQ.0)GO TO 237
      DO 236 I=1,NS
      IF(ABS(FX(I)+TVXA(I)).GT.ABS(0.01*FX(I)))GO TO 231
  236 CONTINUE
      GO TO 238
  237 DO 238 I=1,NS
      IF(ABS(TVXA(I)).GT.0.10)GO TO 231
  238 CONTINUE
      IF(FY(1).EQ.0)GO TO 239
  240 CONTINUE
      DO 241 I=1,NS
      IF(ABS(FY(I)+TVYA(I)).GT.ABS(0.01*FY(I)))GO TO 230
  241 CONTINUE
      GO TO 252
  239 DO 242 I=1,NS
      IF(ABS(TVYA(I)).GT.0.10)GO TO 230
  242 CONTINUE
      GO TO 252
C
C     THE FOLLOWING SECTION CALCULATES INFLUENCE COEFFICIENTS
C
  231 CALL ICXO
      ICX=ICX+1
  243 CONTINUE
      WRITE(6,304)(XO(I),I=1,NS)
  304 FORMAT(1H0,2X,'XO=',9E13.6)
      GO TO 224
  230 CALL ICYO
      ICY=ICY+1
  244 CONTINUE
      WRITE(6,305)(YO(I),I=1,NS)
  305 FORMAT(1H0,2X,'YO=',9E13.6)
      GO TO 225
  255 CONTINUE
      WRITE(6,256)
  256 FORMAT(1H1,4X,'WARNING, NO.OF ITERATION CYCLES INSUFFICIENT -STRUC
     1TURE NOT IN EQUILIBRIUM-')
  252 CONTINUE
      CALL SWAY
  253 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE    SYMPAK
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 100 I=1,NS
      DO 101 J=1,NS
      TTX(I,J)=0.0
      DO 102 L=1,NX
      ADD=KX(L,I,J)
      TTX(I,J)=TTX(I,J)+ADD
  102 CONTINUE
  101 CONTINUE
  100 CONTINUE
      DO 103 I=1,NS
      DO 104 J=1,NS
      TTY(I,J)=0.0
      DO 105 L=1,NY
      ADD=KY(L,I,J)
      TTY(I,J)=TTY(I,J)+ADD
  105 CONTINUE
  104 CONTINUE
  103 CONTINUE
      CALL TOKYO(NS,TTX)
  106 CONTINUE
      DO 107 I=1,NS
      SX(1,I)=0.0
      DO 108 J=1,NS
      PROD=TTX(I,J)*(-FX(J))
      SX(1,I)=SX(1,I)+PROD
  108 CONTINUE
  107 CONTINUE
      DO 109 I=2,NX
      DO 110 J=1,NS
      SX(I,J)=SX(1,J)
  110 CONTINUE
  109 CONTINUE
      CALL TOKYO(NS,TTY)
  112 CONTINUE
      DO 113 I=1,NS
      SY(1,I)=0.0
      DO 114 J=1,NS
      PROD=TTY(I,J)*(-FY(J))
      SY(1,I)=SY(1,I)+PROD
  114 CONTINUE
  113 CONTINUE
```

```
      DO 115 I=2,NY
      DO 116 J=1,NS
      SY(I,J)=SY(1,J)
  116 CONTINUE
  115 CONTINUE
  117 CONTINUE
      RETURN
      END
      SUBROUTINE   WRITE1
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      WRITE(6,101)NS,NX,NY
  101 FORMAT(1H1,2X,'NUMBER OF STORIES = ',I2,4X,'NUMBER OF X FRAMES = '
     1,I2,4X,'NUMBER OF Y FRAMES = ',I2)
      WRITE(6,116)ITERX,ITERY
  116 FORMAT(1H0//,2X,'NUMBER OF ITERATIONS IN X DIRECTION LIMITED TO ',
     1I3,2X,'NUMBER OF ITERATIONS IN Y DIRECTION LIMITED TO ',I3)
      WRITE(6,102)
  102 FORMAT(1H0//,T10,'FLOOR NUMBER',T32,'APPLIED LOAD(KIP)',T61,'POINT
     1 OF APPLICATION(IN)',T93,'CENTROID OF STIFFNESS(IN)')
      WRITE(6,103)
  103 FORMAT(T28,'X DIRECTION',T43,'Y DIRECTION',T60,'X DIRECTION',T75,'
     1Y DIRECTION',T92,'X DIRECTION',T107,'Y DIRECTION')
      DO 104 I=1,NS
      WRITE(6,105)I,FX(I),FY(I),XH(I),YH(I),CX(I),CY(I)
  105 FORMAT(1H0,T16,I2,T28,F8.2,T43,F8.2,T60,F8.2,T75,F8.2,T92,F8.2,
     1T107,F8.2)
  104 CONTINUE
      DO 106 I=1,NX
      WRITE(6,107)I
  107 FORMAT(1H1,2X,'FRAME X NUMBER',I10,2X,'MEMBER PROPERTIES')
      WRITE(6,108)
  108 FORMAT(1H0/,T8,'STORY NUMBER',T22,'STORY HEIGHT',T36,'COLUMN INERT
     1IA',T52,'WALL INERTIA',T65,'WALL WIDTH',T81,'BEAM SPAN(IN)',T102,
     2'BEAM INERTIA(IN4)')
      WRITE(6,109)
  109 FORMAT(T26,'(IN)',T40,'(IN4)',T55,'(IN4)',T68,'(IN)',T77,'FRAME-BE
     1AM',T89,'WALL-BEAM',T100,'FRAME-BEAM',T112,'WALL-BEAM')
      DO 110 J=1,NS
      WRITE(6,111)J,HX(I,J),CIX(I,J),WIX(I,J),WX(I,J),FBLX(I,J),WBLX(I,J
     1),FBIX(I,J),WBIX(I,J)
  111 FORMAT(1H0,T14,I3,T22,F8.2,T34,F12.2,T50,F12.2,T63,F8.2,T75,F10.2,
     1T85,F10.2,T98,F10.2,T109,F10.2)
  110 CONTINUE
      WRITE(6,112)XX(I)
```

