SUPER-ETABS

An Enhanced Version of
the ETABS Program

A Report to the
National Science Foundation

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16. Abstract (Limit: 200 words)
A modified version of the ETABS (2) computer program, which can be used for the linear structural analysis of buildings subjected to static loads and dynamic earthquake loads, is documented. Efficient model formulation and problem solution is achieved by idealizing the building as a system of frame and shear wall substructures interconnected by floor diaphragms which are rigid in their own plane. The extended capabilities of the enhanced program include: the analysis for the gross building response quantities including story deflections, drifts, shears, torques, and overturning moments; the ability to account for second-order contributions to the overturning and torsional moments in static and dynamic analysis; a procedure for approximate static and dynamic analysis without the detailed structural member definition; the use of improved modal combination techniques in response spectrum analysis; automatic generation of UBC and ATC equivalent static lateral seismic forces; calculation of individual member stress ratios (code type stress checks); effective mass calculation for model verification; and a data check feature which can be used to verify input prior to full execution.

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ABSTRACT

Contained in this report is the documentation for a modified version of the ETABS(2) computer program. The program can be used for the linear structural analysis of buildings subjected to static loads, and dynamic earthquake loads. Efficient model formulation and problem solution is achieved by idealizing the building as a system of frame and shear wall substructures interconnected by floor diaphragms which are rigid in their own plane. The extended capabilities of the enhanced program include: the analysis for the gross building response quantities including story deflections, drifts, shears, torques, and overturning moments; the ability to account for the P-Δ effects in static and dynamic analysis; a procedure for approximate static and dynamic analysis without the detailed structural member definition; the use of improved modal combination techniques in response spectrum analysis; automatic generation of UBC and ATC equivalent static lateral seismic forces; calculation of individual member stress ratios (code type stress checks); effective mass calculation for model verification; and, a data check feature which can be used to verify input prior to full execution.

ACKNOWLEDGEMENT

The computer program documented herein represents part of a National Science Foundation project involving the study of computer modeling formulations and special analytical procedures for the earthquake response prediction of multistory buildings. This program was used to analyze many of the buildings examined in the above mentioned project(1). The authors gratefully acknowledge the financial support provided under NSF Grant PFR-7926734. Professor Jack G. Bouwkamp was the principal investigator for this project.

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PART A: DESCRIPTION OF COMPUTER PROGRAM ENHANCEMENTS

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The SUPER-ETABS computer program is a modified version of the ETABS program (Fig. A1). Contained in the following sections are descriptions of the program enhancements. Additional theoretical discussions of many of the features as well as the results from example high-rise building analyses utilizing the enhancements can be found in reference 1. The basic building discretization procedures and problem solution techniques remain unchanged from the original ETABS formulation. A discussion of these can be found in reference 2.

1. GROSS BUILDING RESPONSE CALCULATION

SUPER-ETABS has the ability to perform static and/or dynamic analysis for the solution of the gross building response quantities. The gross response quantities are: (1) story deflections, (2) story drifts, (3) cumulative story shears, and (4) cumulative story overturning moments. The location of these displacement and force quantities are at the floor center of mass. Note that this location can vary from story to story. At each floor level, the floor motions can be idealized as having three mass degrees of freedom (two lateral translational and one torsional about the vertical axis). However, in the following discussion a planar (each floor possessing a single translational degree of freedom) structure is used to simplify the formulae. For the three dimensional case, the equations presented in the following paragraphs can be applied to each component direction. For the torsional degree of freedom, the story deflections, drifts, and shears become story rotations, interstory rotations, and story torques, respectively. Story overturning moments have no meaning with respect to the torsional degree of freedom.

In static analysis, at any floor level, the following response quantities are defined:

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Story Deflection

r_i = Lateral story deflection at level i resulting from the application of static loads. The floor levels are numbered starting from the bottom of the building (Fig. A2(a),(c)).

Story Drift

$$d_i = \frac{(r_i - r_{i-1})}{h_i}$$

where,

d_i = Story drift between levels i and i-1 (Fig. A2(d)).

h_i = Story height between level i and i-1.

Note that the translational story drift is defined as the difference between adjacent story level deflections divided by the story height. For the torsional degree of freedom, the interstory rotations are not divided by the story height.

Cumulative Story Shear

$$V_i = \sum_{j=i}^{n} P_j$$

where,

V_i = Cumulative story shear acting between levels i and i-1 (Fig. A2(e)).

$P_j = R_j + F_j$

in which,

P_j = Lateral force at level j (Fig. A2(b)).

R_j = Externally applied lateral force at level j.

F_j = Equivalent lateral force due to the P-Δ effect at level j.

n = Number of story levels.

Cumulative Story Overturning Moment

$$M_i = \sum_{j=i}^{n} V_j h_j$$

where,

M_i = Overturning moment located at the base of story i (level i-1). See Fig. A2(f).

For dynamic analysis, consider a single vibration mode shape and frequency as determined from solution of the eigen problem using the building's global lateral stiffness and mass matrices. At any given floor level, the following modal response quantities are defined:

Modal Story Deflection

$$r_i^k = \phi_i^k Y^k$$

where,

r_i^k = Modal deflection (in mode k) at level i, in which the floor levels are numbered starting from the bottom of the building (Fig. A-3(a),(b)).

ϕ_i^k = Modal deflection component (in mode k) at level i.

Y^k = Modal amplitude of mode k.

Modal Story Drift

$$d_i^k = \frac{(r_i^k - r_{i-1}^k)}{h_i}$$

where,

d_i^k = Modal drift (in mode k) between levels i and i-1 (Fig. A3(c)).

h_i = Story height between levels i and i-1.

Note that the translational drift is defined as the difference between adjacent story deflections divided by the story height. For the torsional degree of freedom, the interstory rotations are not divided by the story height.

Cumulative Modal Story Shear

$$V_i^k = \sum_{j=i}^{n} P_j^k$$

where,

V_i^k = Cumulative modal shear (in mode k) at level i (Fig. A3(d)).

P_j^k = Lateral force (in mode k) at level i (Fig. A3(e)).

$$P_j^k = m_j \phi_j^k \omega_k^2 Y^k + F_j^k$$

in which,

m_j = Mass at level j

ω_k = Frequency of mode k.

F_j^k = Equivalent lateral force due to the P-Δ effect (in mode k) at level j.

Cumulative Modal Overturning Moment

$$M_i^k = \sum_{j=i}^{n} V_j^k h_j$$

where,

M_i^k =Modal overturning moment (in mode k) located at the base of story i (level i-1). (See Fig. A3(f)).

For time history analysis, the modal amplitude Y is evaluated at each time step and the superposition of the individual modal responses constitutes the total response. For response spectrum analysis, the modal amplitude takes the value of the maximum response by use of the response spectrum. Because the relative time phasing of the individual modal maximum responses are unknown, modal combination procedures are used to estimate the peak responses in spectrum analysis.

In both time history and response spectrum analysis, the gross response quantities can be calculated in the global (X,Y) coordinate system and/or in a local (R,S) coordinate system. The (X,Y) system is the global structural system in which the building's geometry is defined (see Part B, FRAME LOCATION CARDS). The (R,S) system is a system in which the R axis is parallel to the earthquake direction and S is orthogonal to it (Fig. A4). The transformation is performed on the modal story deflections and story forces prior to calculation of the gross response quantities. The transformation for story forces (story deflection calculation is analogous) is as follows:

$$(P_i^k)_r = (P_i^k)_x \sin\theta + (P_i^k)_y \cos\theta$$

$$(P_i^k)_s = -(P_i^k)_x \cos\theta + (P_i^k)_y \sin\theta$$

where,

$(P_i^k)_r$ = Lateral force (in mode k) in the R direction at level i.

$(P_i^k)_s$ = Lateral force (in mode k) in the S direction at level i.

$(P_i^k)_x$ = Lateral force (in mode k) in the global X directionat level i.

$(P_i^k)_y$ = Lateral force (in mode k) in the global Y direction at level i.

θ = Direction of earthquake input with respect to the global Y axis (Fig. A4).