```
 112 FORMAT(1H0//,2X,'FRAME LOCATION FROM REFERENCE POINT = ',F8.2)
 106 CONTINUE
     DO 113 I=1,NY
     WRITE(6,114)I
 114 FORMAT(1H1,2X,'FRAME Y NUMBER',I10,2X,'MEMBER PROPERTIES')
     WRITE(6,108)
     WRITE(6,109)
     DO 115 J=1,NS
     WRITE(6,111)J,HY(I,J),CIY(I,J),WIY(I,J),WY(I,J),FBLY(I,J),WBLY(I,J
    1),FBIY(I,J),WBIY(I,J)
 115 CONTINUE
     WRITE(6,112)YY(I)
 113 CONTINUE
     RETURN
     END

     SUBROUTINE    HXODX
     COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
    1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
    2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
    30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
    4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
    5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
    6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
    7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
    8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
    9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
     COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
    1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
    2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
    3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
    4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
    5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
    6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
    7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
    8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
    94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
     COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
     REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
     REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
     DO 504 I=1,NX
     DO 505 J=1,NS
     RX(I,J)=XO(J)-XX(I)
 505 CONTINUE
 504 CONTINUE
     DO 506 I=1,NX
     DO 507 J=1,NS
     DO 508 L=1,NS
     DX(I,J,L)=0.0
 508 CONTINUE
 507 CONTINUE
 506 CONTINUE
     DO 509 I=1,NX
     DO 510 J=1,NS
     DX(I,J,J)=RX(I,J)
     IF(J.EQ.1)GO TO 510
     DX(I,J,(J-1))=-RX(I,(J-1))
 510 CONTINUE
 509 CONTINUE
     RETURN
     END

     SUBROUTINE    DXOTTX
     COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
    1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
    2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
```

```
30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
 COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
 COMMON WBFY(3,20),DLX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
 REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
 REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
 DO 512 I=1,NX
 DO 513 J=1,NS
 DO 514 M=1,NS
 SUM=0.0
 DO 515 L=1,NS
 PROD=KX(I,J,L)*DX(I,L,M)
515 SUM=SUM+PROD
 KDX(I,J,M)=SUM
514 CONTINUE
513 CONTINUE
512 CONTINUE
 DO 516 I=1,NX
 DO 517 J=1,NS
 DO 518 L=1,NS
 TX(I,J,L)=XX(I)*KDX(I,J,L)
518 CONTINUE
517 CONTINUE
516 CONTINUE
 DO 519 I=1,NS
 DO 520 J=1,NS
 TTX(I,J)=0.0
 DO 521 L=1,NX
 ADD=TX(L,I,J)
 TTX(I,J)=TTX(I,J)+ADD
521 CONTINUE
520 CONTINUE
519 CONTINUE
 RETURN
 END

 SUBROUTINE   VXOTVX
 COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
 COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
```

```
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 522 I=1,NX
      DO 523 J=1,NS
      VX(I,J)=0.0
      DO 524 L=1,NS
      PROD=KDX(I,J,L)*ROT(L)
      VX(I,J)=VX(I,J)+PROD
  524 CONTINUE
  523 CONTINUE
  522 CONTINUE
      DO 525 J=1,NS
      TVX(J)=0.0
      DO 526 I=1,NX
      TVX(J)=TVX(J)+VX(I,J)
  526 CONTINUE
  525 CONTINUE
      RETURN
      END

      SUBROUTINE    HYDDY
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 604 I=1,NY
      DO 605 J=1,NS
      RY(I,J)=YO(J)-YY(I)
  605 CONTINUE
  604 CONTINUE
      DO 606 I=1,NY
      DO 607 J=1,NS
      DO 608 L=1,NS
      DY(I,J,L)=0.0
  608 CONTINUE
  607 CONTINUE
  606 CONTINUE
      DO 609 I=1,NY
      DO 610 J=1,NS
      DY(I,J,J)=RY(I,J)
      IF(J.EQ.1)GO TO 610
```

```
      DY(I,J,(J-1))=-KY(I,(J-1))
  610 CONTINUE
  609 CONTINUE
      RETURN
      END

      SUBROUTINE   DYUTTY
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 612 I=1,NY
      DO 613 J=1,NS
      DO 614 M=1,NS
      SUM=0.0
      DO 615 L=1,NS
      PROD=KY(I,J,L)*DY(I,L,M)
  615 SUM=SUM+PROD
      KDY(I,J,M)=SUM
  614 CONTINUE
  613 CONTINUE
  612 CONTINUE
      DO 616 I=1,NY
      DO 617 J=1,NS
      DO 618 L=1,NS
      TY(I,J,L)=YY(I)*KDY(I,J,L)
  618 CONTINUE
  617 CONTINUE
  616 CONTINUE
      DO 619 I=1,NS
      DO 620 J=1,NS
      TTY(I,J)=0.0
      DO 621 L=1,NY
      ADD=TY(L,I,J)
      TTY(I,J)=TTY(I,J)+ADD
  621 CONTINUE
  620 CONTINUE
  619 CONTINUE
      RETURN
      END

      SUBROUTINE   VYOTVY
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
```

```
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 622 I=1,NY
      DO 623 J=1,NS
      VY(I,J)=0.0
      DO 624 L=1,NS
      PROD=KDY(I,J,L)*ROT(L)
      VY(I,J)=VY(I,J)-PROD
  624 CONTINUE
  623 CONTINUE
  622 CONTINUE
      DO 625 J=1,NS
      TVY(J)=0.0
      DO 626 I=1,NY
      TVY(J)=TVY(J)+VY(I,J)
  626 CONTINUE
  625 CONTINUE
      RETURN
      END

      SUBROUTINE   RTOROT
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 530 I=1,NS
      DO 531 J=1,NS
      RT(I,J)=TTX(I,J)+TTY(I,J)+KV(I,J)
  531 CONTINUE
  530 CONTINUE
      CALL TOKYO (NS,RT)
```

```
  532 CONTINUE
      DO 533 I=1,NS
      ROT(I)=0.0
      DO 534 J=1,NS
      PROD=RT(I,J)*(-MT(J))
      ROT(I)=ROT(I)+PROD
  534 CONTINUE
  533 CONTINUE
      RETURN
      END

      SUBROUTINE   SWAY
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      IF(INSYM.EQ.1)GO TO 114
      DO 100 I=1,NX
      DO 101 J=1,NS
      SX(I,J)=0.0
      DO 102 L=1,NS
      PROD=DX(I,J,L)*ROT(L)
      SX(I,J)=SX(I,J)+PROD
  102 CONTINUE
  101 CONTINUE
  100 CONTINUE
      DO 103 I=1,NY
      DO 104 J=1,NS
      SY(I,J)=0.0
      DO 105 L=1,NS
      PROD=DY(I,J,L)*(-ROT(L))
      SY(I,J)=SY(I,J)+PROD
  105 CONTINUE
  104 CONTINUE
  103 CONTINUE
  114 CONTINUE
      DO 106 I=1,NX
      DO 107 J=1,NS
      ROTXC(I,J)=0.0
      ROTXW(I,J)=0.0
      DO 108 L=1,NS
      PROD1=KXROTC(I,J,L)*SX(I,L)
      ROTXC(I,J)=ROTXC(I,J)+PROD1
      PROD2=KXROTW(I,J,L)*SX(I,L)
      ROTXW(I,J)=ROTXW(I,J)+PROD2
  108 CONTINUE
  107 CONTINUE
```

```
106 CONTINUE
    DO 109 I=1,NY
    DO 110 J=1,NS
    ROTYC(I,J)=0.0
    ROTYW(I,J)=0.0
    DO 111 L=1,NS
    PROD1=KYROTC(I,J,L)*SY(I,L)
    ROTYC(I,J)=ROTYC(I,J)+PROD1
    PROD2=KYROTW(I,J,L)*SY(I,L)
    ROTYW(I,J)=ROTYW(I,J)+PROD2
111 CONTINUE
110 CONTINUE
109 CONTINUE
    IF(INSYM.EQ.1)GO TO 112
    CALL WRITE3
112 CONTINUE
    CALL CALPAK
113 CONTINUE
    RETURN
    END