2. P-Δ FORMULATION

When a building is subjected to vertical and lateral loads, internal resisting forces and moments at each story are induced. The vertical force and horizontal shear force acting at a given story are equivalent to the summations of the respective vertical and lateral loads applied above that story. The overturning and torsional moments acting at a given story have two contributing components: (1) primary moments resulting from the applied lateral and vertical loads acting over their respective lever arms measured from the points of application in the undeformed building configuration; and, (2) second-order moments caused by the vertical loads acting over their respective incremental lever arms resulting from the lateral deflection of the building. This latter second-order contribution to the overturning and torsional moments is commonly referred to as the P-Δ effect.

SUPER-ETABS has the capability to include the P-Δ effect in static and dynamic analysis. The formulation involves the introduction of a geometric stiffness matrix which modifies the global lateral structural stiffness matrix. In the following presentation, a planar (each floor level possessing a single translational degree of freedom) structure is considered initially to simplify the representative equations. The extension of the concepts to the three dimensional case is straightforward and is discussed subsequently.

The second order overturning moments vary linearly with the lateral deflections and may be represented by an equivalent set of lateral force couples (Fig. A5). The relation may be written as:

$$\underline{F} = \underline{K}_G \, \underline{r} \qquad (2.1)$$

where,

$\underline{F}$ = Equivalent lateral force vector resulting from the P-Δ effect.

$\underline{r}$ = Lateral displacement vector.

$\underline{K}_G$ = Geometric stiffness matrix, defined as:

$$\underset{(n\times n)}{\underline{K}_G} = \left[\begin{array}{cccccc} P^*_n/h_n & -P^*_n/h_n & 0 & & & \\ -P^*_n/h_n & P^*_n/h_n + P^*_{n-1}/h_{n-1} & -P^*_{n-1}/h_{n-1} & & & \\ 0 & -P^*_{n-1}/h_{n-1} & P^*_{n-1}/h_{n-1} + P^*_{n-2}/h_{n-2} & & & \\ & & & \ddots & & \\ & & & & P^*_3/h_3 + P^*_2/h_2 & -P^*_2/h_2 \\ & & & & -P^*_2/h_2 & P^*_2/h_2 + P^*_1/h_1 \end{array}\right] \begin{array}{c} \text{Story} \\ n \\ n-1 \\ n-2 \\ \vdots \\ 2 \\ 1 \end{array} \qquad (2.2)$$

in which,

h_i = Story height between levels i and i-1.

$$P = g \sum_{j=i}^{n} m_i$$

g = Acceleration of gravity.

m_i = Mass at level i.

n = Number of story levels.

For static analysis, the equations of equilibrium have the form:

$$\underline{K}\underline{r} = \underline{R} + \underline{F} \qquad (2.3)$$

where,

$\underline{K}$ = Global lateral stiffness matrix.

$\underline{R}$ = Applied lateral forces

Substitution of equation 2.1 into equation 2.3 and rearrangement yields:

$$[\underline{K} - \underline{K}_G] = \underline{R} \qquad (2.4)$$

In the solution of Equation 2.4 the lateral stiffness is decreased with the inclusion of $\underline{K}_G$ and the resulting lateral displacements are increased. These increased displacements are used in the backsubstitution solution phase and will lead to increased local element deformations and corresponding member forces. For the gross building response, the cumulative story shear and overturning moment calculations include the equivalent lateral forces $\underline{F}$.

For dynamic analysis, the equation of dynamic equilibrium has the form:

$$\underline{M}\ddot{\underline{r}}(t) + \underline{C}\dot{\underline{r}}(t) + \underline{K}\underline{r}(t) = \underline{F}(t) - \underline{M}\underline{1}\ddot{\underline{r}}_g(t) \qquad (2.5)$$

where,

$\underline{M}, \underline{C}, \underline{K}$ = Mass, damping, lateral stiffness matrices, respectively.

$\ddot{\underline{r}}(t), \dot{\underline{r}}(t), \underline{r}(t)$ = Lateral acceleration, velocity, displacement vectors, respectively. These quantities are measured relative to the building's base.

$\underline{F}(t)$ = Equivalent lateral force vector resulting from the P-Δ effect.

$\underline{1}$ = Column vector of ones.

$\ddot{r}_g(t)$ = ground acceleration.

If the geometric stiffness matrix is assumed to be constant during the dynamic loading, then the substitution of equation 2.1 into equation 2.5 yields:

$$\underline{M}\ddot{\underline{r}}(t) + \underline{C}\dot{\underline{r}}(t) + [\underline{K} - \underline{K}_G]\underline{r}(t) = -\underline{M}\underline{1}\ddot{r}_g(t) \qquad (2.6)$$

This equation can be transformed to normal coordinates in the same manner as if the P-Δ effect were not included. Since modifying $\underline{K}$ by $\underline{K}_G$ effectively reduces the lateral stiffness, the resulting frequencies will be smaller and the mode shapes will be slightly different than if the P-Δ effects are ignored. The modal displacement response is determined by multiplying the mode shape by the modal amplitude as calculated from the uncoupled equations in the normal coordinates. These displacements are used in the backsubstitution phase to solve for local deformations and corresponding member forces. For the gross building response the cumulative story shear and overturning moment calculation include the equivalent lateral P-Δ forces $\underline{F}(t)$.

It should be noted that the equivalent lateral forces are ficticious forces which are introduced to account for the second-order overturning moments. Although not a true lateral load, the equivalent lateral forces result in increased story shear forces acting normal to the deflected configuration of the building caused by the story vertical load. These increased story shears are generally considered appropriate for design (3).

For a multistory building, the torsional geometric stiffness matrix containing rotational degrees of freedom only is of the same form as the translational geometric stiffness matrix as shown in Equation 2.2 with T_i^* being substituted for P_i^*:

$$T_i^* = \sum_{j=i}^{n} (P_j D_j^2) \tag{2.7}$$

where,

P_j = Vertical force at level j.

D_j = The radius of gyration of column axial forces about the floor center of rotation.

If the structural system of a building provides roughly uniform vertical support over the plan area of the floor (e.g., regularly spaced columns over the floor area), and dead loads are evenly distributed over the floor area, then equation 2.7 can be approximated by:

$$T_i^* = \left[\sum_{j=i}^{n} m_{R_j} \right] g \tag{2.8}$$

where,

m_{R_j} = Floor mass moment of inertia at level j.

g = Acceleration of gravity.

The program calculates T_j^* according to equation 2.8 based upon the floor mass moment of inertia input (see Part B, STORY DATA).

In three-dimensional analysis where each floor is assigned three mass degrees of freedom (two lateral translational and one rotational about the vertical axis), the equivalent P-Δ lateral and torsional forces are uncoupled. That is, the equivalent force or torque is dependent only upon the corresponding translational, or rotational displacement degree of freedom, respectively. Therefore, a full three-dimensional geometric matrix (dimension 3n x 3n) is constructed by the appropriate insertion of terms from the global x and y translational $\underline{K}_G$ matrices and from the torsional $\underline{K}_G$ matrix (all of dimension n x n). In this form, the geometric stiffness matrix can now be used for static and dynamic analysis (as previously described) to evaluate three dimensional P-Δ influences including torsional effects.

3. APPROXIMATE ANALYSIS FORMULATION

SUPER-ETABS has the ability to perform approximate static or dynamic analysis based on estimates of the natural periods and corresponding approximate mode shapes. The approximate dynamic properties in conjunction with data such as floor masses and story heights, are used for the calculation of the gross building response quantities. The user has the option of inputing mode shape estimates or having the program automatically generate the mode shapes.

Two types of mode shape generation are available. The first type is based on an empirical rule developed from the actual experimentally determined mode shapes from four high-rise buildings of steel construction (1). In this rule, for a given mode number `m', the total height of the building is divided into m different regions represented by the vertical heights $h_1, h_2, \ldots, h_m$ as shown in Figure A6. These regions define the location of the m node points of the mode. Region h_m, the uppermost region, is bounded by the highest (m^{th}) node point at its lower end and by the top of the building at its upper end. All other regions are bounded by two adjacent node points. The height of each region is determined as follows.

$$h_i = (a_i/a_T) \cdot H$$

where,

h_i = The height of each region i.

a_1 = 1.0

$a_i = 1.0 + [(\pi-1)\cdot(\sum_{n=1}^{i-1} \frac{1}{n})]$ for $i \geq 2$

$a_T = \sum_{k=1}^{m} a_k$

H = The total building height.