    SUBROUTINE   WRITE3
    COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
   1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
   2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
   30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
   4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
   5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
   6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
   7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
   8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
   9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
    COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
   1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
   2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
   3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
   4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
   5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
   6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
   7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
   8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
   94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
    COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
    REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
    REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
    WRITE(6,252)(TVXA(I),I=1,NS)
252 FORMAT(1H1,(4X,'RESULTANT SHEAR IN X-DIRECTION =',E13.6/))
    DO 260 I=1,NX
    WRITE(6,261)(VX(I,J),J=1,NS)
261 FORMAT(/1H0,(4X,'INDIVIDUAL FRAME X SHEAR =',3E13.6/))
260 CONTINUE
    WRITE(6,253)(TVYA(I),I=1,NS)
253 FORMAT(1H1,(4X,'RESULTANT SHEAR IN Y-DIRECTION =',E13.6/))
    DO 262 I=1,NY
    WRITE(6,263)(VY(I,J),J=1,NS)
263 FORMAT(/1H0,(4X,'INDIVIDUAL FRAME Y SHEAR =',3E13.6/))
262 CONTINUE
    WRITE(6,254)(XO(I),I=1,NS)
254 FORMAT(1H1,(4X,'CENTRE OF ROTATION IN X-DIRECTION =',F11.2/))
    WRITE(6,255)(YO(I),I=1,NS)
255 FORMAT(1H1,(4X,'CENTRE OF ROTATION IN Y-DIRECTION =',F11.2/))
    WRITE(6,256)(ROT(I),I=1,NS)
256 FORMAT(1H1,(4X,'ROTATION IN RADIANS =',E13.6/))
    WRITE(6,257)ICX
257 FORMAT(1H1,4X,'NUMBER OF ITERATION CYCLES X =',I3)
    WRITE(6,258)ICY
```

```
  258 FORMAT(1H0,4X,'NUMBER OF ITERATION CYCLES Y =',I3)
      WRITE(6,270)IX
  270 FORMAT(1H0,4X,'NUMBER OF RESET CYCLES X = ',I3)
      WRITE(6,271)IY
  271 FORMAT(1H0,4X,'NUMBER OF RESET CYCLES Y = ',I3)
  259 CONTINUE
      RETURN
      END

      SUBROUTINE   ICXO
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 238 N=1,NS
      DO 239 I=1,NX
      RX(I,N)=RX(I,N)+1.0
      DX(I,N,N)=DX(I,N,N)+1.0
      IF(N.EQ.NS)GO TO 239
      DX(I,(N+1),N)=DX(I,(N+1),N)-1.0
  239 CONTINUE
      CALL DXOTTX
  240 CONTINUE
      CALL RTOROT
  242 CONTINUE
      CALL VXOTVX
  243 CONTINUE
      DO 244 J=1,NS
      TVXC(N,J)=TVX(J)
  244 CONTINUE
      DO 245 I=1,NX
      RX(I,N)=RX(I,N)-1.0
      DX(I,N,N)=DX(I,N,N)-1.0
      IF(N.EQ.NS)GO TO 245
      DX(I,(N+1),N)=DX(I,(N+1),N)+1.0
  245 CONTINUE
      DO 246 J=1,NS
      TVXC(N,J)=TVXC(N,J)-TVXA(J)
  246 CONTINUE
  238 CONTINUE
      DO 247 N=1,NS
      DO 248 J=1,NS
      TTVXC(J,N)=TVXC(N,J)
  248 CONTINUE
  247 CONTINUE
      CALL TOKYO (NS,TTVXC)
  249 CONTINUE
      DO 250 I=1,NS
```

```
      DO 251 J=1,NS
      PROD=TTVXC(I,J)*((-FX(J))-(TVXA(J)))
      XO(I)=XO(I)+PROD/4.0
  251 CONTINUE
  250 CONTINUE
      DO 252 I=1,NS
      IF(XO(I).GT.20.0*XX(NX))GO TO 253
  252 CONTINUE
      GO TO 254
  253 CONTINUE
      IX=IX+1
      DO 254 I=1,NS
      XO(I)=CX(I)*(1.2+(0.2*IX))
  254 CONTINUE
      RETURN
      END

      SUBROUTINE   ICYO
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 238 N=1,NS
      DO 239 I=1,NY
      RY(I,N)=RY(I,N)+1.0
      DY(I,N,N)=DY(I,N,N)+1.0
      IF(N.EQ.NS)GO TO 239
      DY(I,(N+1),N)=DY(I,(N+1),N)-1.0
  239 CONTINUE
      CALL DYOTTY
  240 CONTINUE
      CALL RTOROT
  242 CONTINUE
      CALL VYOTVY
  243 CONTINUE
      DO 244 J=1,NS
      TVYC(N,J)=TVY(J)
  244 CONTINUE
      DO 245 I=1,NY
      RY(I,N)=RY(I,N)-1.0
      DY(I,N,N)=DY(I,N,N)-1.0
      IF(N.EQ.NS)GO TO 245
      DY(I,(N+1),N)=DY(I,(N+1),N)+1.0
  245 CONTINUE
      DO 246 J=1,NS
      TVYC(N,J)=TVYC(N,J)-TVYA(J)
  246 CONTINUE
```

```
  238 CONTINUE
      DO 247 N=1,NS
      DO 248 J=1,NS
      TTVYC(J,N)=TVYC(N,J)
  248 CONTINUE
  247 CONTINUE
      CALL TOKYO (NS,TTVYC)
  249 CONTINUE
      DO 250 I=1,NS
      DO 251 J=1,NS
      PROD=TTVYC(I,J)*((-FY(J))-(TVYA(J)))
      YO(I)=YO(I)+PROD/4.0
  251 CONTINUE
  250 CONTINUE
      DO 252 I=1,NS
      IF(YO(I).GT.20.0*YY(NY))GO TO 253
  252 CONTINUE
      GO TO 254
  253 CONTINUE
      IY=IY+1
      DO 254 I=1,NS
      YO(I)=CY(I)*(1.2+(0.2*IY))
  254 CONTINUE
      RETURN
      END

      SUBROUTINE   CALPAK
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),KT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
C
C     THIS SECTION READS IN JOINT ROTATION,STORY SWAY,MEMBER PROPERTIES
C     AND THEN CALCULATES ALL THE MEMBER FORCES
C
      DO 101 L=1,NX
      CALL CALC1(L)
  101 CONTINUE
      DO 104 L=1,NY
      CALL CALC2(L)
  104 CONTINUE
      CALL WRITE4
      RETURN
      END
```

```
      SUBROUTINE   CALC1(L) ,
      COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
     1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
     2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
     30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
     4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
     5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
     6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
     7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
     8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
     9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
      COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
     1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
     2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
     3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
     4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
     5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
     6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
     7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
     8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
     94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
      COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
      DIMENSION SWX(4,20)
      REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
      REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
      DO 106 I=1,NS
      H(I)=HX(L,I)
      CI(I)=CIX(L,I)
      WI(I)=WIX(L,I)
      WBL(I)=WBLX(L,I)
      W(I)=WX(L,I)
      FBL(I)=FBLX(L,I)
      WBI(I)=WBIX(L,I)
      FBI(I)=FBIX(L,I)
      SWX(L,I)=SX(L,I)
      FBMX(L,I)=(E*FBI(I)/FBL(I))*(6.0*ROTXC(L,I))
      FBSX(L,I)=(E*FBI(I)/(FBL(I)*FBL(I)))*(12.0*ROTXC(L,I))
      WBMXC(L,I)=(E*WBI(I)/WBL(I))*((4.0*ROTXC(L,I))+(2.0*ROTXW(L,I))+((
     16.0/WBL(I))*(W(I)*ROTXW(L,I)/2.0)))
      WBMXW(L,I)=(E*WBI(I)/WBL(I))*((2.0*ROTXC(L,I))+(4.0*ROTXW(L,I))+((
     16.0/WBL(I))*(W(I)*ROTXW(L,I)/2.0)))
      WBSX(L,I)=(E*WBI(I)/(WBL(I)*WBL(I)))*((6.0*ROTXC(L,I))+(6.0*ROTXW(
     1L,I))+((12.0/WBL(I))*(W(I)*ROTXW(L,I)/2.0)))
  106 CONTINUE
      DO 100 I=2,NS
      N=I-1
      CMXB(L,I)=(E*CI(I)/H(I))*((4.0*ROTXC(L,N))+(2.0*ROTXC(L,I))-(6.0*S
     1WX(L,I)/H(I)))
      CMXT(L,I)=(E*CI(I)/H(I))*((2.0*ROTXC(L,N))+(4.0*ROTXC(L,I))-(6.0*S
     1WX(L,I)/H(I)))
      CSX(L,I)=((E*CI(I)/(H(I)*H(I))))*((6.0*ROTXC(L,N))+(6.0*ROTXC(L,I
     1))-(12.0*SWX(L,I)/H(I)))
  100 CONTINUE
      CMXB(L,1)=(E*CI(1)/H(1))*((2.0*ROTXC(L,1))-(6.0*SWX(L,1)/H(1)))
      CMXT(L,1)=(E*CI(1)/H(1))*((4.0*ROTXC(L,1))-(6.0*SWX(L,1)/H(1)))
      CSX(L,1)=((E*CI(1)/(H(1)*H(1))))*((6.0*ROTXC(L,1))-(12.0*SWX(L,1)/
     1H(1)))
      DO 101 I=2,NS
      N=I-1
      WMXB(L,I)=(EW*WI(I)/H(I))*((4.0*ROTXW(L,N))+(2.0*ROTXW(L,I))-(6.0*
     1SWX(L,I)/H(I)))
      WMXT(L,I)=(EW*WI(I)/H(I))*((2.0*ROTXW(L,N))+(4.0*ROTXW(L,I))-(6.0*
     1SWX(L,I)/H(I)))
      WSX(L,I)=((EW*WI(I)/(H(I)*H(I))))*((6.0*ROTXW(L,N))+(6.0*ROTXW(L,I
     1))-(12.0*SWX(L,I)/H(I)))
```