Having identified the node point locations and corresponding regions over the height of the building as described above, separate functions are used to represent the mode shape variation within each region as follows. For the highest region,

$$\phi_1(x_1) = x_1/h_1$$

For the intermediate regions $(1<i<m)$,

$$\phi_i(x_i) = (-1)^{i-1} \cdot \sin \frac{\pi x_i}{h_i}$$

For the lowest region,

$$\phi_m(x_m) = (-1)^{m-1} \cdot \sin\pi \left(\frac{x_m}{h_m}\right)^{1.357}$$

where,

ϕ_i = The mode shape function defined over region i.

x_i = The vertical distance above the lower bounding node of region i.

The second rule generates mode shapes corresponding to those from a vertical shear beam fixed at its base with uniform mass and stiffness properties. The rule is as follows.

$$\phi_m(x) = \sin\left[\frac{(2m-1)\pi}{2} \; \frac{x}{H}\right]$$

ϕ = Mode shape function over the building height.

m = Mode number.

x = Height above base.

H = Total building height.

Shown in Figure A7 are the first four mode shapes as generated by each of the two rules as well as the actual mode shapes of existing buildings as determined by experimental tests (1).

The natural period corresponding to each mode shape (generated or input) must be input. For buildings with vertically regular framing systems over their full building heights, the ratios of the higher modal periods to the fundamental period are similar to those of a uniform shear beam. The period ratios for a uniform shear beam and the average period ratios of the experimentally tested buildings (1) are:

	T_1/T_i	
Mode Number, i	Shear Beam	Actual Buildings
2	3.0	2.89
3	5.0	5.12
4	7.0	7.20

These ratios can be used as a guide to estimate the higher modal periods based on the fundamental period value.

For approximate static analysis, the deflections resulting from applied static lateral loads are calculated as follows:

$$\underline{r} = \underline{\Phi}\,\underline{\Lambda}^{-1}\,\underline{\Phi}^{T}\,\underline{R}$$

$\underline{r}$ = The resulting lateral displacement vector (n x 1).

$\underline{\Phi}$ = Matrix of mode shapes (n x N) .

$\underline{\Lambda}$ = A diagonal matrix (N x N), with $\lambda_{ii} = (2\pi/T_i)^2$

$\underline{R}$ = The applied static lateral load vector (n x 1).

n = Total number of lateral translational and torsional degrees of freedom.

N = Number of frequencies ($N \leq n$).

The other static gross response quantities are calculated using the equations presented in Section 1. For approximate dynamic analysis, the dynamic gross response quantities are calculated using the approximate mode shapes and periods as shown in the equations presented in section 1. Note that when performing approximate static or dynamic analysis, the P-Δ formulation presented in Section 2 cannot be used.

4. IMPROVED MODAL COMBINATION RULES

In addition to the square-root-sum-of-the-squares (SRSS) and absolute sum modal combination methods, the double sum (DSC) and the complete quadratic combination (CQC) techniques are available for use in response spectrum analysis to estimate peak element responses and gross building response quantities. The SRSS rule usually provides good peak response estimates as compared to the corresponding peak time history values when the structure has well separated natural periods. However, for systems with coupled modes having closely spaced periods, the SRSS method can lead to significant errors in response prediction. For these situations, the DSC(4) or the CQC(5) methods should be used.

For both the DSC and CQC methods, the form of the combination rule is:

$$R^{max} = \sqrt{\sum_{i=1}^{N} \sum_{j=1}^{N} R^i \, P^{ij} \, R^j}$$

where,

R^{max} = Estimated maximum response for quantity R.

R^i = Maximum response of quantity R in mode i.

N = Number of modes considered.

For the DSC method the matrix P^{ij} takes the form:

$$P^{ij} = \left[1 + \left(\frac{(\omega'_i - \omega'_j)}{(\beta'_i \; \omega_i + \beta'_j \; \omega_j)} \right)^2 \right]^{-1}$$

in which, $\omega'_i = \omega_i \sqrt{1 - (\beta'_i)^2}$

$$\beta'_i = \beta_i + \frac{2}{S \; \omega_i}$$

ω_i = Natural frequency of the ith mode

β_i = Critical damping ratio for the ith mode

S = Time duration of "white noise" segment of earthquake excitation. For actual earthquake records this may be respresented by the strong motion segment characterized by extremely irregular accelerations of roughly equal intensity.

For the CQC method, the matrix P^{ij} takes the form:

$$P^{ij} = \frac{8 \sqrt{\beta_i \; \beta_j \; \omega_i \; \omega_j} (\beta_i \; \omega_i + \beta_j \; \omega_j) \quad \omega_i \; \omega_j}{(\omega_i^2 - \omega_j^2)^2 + 4 \; \beta_i \; \beta_j \; \omega_i \; \omega_j \; (\omega_i^2 + \omega_j^2) + 4 \; (\beta_i^2 + \beta_j^2) \; \omega_i^2 \; \omega_j^2}$$

The computer program formulation requires the input of the earthquake duration parameter S (for DSC) and the critical damping ratio which is assumed to be constant for all modes (in both DSC and CQC).

The peak response quantity estimations using the DSC or the CQC methods require more numerical calculations than those computed using the

SRSS rule. For the solution of large numbers of response quantities involving many modes, the DSC and CQC methods may require significantly greater computational effort than the SRSS method. However, when the structural periods are well separated, the DSC and CQC methods are equivalent to the SRSS rule. Therefore, it is recommended that the DSC or CQC methods be used only when necessary (i.e. for systems with coupled modes having closely spaced periods).

5. STATIC LATERAL FORCE GENERATION

SUPER-ETABS has a feature which allows automatic generation of static lateral forces according to the UBC(6) and ATC(7) recommended criteria. The generated lateral forces are entered into the static lateral load cases A and/or B (see Part B, STORY DATA).

For UBC force generation, the rule is as follows:

$$P_i = \frac{(V-P_t)m_i h_i}{\sum_{j=1}^{n} m_j h_j}$$

where,

P_i = Generated static lateral load at level i.

V = ZIKCSGM, where Z,I,K,C,S are defined in reference 6.

P_t = 0.07 TV

$P_t \leq 0.25$ V

P_t = 0.0; when $T < 0.70$ sec.

m_i = Story mass at level i.

h_i = Height above base to level i.

n = Total number of story levels.

G = Acceleration of gravity

M = Total translational mass

T = Fundamental elastic period.

For ATC force generation, the rule is as follows:

$$P_i = \frac{V\, m_i h_i^k}{\sum_{j=1}^{n} m_i h_i^k}$$

where,

P_i = Generated lateral force at level i.

$V = C_s\, GM$

$$k = \begin{cases} 1.0, \text{ when } T \leq 0.5 \\ 1.0 + 0.50\ (T-0.5), \text{ when } 0.5 < T < 2.5 \\ 2.0, \text{ when } T \geq 2.5 \end{cases}$$

m_i = Story mass at level i.

h_i = Height above base to level i.

n = Total number of story levels.

in which,

C_s = Numerical coefficient defined in reference 7.

G = Acceleration of gravity.

M = Total translational mass.

T = Fundamental elastic period.

6. MEMBER STRESS RATIO CALCULATION

SUPER-ETABS has the ability to perform code type stress ratio calculations for the column, beam, and diagonal brace elements. When this option is requested, the stress ratios are output in addition to the member forces.

For columns, stress ratios are calculated at each end of the element.

The form of the equation is as follows:

$$R = \left|\frac{P}{AF_a}\right| + \left|\frac{M_x}{S_x F_x}\right| + \left|\frac{M_y}{S_y F_y}\right|$$

where,

R = Stress ratio.

P, M_x, M_y = Axial force, major axis moment, minor axis moment, respectively.

A, S_x, S_y = Section area, major axis section modulus, minor axis section modulus, respectively.

F_a, F_x, F_y = Allowable axial stress, major axis bending stress, minor axis bending stress, respectively.

For beams, stress ratios are calculated at each end of the element. The form of the equation is as follows:

$$R = \left|\frac{M}{SF}\right|$$

where,

M = Bending moment.

S = Section modulus.

F = Allowable bending stress.

For bracing, a single stress ratio is calculated as follows:

$$R = \left|\frac{P}{AF}\right|$$

where,

P = Axial force.

A = Section area.

F = Allowable axial stress.