```
101 CONTINUE
    WMXB(L,1)=(EW*WI(1)/H(1))*((2.0*ROTXW(L,1))-(6.0*SWX(L,1)/H(1)))
    WMXT(L,1)=(EW*WI(1)/H(1))*((4.0*ROTXW(L,1))-(6.0*SWX(L,1)/H(1)))
    WSX(L,1)=((EW*WI(1)/(H(1)*H(1))))*((6.0*ROTXW(L,1))-(12.0*SWX(L,1)
   1/H(1)))
    WBFX(L,NS)=WSX(L,NS)
    WFX(L,NS)=WBSX(L,NS)
    M=NS-1
    DO 102 I=1,M
    N=I+1
    WBFX(L,I)=WSX(L,I)-WSX(L,N)
    WFX(L,(NS-I))=WFX(L,(NS+1-I))+WBSX(L,(NS-I))
102 CONTINUE
103 CONTINUE
    FBFX(L,NS)=CSX(L,NS)+WBFX(L,NS)
    CFX(L,NS)=FBSX(L,NS)-WBSX(L,NS)
    M=NS-1
    DO 104 I=1,M
    N=I+1
    FBFX(L,I)=(CSX(L,I)-CSX(L,N))+WBFX(L,I)
    CFX(L,(NS-I))=CFX(L,(NS+1-I))+FBSX(L,(NS-I))-WBSX(L,(NS-I))
104 CONTINUF
    DEX(L,1)=SWX(L,1)
    DO 105 I=2,NS
    DEX(L,I)=DEX(L,(I-1))+SWX(L,I)
105 CONTINUE
    RETURN
    END

    SUBROUTINE   CALC2(L)
    COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
   1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYRUT
   2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
   30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
   4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
   5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
   6(20),TVXA(20),TVYA(20).XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
   7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
   8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
   9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
    COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
   1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
   2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
   3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),RUTXW(4,20),
   4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
   5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
   6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
   7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
   8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
   94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
    COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
    DIMENSION SWY(3,20)
    REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYRUTW,KDX,KDY,MT
    REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
    DO 106 I=1,NS
    H(I)=HY(L,I)
    CI(I)=CIY(L,I)
    WI(I)=WIY(L,I)
    WBL(I)=WBLY(L,I)
    W(I)=WY(L,I)
    FBL(I)=FBLY(L,I)
    WBI(I)=WBIY(L,I)
    FBI(I)=FBIY(L,I)
    SWY(L,I)=SY(L,I)
    FBMY(L,I)=(E*FBI(I)/FBL(I))*(6.0*ROTYC(L,I))
    FBSY(L,I)=(E*FBI(I)/(FBL(I)*FBL(I)))*(12.0*ROTYC(L,I))
```

```
106 CONTINUE
    DO 109 I=1,NY
    DO 110 J=1,NS
    ROTYC(I,J)=0.0
    ROTYW(I,J)=0.0
    DO 111 L=1,NS
    PROD1=KYROTC(I,J,L)*SY(I,L)
    ROTYC(I,J)=ROTYC(I,J)+PROD1
    PROD2=KYROTW(I,J,L)*SY(I,L)
    ROTYW(I,J)=ROTYW(I,J)+PROD2
111 CONTINUE
110 CONTINUE
109 CONTINUE
    IF(INSYM.EQ.1)GO TO 112
    CALL WRITE3
112 CONTINUE
    CALL CALPAK
113 CONTINUE
    RETURN
    END

    SUBROUTINE   WRITE3
    COMMON KJ(20,20),KP(20,20),KS(20,20),KX(4,20,20),KY(3,20,20),KV(20
   1,20),K(20,20),NS,NX,NY,ICX,ICY,XO(20),YO(20),KXROTW(4,20,20),KYROT
   2C(3,20,20),KYROTW(3,20,20),H(20),CI(20),WI(20),WBL(20),W(20),FBL(2
   30),WBI(20),E,EW,EGC,EGW,FX(20),FY(20),XX(4),YY(3),CX(20),CY(20),RX
   4(4,20),DX(4,20,20),KDX(4,20,20),TTX(20,20),ROT(20),VX(4,20),TVX(20
   5),RY(3,20),DY(3,20,20),KDY(3,20,20),TTY(20,20),VY(3,20),TVY(20),MT
   6(20),TVXA(20),TVYA(20),XH(20),YH(20),FBI(20),KXROTC(4,20,20),INDIC
   7X(4),INDICY(3),HX(4,20),CIX(4,20),WIX(4,20),WBLX(4,20),WX(4,20),FB
   8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
   9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
    COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
   1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
   2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
   3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
   4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
   5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
   6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
   7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
   8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
   94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
    COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
    REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
    REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
    WRITE(6,252)(TVXA(I),I=1,NS)
252 FORMAT(1H1,(4X,'RESULTANT SHEAR IN X-DIRECTION =',E13.6/))
    DO 260 I=1,NX
    WRITE(6,261)(VX(I,J),J=1,NS)
261 FORMAT(/1H0,(4X,'INDIVIDUAL FRAME X SHEAR =',3E13.6/))
260 CONTINUE
    WRITE(6,253)(TVYA(I),I=1,NS)
253 FORMAT(1H1,(4X,'RESULTANT SHEAR IN Y-DIRECTION =',E13.6/))
    DO 262 I=1,NY
    WRITE(6,263)(VY(I,J),J=1,NS)
263 FORMAT(/1H0,(4X,'INDIVIDUAL FRAME Y SHEAR =',3E13.6/))
262 CONTINUE
    WRITE(6,254)(XO(I),I=1,NS)
254 FORMAT(1H1,(4X,'CENTRE OF ROTATION IN X-DIRECTION =',F11.2/))
    WRITE(6,255)(YO(I),I=1,NS)
255 FORMAT(1H1,(4X,'CENTRE OF ROTATION IN Y-DIRECTION =',F11.2/))
    WRITE(6,256)(ROT(I),I=1,NS)
256 FORMAT(1H1,(4X,'ROTATION IN RADIANS =',E13.6/))
    WRITE(6,257)ICX
257 FORMAT(1H1,4X,'NUMBER OF ITERATION CYCLES X =',I3)
    WRITE(6,258)ICY
```

```
      8LX(4,20),WBIX(4,20),FBIX(4,20),HY(3,20),CIY(3,20),WIY(3,20),WBLY(3
      9,20),WY(3,20),FBLY(3,20),WBIY(3,20),FBIY(3,20)
       COMMON KA(20,20),KB(20,20),KD(20,20),KE(20,20),KC(20,20),KF(20,20)
      1,KG(20,20),KH(20,20),KI(20,20),KK(20,20),KL(20,20),KM(20,20),KN(20
      2,20),KO(20,20),KQ(20,20),KR(20,20),KT(20,20),KW(20,20),TX(4,20,20)
      3,TY(3,20,20),RT(20,20),SX(4,20),SY(3,20),ROTXC(4,20),ROTXW(4,20),
      4ROTYC(3,20),ROTYW(3,20),TTVXC(20,20),TVXC(20,20),TTVYC(20,20),TVYC
      5(20,20),CMXB(4,20),CMXT(4,20),WMXB(4,20),WMXT(4,20),FBMX(4,20),WBM
      6XC(4,20),WBMXW(4,20),CMYB(3,20),CMYT(3,20),WMYB(3,20),WMYT(3,20),F
      7BMY(3,20),WBMYC(3,20),WBMYW(3,20),CSX(4,20),WSX(4,20),FBSX(4,20),W
      8BSX(4,20),CSY(3,20),WSY(3,20),FBSY(3,20),WBSY(3,20),CFX(4,20),WFX(
      94,20),FBFX(4,20),WBFX(4,20),CFY(3,20),WFY(3,20),FBFY(3,20)
       COMMON WBFY(3,20),DEX(4,20),DEY(3,20),INSYM,ITERX,ITERY,IX,IY
       REAL KJ,KP,KS,KX,KY,KV,K,KXROTC,KXROTW,KYROTC,KYROTW,KDX,KDY,MT
       REAL KA,KB,KD,KE,KC,KF,KG,KH,KI,KK,KL,KM,KN,KO,KQ,KR,KT,KW
       DO 100 I=1,NX
       WRITE(6,101)I
  101 FORMAT(1H1,2X,'FRAME X NUMBER',T23,I2)
       WRITE(6,102)
  102 FORMAT(1H0//,4X,'COLUMN DATA')
       WRITE(6,103)
  103 FORMAT(1H0/,T10,'STORY NUMBER',T26,'JOINT ROTATION(RAD)',T49,
      1'BOTTOM MOMENT(KIN)',T72,'TOP MOMENT(KIN)',T93,'SHEAR(KIP)',T111,
      2'AXIAL LOAD(KIP)')
       DO 104 J=1,NS
       WRITE(6,105)(J,ROTXC(I,J),CMXB(I,J),CMXT(I,J),CSX(I,J),CFX(I,J))
  105 FORMAT(1H0,T14,I2,T28,E13.6,T51,E13.6,T73,E13.6,T92,E13.6,T112,
      1E13.6)
  104 CONTINUE
       WRITE(6,106)
  106 FORMAT(1H0//,4X,'WALL DATA')
       WRITE(6,103)
       DO 107 J=1,NS
       WRITE(6,105)(J,ROTXW(I,J),WMXB(I,J),WMXT(I,J),WSX(I,J),WFX(I,J))
  107 CONTINUE
       WRITE(6,108)
  108 FORMAT(1H0//,4X,'BEAM DATA')
       WRITE(6,109)
  109 FORMAT(1H0/,T10,'FLOOR NUMBER',T26,'FRAME-BEAM',T43,'WALL-BEAM MOM
      1ENT(KIN)',T79,'SHEAR(KIP)',T106,'AXIAL LOAD(KIP)')
       WRITE(6,110)
  110 FORMAT(T26,'MOMENT(KIN)',T40,'COLUMN-END',T55,'WALL-END',T72,'FRAM
      1E-BEAM',T87,'WALL-BEAM',T100,'FRAME-BEAM',T115,'WALL-BEAM')
       DO 111 J=1,NS
       WRITE(6,112)(J,FBMX(I,J),WBMXC(I,J),WBMXW(I,J),FBSX(I,J),WBSX(I,J)
      1,FBFX(I,J),WBFX(I,J))
  112 FORMAT(1H0,T14,I2,T24,E13.6,T38,E13.6,T53,E13.6,T69,E13.6,T84,E13.
      16,T100,E13.6,T115,E13.6)
  111 CONTINUE
       WRITE(6,113)
  113 FORMAT(1H0//,4X,'FLOOR NUMBER',T25,'DEFLECTION(IN)')
       DO 114 J=1,NS
       WRITE(6,115)(J,DEX(I,J))
  115 FORMAT(1H0,T8,I2,T25,E13.6)
  114 CONTINUE
  100 CONTINUE
       DO 116 I=1,NY
       WRITE(6,117)I
  117 FORMAT(1H1,2X,'FRAME Y NUMBER',T23,I2)
       WRITE(6,102)
       WRITE(6,103)
       DO 118 J=1,NS
       WRITE(6,105)(J,ROTYC(I,J),CMYB(I,J),CMYT(I,J),CSY(I,J),CFY(I,J))
  118 CONTINUE
       WRITE(6,106)
       WRITE(6,103)
```