7. EFFECTIVE MASS CALCULATION

SUPER-ETABS calculates for each mode the fraction of the total mass participating in each of the global translational (X,Y) and rotational displacement directions. The formulation is as follows.

$$F_x^i = \frac{([\underline{\phi}^i]^T \, \underline{m} \, \underline{r}_x)^2}{M_T}$$

$$F_y^i = \frac{([\underline{\phi}^i]^T \, \underline{m} \, \underline{r}_y)^2}{M_T}$$

$$F_\theta^i = \frac{([\underline{\phi}^i]^T \, \underline{m} \, \underline{r}_\theta)^2}{M_R}$$

where,

F_x^i, F_y^i = The ratio of the total translational mass in mode i that is participating in the global X and Y directions, respectively.

F_θ^i = The fraction of the total rotational mass in mode i that is participating in the rotational (torsional) direction.

$\underline{m}$ = Diagonal mass matrix.

$\underline{\phi}^i$ = Vibrational mode shape for the ith mode. These are mass normalized such that;

$$[\underline{\phi}^i]^T \underline{m} \underline{\phi}^i = 1.0$$

$\underline{r}_x$ = Earthquake influence coefficient column vector for the global X direction which contains ones (1's) in the degrees of freedom that correspond to the global X direction, and has zeros (0's) for the rest.

$\underline{r}_y, \underline{r}_\theta$ = Earthquake influence coefficient column vectors for the global Y and torsional directions, respectively.

M_T = Total translational mass.

M_R = Total rotational mass moment of interias.

In dynamic analysis, the sum of the mass ratios (F^i) in each global component direction indicates the fraction of the total mass that is participating in the respective global component direction. As a general rule, the number of modes to be used in a dynamic analysis should be such that the sum of the modal mass fractions are greater than .90 in each global component direction (8).

8. DATA CHECK FEATURE

The program has a data check feature which allows processing of the input data but terminates without the matrix assembly and solution phases. This feature can be used to review the input for data errors without risking the costs required for complete execution. In addition, the program will output computer memory storage requirements for the execution of the various solution tasks requested. This information can be used to evaluate the amount of program memory storage (MTOT) required for a particular problem. When the data check feature is used, the program internally sets the memory storage to a large value (i.e. MTOT = 300000).

9. REFERENCES

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7. Applied Technology Council, Tentative Provisions for the Development of Seismic Regulation for Buildings, NSF Publication 78-8, NBS Special Publication 510, U.S. Dept. of Commerce, Washington, D.C., June, 1978.

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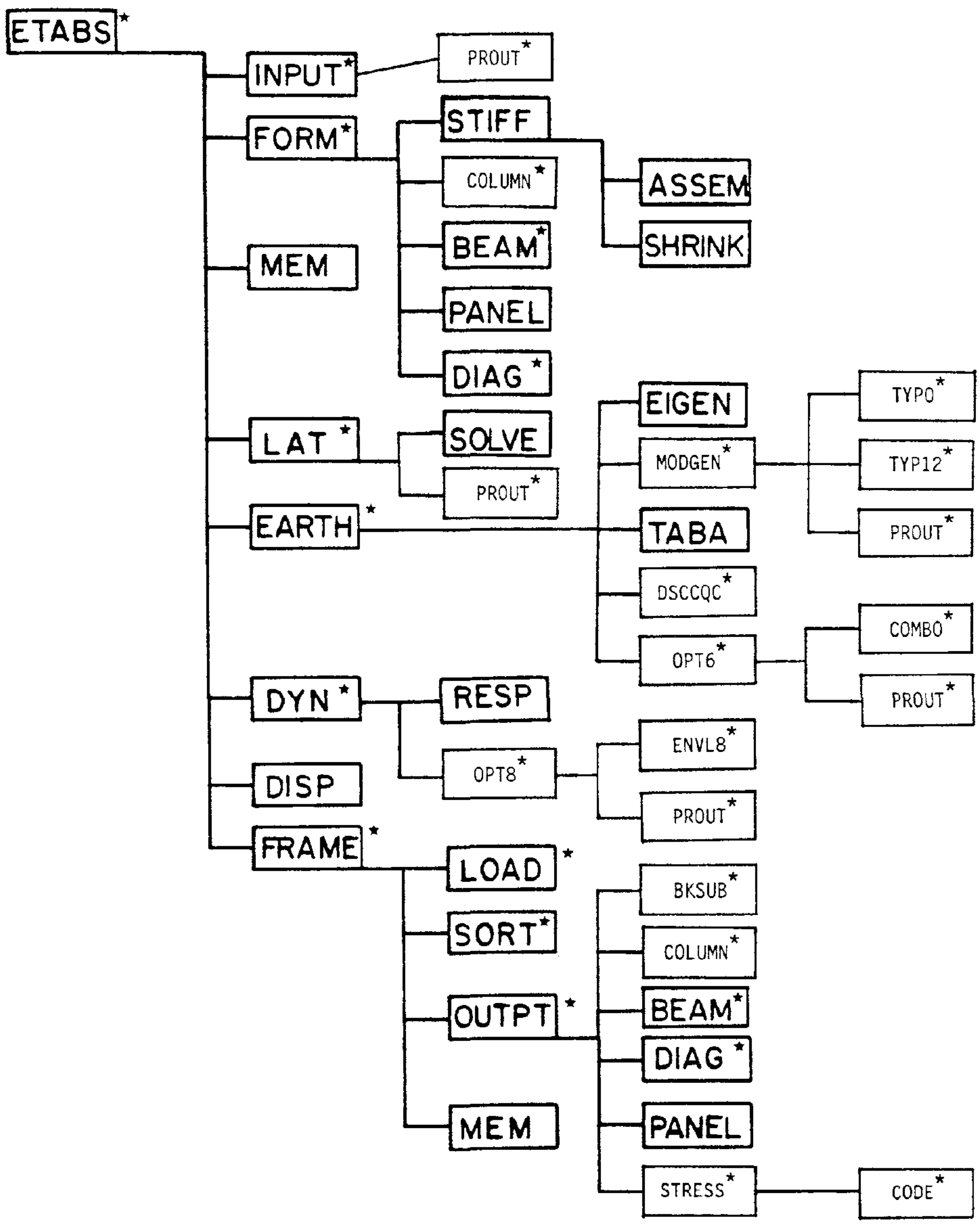
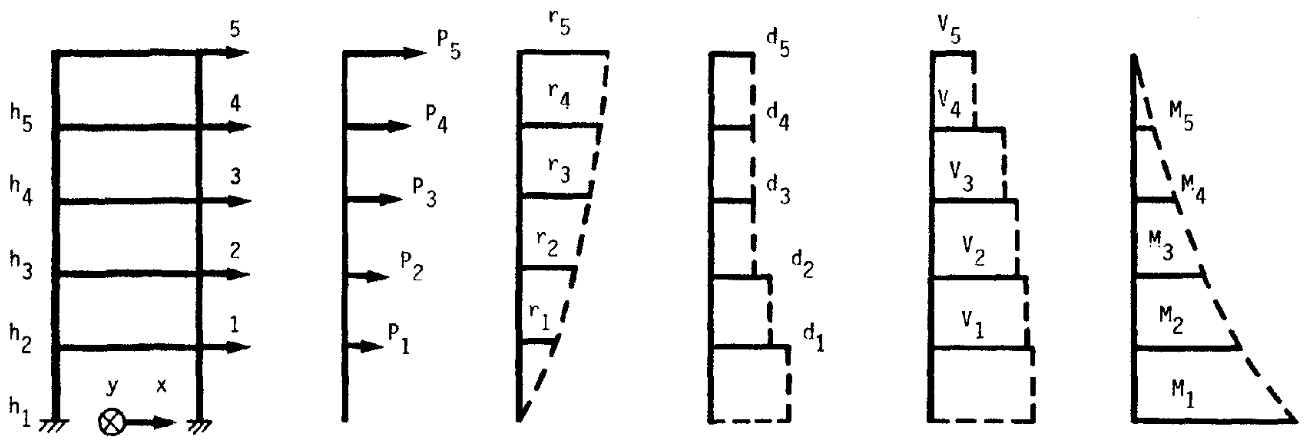
10. FIGURES



* New or modified routine for SUPER-ETABS.

Figure A1: Program Organization



(a) Building Configuration

(b) Applied Forces

(c) Deflections

(d) Drifts

(e) Shears

(f) Overturning Moments

Figure A2: Building Gross Response Quantities (Static Analysis)

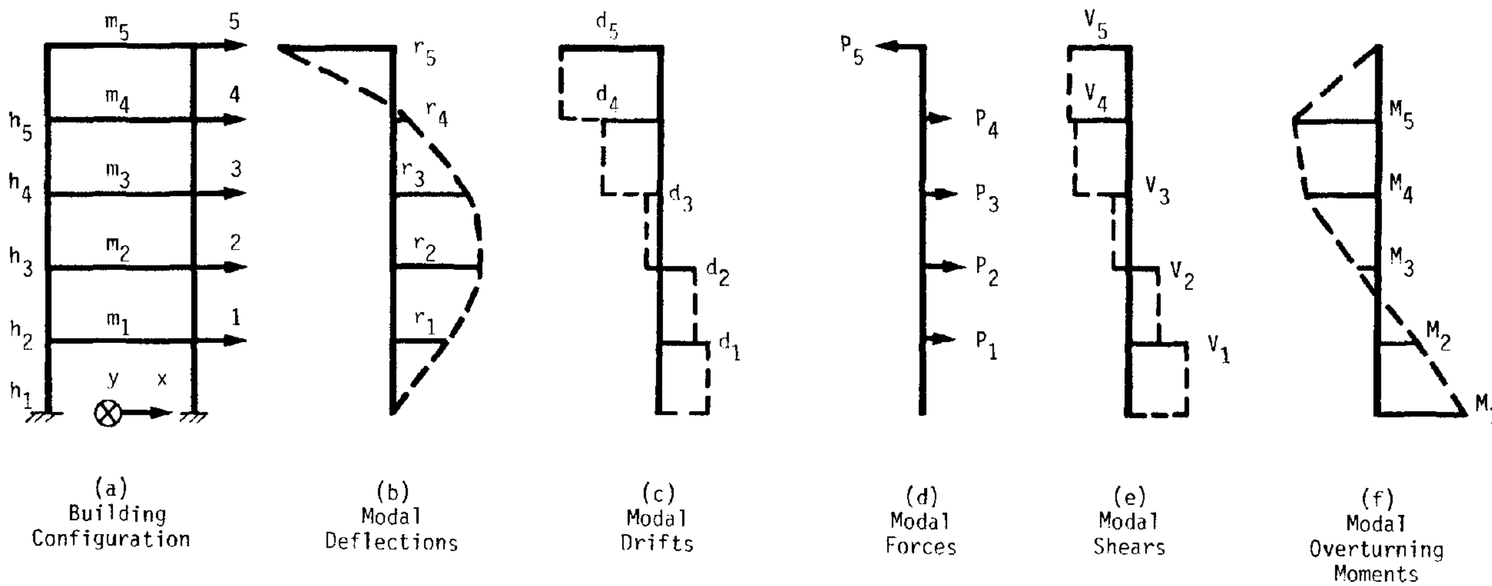


Figure A3: Modal Building Gross Response Quantities (Dynamic Analysis)

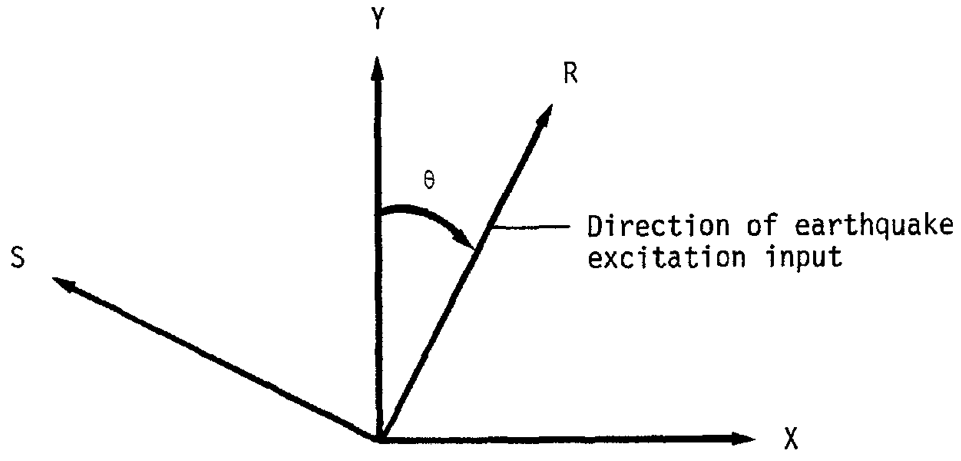


Figure A4: Orientation of (R,S) Coordinate System with respect to Global (X,Y) Coordinate System.