```
      DO 119 J=1,NS
      WRITE(6,105)(J,ROTYW(I,J),WMYB(I,J),WMYT(I,J),WSY(I,J),WFY(I,J))
  119 CONTINUE
      WRITE(6,108)
      WRITE(6,109)
      WRITE(6,110)
      DO 120 J=1,NS
      WRITE(6,112)(J,FBMY(I,J),WBMYC(I,J),WBMYW(I,J),FBSY(I,J),WBSY(I,J)
     1,FBFY(I,J),WBFY(I,J))
  120 CONTINUE
      WRITE(6,113)
      DO 121 J=1,NS
      WRITE(6,115)(J,DEY(I,J))
  121 CONTINUE
  116 CONTINUE
      RETURN
      END
```

BIBLIOGRAPHY

1. Guhamajumdar, S.N., Nikhed, R.P., MacGregor, J.G. and Adams, P.F., "Approximate Analysis of Frame-Shear Wall Structures," Structural Engineering Report No. 14, University of Alberta, Edmonton, Alberta, Canada, May 1968.

2. Clough, R.W., King, J.P. and Wilson, E.L., "Structural Analysis of Multi-Story Buildings," Proceedings ASCE, V.90, ST3, June 1964.

3. Wilbur, J.B., "Distribution of Wind Loads to the Bents of a Building," Proceedings Boston Society of Civil Engineers, V.22, 1935.

4. Benjamin, J.R., "Statically Indeterminate Structures," McGraw-Hill Book Co. Inc., New York, 1959.

5. Weaver, W. and Nelson, M.F., "Three-Dimensional Analysis of Tier Buildings," Proceedings ASCE, V.92, ST6, December 1966.

6. Winokur, A. and Glück, J., "Lateral Loads in Asymmetric Multistory Structures," Proceedings ASCE, V.94, ST3, March 1968.

7. "Caracas Earthquake Damage Reported by Portland Cement Association Team," Proceedings ACI, V.65, April 1968.

8. Berg, G.V. and Stratta, J.L., "Anchorage and the Alaska Earthquake of March 12, 1964," American Iron and Steel Institute, New York, 1964.

9. Clough, R.W., Binder, R.W., Higgins, T.R. and Kirkland, W.G., "The Agadir Morocco Earthquake," American Iron and Steel Institute, New York, 1960.

10. "National Building Code of Canada 1965," Part 4 - Design, Section 4.1, National Research Council, Ottawa, Canada, 1965.

11. "Recommended Lateral Force Requirements," Seismology Committee, Structural Engineers Association of California, San Francisco 5, California, July 1959.

12. Blume, J.A., Newmark, N.M. and Corning, L.H., "Design of Multistory Reinforced Concrete Buildings for Earthquake Motions," Portland Cement Association, Chicago, Illinois, 1961, V.1, June 1967.

13. Seto, Yu, "Analysis of Single-Storey Shear-Wall Structures," The Journal of the Concrete Society, London, June 1967.

14. Khan, F.R. and Sbarounis, J.A., "Interaction of Shear Wall with Frames in Concrete Structures under Lateral Loads," Proceedings ASCE, V.90, June 1964.

15. "ICES STRUDL-1," The Structural Design Language, Civil Engineering Systems Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts, January 1968.

16. "Handbook of Steel Construction," Canadian Institute of Steel Construction, Toronto 7, Ontario, October 1967.

ACKNOWLEDGEMENTS

This study forms part of a general investigation "Behavior of Multi-Story Structures", currently in progress at the Department of Civil Engineering, University of Alberta. The project is directed by Drs. J.G. MacGregor and P.F. Adams and receives financial support from the National Research Council of Canada and the Defence Research Board. A scholarship, awarded to J.H. Wynhoven by the Alberta Regional Committee, Canadian Institute of Steel Construction, is gratefully acknowledged.

The authors wish to acknowledge most gratefully the fruitful discussions held with Messrs. W.J. Clark, S.N. Guhamajumdar and R.P. Nikhed. The matrix inversion subroutine was written by Mr. Masaaki Suko; his assistance is appreciated. The co-operation of Mr. W.R. Hibbard, who analyzed several of the structures by STRUDL, is recognized.

The manuscript was typed by Miss Lynne Fiveland whose co-operation is appreciated.