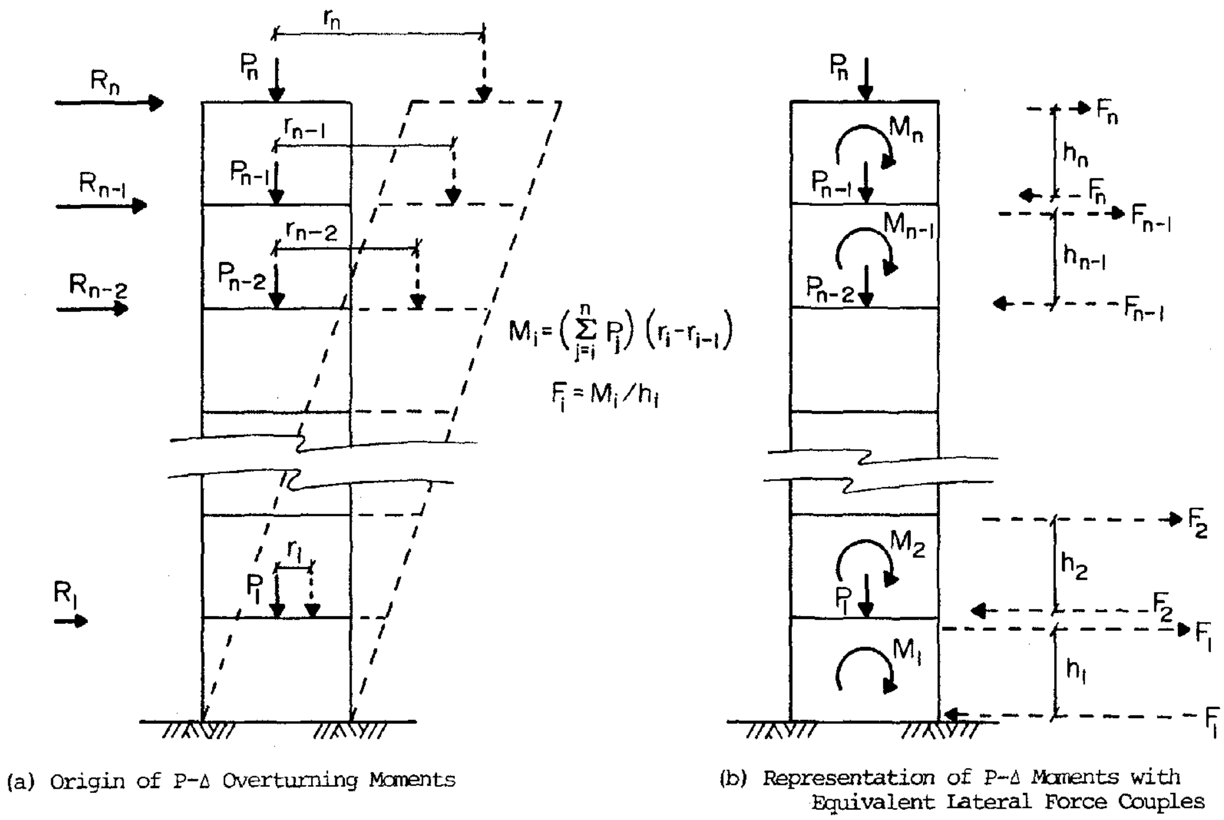


Figure A5: Equivalent Lateral Force Formulation

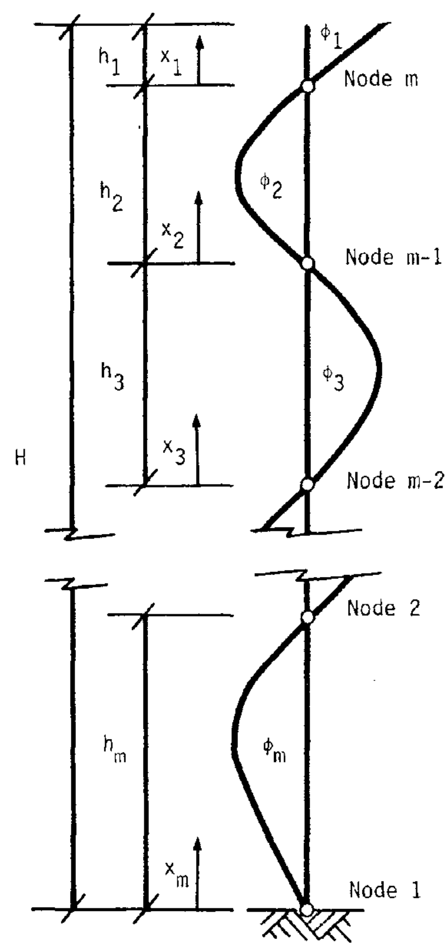


Figure A6: Empirical Mode Shape for the mth Mode

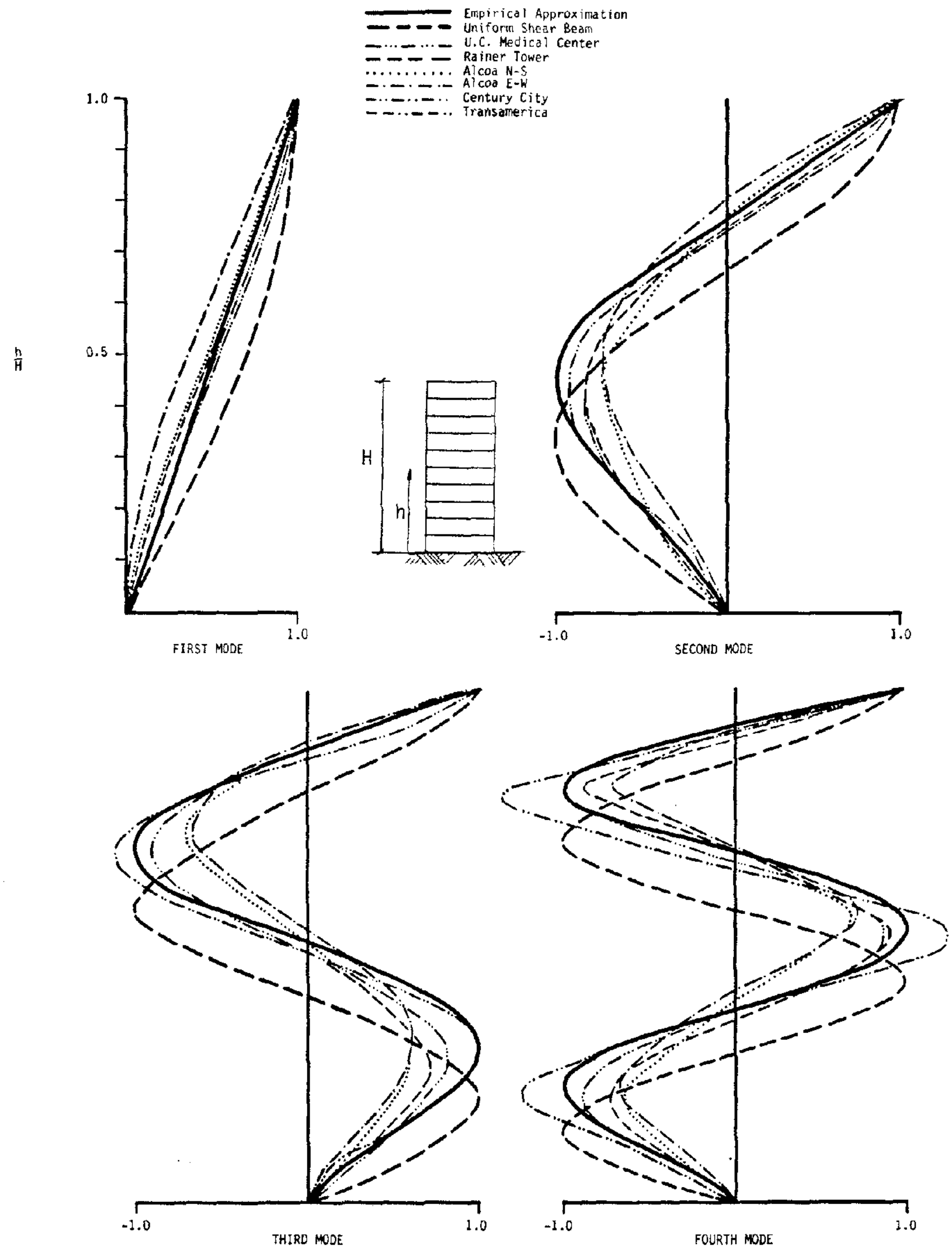


Figure A7: Approximate vs. Actual Mode Shapes of Multistory Buildings

PART B: DESCRIPTION OF SUPER-ETABS INPUT DATA

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1. <u>CONTROL INFORMATION CARD</u> (7I5,1X,4I1,F10.0,6A5)

Columns	Note*	Entry
1 - 5		Number of stories in the complete building (not including the footing line).
6 - 10	(1)	Number of frames with different properties or different vertical loading.
11 - 15	(1)	Total number of frame or shear wall elements in the structure.
16 - 20	(2)	Total number of load conditions.
21 - 25+		Analysis type code (See Fig. B1):
	(3)	EQ.0; Static loads only.
		EQ.1; Mode shapes and frequencies only.
	(56)	EQ.-1; Input and/or generation of approximate mode shapes and periods plus static analysis using lateral force cases (A and B) for the solution of the gross response quantities.
		EQ.2; Static load analysis plus modeshapes and frequencies.
		EQ.3; Lateral earthquake response spectrum analysis for the solution of individual frame displacements and member forces in addition to analysis type 2, above.
	(58)	EQ.4; Lateral earthquake time history response analysis for the solution of individual frame displacements and member forces in addition to analysis type 2, above.
		EQ.5; This option is not available for use.
	(56)	EQ.6; Lateral earthquake response spectrum analysis for the solution of the gross response quantities.
	(56)	EQ.-6 Input and/or generation of approximate mode shapes and periods plus lateral earthquake response spectrum analysis for the gross response quantities.

IMPORTANT NOTATIONS :

* See Section 8 for notes.
\+ Indicates new data for SUPER-ETABS enhancement.

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Columns	Note	Entry
		EQ.7; Both analysis types 3 and 6, above.
	(56)	EQ.8; Lateral earthquake time history response analysis for solution of the gross response quantities.
	(56)	EQ.-8; Input and/or generation of approximate mode shapes and periods plus lateral earthquake time history response analysis for the gross building response quantities.
		EQ.9; Both analysis types 4 and 8, above.
26 - 30	(4)	Number of frequencies to be calculated (NFQ).
31 - 35	(5)	Allowable story degrees of freedom:
		EQ.0; X, Y translations + story rotations.
		EQ.1; X translation only (for symmetrical buildings only).
		EQ.2; Y translation only (for symmetrical buildings only).
36		Blank
37+		Lateral load case A force generation code (see LATERAL FORCE GENERATION CARDS):
		EQ.0; No force generation.
		EQ.1; Generate forces in X direction.
		EQ.2; Generate forces in Y direction.
		EQ.3; Generate forces in both X and Y directions.
38+		Lateral load case B force generation code.
39+	(52)	Element stress ratio calculation code (see FRAME DATA):
		EQ.0; No stress ratios calculated.
		EQ.1; Stress ratios calculated for column, beam and diagonal brace elements.
40+		Execution code:
		EQ.0; Full Execution
		EQ.1; Data check.
41 - 50+	(51)	Acceleration of gravity for use in calculation of P-Δ effects.
51 - 80		Building identification information to be printed with the output.

2A. STORY DATA - Prepare two (2) cards per story level; data is entered in sequence from top to bottom of the structure.

First Card (A5,I5,7F10.0)

Columns	Note	Entry
1 - 5		Five characters to be used for level identification.
6 - 10		Blank
11 - 20		Story height [distance from the floor (or roof) level to the floor (or foundation) level below].
21 - 30	(6)	Translational mass.
31 - 40	(6)	Rotational mass moment of inertia about a vertical axis through the center of mass.
41 - 50	(7)	X-distance to the center of mass measured from the reference point.
51 - 60	(7)	Y-distance to the center of mass measured from the reference point.
61 - 70	(8)	External story stiffness in the X-direction.
71 - 80	(8)	External story stiffness in the Y-direction.

Second Card (8F10.0)

Columns	Note	Entry
1 - 10	(48)	Fx_A; load for lateral load case A.
11 - 20	(48)	Fy_A; load for lateral load case A.
21 - 30		X_A; X-ordinate at the point of load application for load case A (see Figure B2).
31 - 40		Y_A; Y-ordinate at the point of load application for load case A (see Figure B2).
41 - 50	(48)	Fx_B; load for lateral load case B.
51 - 60	(48)	Fy_B; load for lateral load case B.
61 - 70		X_B; X-ordinate at the point of load application for load case B (see Figure B2).
71 - 80		Y_B; Y-ordinate at the point of load application for load case B (see Figure B2).

2B. LATERAL FORCE GENERATION

UBC and/or ATC type lateral force generation are available. See Part A for description of force generation procedures. No cards required if force generation not requested; otherwise, input one card for each lateral load case for which force generation is requested (see CONTROL INFORMATION CARD, columns 37-38). If force generation requested for both load cases A and B, then first card is for case A. Format according to a or b below, depending upon type.

a. UBC Force Generation (I5,5X,7F10.0)

Columns	Note	Entry
1 - 5+		Punch 1 to indicate UBC force generation.
6 - 10		Blank
11 - 20+	(49)	Fundamental period value.
21 - 30+	(49)	Acceleration of gravity.
31 - 40+	(49)	Z coefficient.
41 - 50+	(49)	I coefficient.
51 - 60+	(49)	K coefficient.
61 - 70+	(49,50)	C coefficient.
71 - 80+	(49,50)	S coefficient.

b. ATC Force Generation (I5,5X,3F10.0)

Columns	Note	Entry
1 - 5+		Punch 2 to indicate ATC force generation.
5 - 10+		Blank
11 - 20+	(49)	Fundamental period value.
21 - 30+	(49)	Acceleration of gravity.
31 - 40+	(49)	C_s seismic coefficient.

3. APPROXIMATE ANALYSIS DATA

For analysis types -1, -6, and -8, replace FRAME DATA and FRAME LOCATION CARDS with the following data. See Part A for description of mode shape generation procedures.

a. Period and Mode Shape Generation Cards

First Card (I5,5X,7F10.0)

Columns	Note	Entry
1 - 5+		Mode shape generation code:
	(57,59)	EQ.0; Empirical rule generation.
	(59)	EQ.1; Shear beam rule generation.
		EQ.2; Mode shapes input.
6 - 10		Blank
11 - 20+	(59)	First period value
21 - 30+		Second period value
.		.
.		.
71 - 80+		Seventh period value

Additional Period Cards (8F10.0)

As many cards as required to define NFQ periods (see CONTROL INFORMATION CARD, Columns 26-30).

Columns	Note	Entry
1 - 10+		Eighth period value
11 - 20+		.
.		.
.		.
71 - 80+		.

b. Mode Shape Cards (2I5,3F10.0)

Required only if mode shape generation code equals 2 (see section 3a above, Columns 1-5). Modes are input in the same order corresponding to the periods (see section 3a above). The program will order the periods and mode shapes in descending order according to period value. The mode shapes are mass normalized within the program; therefore, any relative magnitude can be used to define the shapes. Each mode shape is input starting from the top to the bottom of the structure. For story levels omitted, a straight line interpolation is performed using the modal component values of the closest floor levels above and below the omitted floor that have modal components defined. For each mode shape, the top floor level and the first floor level modal components must be input.

Columns	Note	Entry
1 - 5+		Mode number
6 - 10+		Floor level
11 - 20+		X translational modal component
21 - 30+		Y translational modal component
31 - 40+		Rotational modal component

4. FRAME DATA - One set of data must be entered for each different frame. Frames with different locations but identical properties and vertical loading need be entered only once.

a. Frame Control Card (9I5,7A5)

Columns	Note	Entry
1 - 5	(9)	Frame identification number.
6 - 10	(10)	Number of levels above foundation for this frame.
11 - 15	(11)	Number of vertical column lines in frame.
16 - 20		Number of bays in frame.
21 - 25	(12)	Number of sets of different column properties.
26 - 30	(13)	Number of sets of different beam (girder) properties.
31 - 35	(14)	Number of sets of different fixed end moments and shears to be applied as vertical loads to beams (girders).
36 - 40	(15)	Number of infill shear panels in this frame.
41 - 45	(16)	Number of bracing elements in this frame.
46 - 80		Label to be used to identify this frame type.

b. Vertical Column Line Coordinates (I5,2F10.0)

Columns	Note	Entry
1 - 5	(17)	Column line identification number.
6 - 15	(18)	x-distance to column line from frame reference point.
16 - 25		y-distance to column line from frame reference point.

c. Column Property Cards

One column property set must be supplied for each different column in this frame.

First Card (I5,F15.0,F10.0,2F5.0,3F10.0,2F5.0)

Columns	Note	Entry
1 - 5	(19)	Identification number for this column property set.
6 - 20		Modulus of elasticity, E.
21 - 30		Axial area, A.
31 - 35	(24)	Shear area associated with shear forces in major axis direction, MAJ. SA.
36 - 40	(24)	Shear area associated with shear forces in minor axis direction, MIN SA.
41 - 50	(23)	Torsional inertia.
51 - 60		Flexural inertia for bending in the major axis direction, MAJ. I.
61 - 70		Flexural inertia for bending in the minor axis direction, MIN I.
71 - 75	(20)	Rigid zone depth at top of column (for both axes), DT (see Figure B3).
76 - 80	(21)	Rigid zone depth at bottom of column, DB (see Figure B3).

Second Card (5F10.0)

Omit if stress ratio calculation not requested (see CONTROL INFORMATION CARD, Column 39).

Columns	Note	Entry
1 - 10+	(53)	Allowable axial stress.
11 - 20+	(53)	Allowable major axis bending stress.
21 - 30+	(53)	Allowable minor axis bending stress.
31 - 40+	(53)	Major axis section modulus.
41 - 50+	(53)	Minor axis section modulus.

d. Beam Property Cards

One beam property set must be supplied in this section for each different beam in the frame; skip this input if the frame has only one column line, or no bays.

First Card (I5,F15.0,F10.0,F5.0,2F10.0,5F5.0)

Columns	Note	Entry
1 - 5	(22)	Identification number for this beam property set.
6 - 20		Modulus of elasticity, E.
21 - 25	(24)	Shear area, SA.
26 - 35	(23)	Torsional inertia.
36 - 45		Flexural inertia, I.
46 - 50		K_{II} - stiffness factor (e.g. 4). See Figure B4.
51 - 55		K_{JJ} - stiffness factor (e.g. 4). See Figure B4.
56 - 60		K_{IJ} - stiffness factor (e.g. 2). See Figure B4.
61 - 65	(25)	Rigid zone at end I, wI.
66 - 70		Rigid zone at end J, wJ.

Second Card (2F10.0)

Omit if stress ratio calculation not requested (see CONTROL INFORMATION CARD, Column 39).

Columns	Note	Entry
1 - 10+	(53)	Allowable bending stress.
11 - 20+	(53)	Section modulus.

e. Fixed-End Beam Loads (2I5,5F10.0)

One card must be supplied for each different type of vertical beam loading; omit if this is a single column line frame.

Columns	Note	Entry
1 - 5	(26)	Identification number for this vertical loading set.
6 - 10		Input code: EQ.0; Fixed-end forces are applied at the column faces. EQ.1; Fixed-end forces are applied at the column center-lines.
11 - 20	(27)	Fixed-end reaction, M_1 (see Figure B5).
21 - 30		Fixed-end reaction, V_1 (see Figure B5).
31 - 40		Fixed-end reaction, M_2 (see Figure B5).
41 - 50		Fixed-end reaction, V_2 (see Figure B5).
51 - 60	(28)	Uniform force per unit length, w, acting downward to be added to fixed-end reactions.

f. Beam Cards (8I5)

One card per girder must be input from top to bottom and from bay to bay in the frame (unless the data generation option is used). See Figure B6(c) for sign convention of member forces.

Columns	Note	Entry
1 - 5		Bay identification number for this beam.
6 - 10	(29)	Column line number at end I.
11 - 15		Column line number at end J.
16 - 20	(30)	Beam property set identification number for this girder.

21 - 25	(31)	Number of beams in sequence below to be generated having the same properties and vertical loading as this beam.
26 - 30	(32)	Vertical loading set identification number for vertical load case I.
31 - 35		Vertical loading set identification number for vertical load case II.
36 - 40		Vertical loading set identification number for vertical load case III.

g. Column Cards (4I5)

One card per column must be input from top to bottom and from column line to column line of the frame (unless the data generation option is used). See Figure B6(a) for sign convention of member forces.

Columns	Note	Entry
1 - 5		Column line identification number for this column.
6 - 10	(33)	Column property set identification number.
11 - 15	(34)	Column line number defining direction of major axis.
16 - 20	(35)	Number of columns in sequence below to be generated having the same properties as this column member.

h. Panel Element Cards (3I5,5F10.0)

Enter one card per panel in any order; no generation is allowed. See Figure B6(b) for sign convention of member forces.

Columns	Note	Entry
1 - 5	(36)	Level identification number at the top of this panel.
6 - 10		Column line number at the I side of this panel.
11 - 15		Column line number at the J side of this panel.
16 - 25		Modulus of elasticity, E.
26 - 35		Gross sectional area, A.
36 - 45	(45)	Moment of inertia, I.
46 - 55		Effective shear area, A_v.
56 - 65		Shear modulus, G.

i. Bracing Element Cards (3I5,3F10.0)

Enter one card per brace in order; no generation is allowed. See Figure B6(d) for sign convention of member forces.

Columns	Note	Entry
1 - 5		Level identification number at the top of this brace.
6 - 10		Column line number at the upper end of this brace.
11 - 15		Column line number at the lower end of this brace.
16 - 25		Modulus of elasticity, E.
26 - 35		Cross-sectional area, A.
36 - 45^{+}	(53)	Allowable axial stress. Omit if stress ratio calculation not requested (see CONTROL INFORMATION CARD, Column 39).

5. FRAME LOCATION CARDS (2I5,4F10.0,4A5)

One card must be entered in this section for each frame (or single column) in the building; the total number of frame locations to be read is controlled by the entry in card columns 11-15 of the CONTROL INFORMATION CARD.

Columns	Note	Entry
1 - 5	(37)	Frame identification number.
6 - 10	(38)	Force calculation code:
		EQ.0; Frame forces will be calculated and printed.
		EQ.1; Frame forces will not be calculated.
11 - 20	(39)	Distance, X_1 (see Figure B7).
21 - 30		Distance, Y_1 (see Figure B7).
31 - 40	(40)	Angle ϕ between the frame x axis and structure (Global) X axis (counter-clockwise X to x). See Figure B7.
41 - 60		Information to be printed with the output which will identify this particular frame.

6A. EARTHQUAKE ACCELERATION SPECTRUM CARDS

These data cards are required if the analysis type code is set equal to three (3), six (6), seven (7), or minus six (-6); see CONTROL INFORMATION CARD, Columns 21-25.

a. Control Card (2I5,2F10.0,2F5.0,5I1,7A5)

Columns	Note	Entry
1 - 5		Number of period cards to define response spectrum (see section b below).
6 - 10		The number of modes, in sequence, starting with the lowest, to be printed separately.
11 - 20		Acceleration, units/sec/sec.
21 - 30	(41)	Direction of earthquake input, θ, in degrees and decimals (0.000). See Figure B8.
31 - 35+	(46)	Damping ratio (modal damping/critical damping) to be used in the calculation of the double sum (DSC) and complete quadratic combination (CQC) modal cross-correlation coefficient matrices.
36 - 40+	(46)	Earthquake strong motion duration used for the calculation of the DSC modal cross-correlation coefficient matrix. Default to value of 1.0E+03.
41+	(42)	Output code for SRSS of modal gross building responses (for analysis types 6, 7, and -6). EQ.0; Response values not printed. EQ.1; Response values printed.
42+	(42,54)	Output code for DSC of modal responses (for analysis types 3, 6, 7, and -6). See note 54 regarding use of code in type 3 analysis.
43+	(42,54)	Output code for CQC of modal responses (for analysis types 3,6,7, and -6). See note 54 regarding use of code in type 3 analysis.
44+	(42)	Output code for absolute sum of modal gross building responses (for analysis types 6, 7, and -6).
45+		Analysis types 6,7, and -6 gross building response direction output code: EQ.0; Response quantities are calculated and printed with respect to global structural coordinate system (X,Y). EQ.1; Response quantities are calculated and printed with respect to coordinate system (R,S) defined by direction of earthquake input (see Figure B8).

EQ.2; Response quantities are calculated and printed with respect to both (X,Y) and (R,S) coordinate systems.

46 - 80 User information to be printed with output.

b. Period Cards (2F10.0)

Columns	Note	Entry
1 - 10		Period entered in increasing numerical sequence.
11 - 20		Spectrum acceleration.

6B. TIME HISTORY CARDS

These data cards are required only if the analysis type code was set to four (4), eight (8), nine (9), or minus eight (-8); see CONTROL INFORMATION CARD, Columns 21-25.

a. Control Card (2I5,3F10.0,5I1,7A5)

Columns	Note	Entry
$1 - 5^+$		Number of acceleration values (NPC). Two different input formats are available (see section c below).
6 - 10	(44)	Number of time steps to be used in the analysis.
11 - 20		Scale factor for accelerations.
21 - 30	(41)	Direction of earthquake input, θ. See Figure B8.
31 - 40		Time increment, Δt, for response evaluation (see Columns 6-10 above)
41^+	(47)	Output code for time history print of story deflections (for analysis types 8, 9, and -8).
		EQ.0; Response values not printed.
		EQ.1; Response values printed at time increments Δt (see Columns 31-40, above).
42^+	(47)	Output code for time history print of story drifts (for analysis types 8, 9, and -8).
43^+	(47)	Output code for time history print of cumulative story shears (for analysis types 8, 9, and -8).
44^+	(47)	Output code for time history print of cumulative story overturning moments (for analysis types 8, 9, and -8).
45^+		Analysis types 8, 9, and -8 gross building response

direction output code:

EQ.0; Response quantities are calculated and printed with respect to global structural coordinate system (X,Y).

EQ.1; Response quantities are calculated and printed with respect to coordinate system (R,S) defined by direction of earthquake input (see Figure B8).

EQ.2; Response quantities are calculated and printed with respect to both (X,Y) and (R,S) coordinate systems.

46-80 User information to be printed with output.

b. Damping Cards (I5,F10.2)

One card must be supplied for each frequency in the analysis (See Note 4).

Columns	Note	Entry
1 - 5	(4)	Mode number (in ascending order).
6 - 15		Damping ratio: Modal Damping/Critical Damping.

c. Ground Motion Acceleration Data

Two formats for input of ground acceleration data are available. The format used is dependent upon the sign of NPC (see card a, columns 1-5, above).

If NPC.GT.0 then:

One card must be supplied for each time increment, at which ground acceleration is specified in increasing time order. The time span must be greater than the number of time steps multiplied by Δt.

Time and Acceleration Cards (2F10.0)

Columns	Note	Entry
1 - 10		Time
11 - 20		Ground acceleration

If NPC.LT.0 then:

The ground acceleration points are input at equal time intervals. The number of acceleration points input is equal to NPC . The time span must be greater than the number of time steps multiplied by Δt.

Acceleration Time Interval Card (F10.0)

Columns	Note	Entry
$1 - 10^+$		Time interval between acceleration input points.

Acceleration Cards (8F9.0)

As many cards as necessary to define NPC acceleration values.

Columns	Note	Entry
1 - 9+		
10 - 18+		Ground accelerations
.		
64 - 72+		

7. LOAD CASE DEFINITION CARDS (5F10.0,4F5.0,F10.0)

Load cases for the complete building are defined as a combination of vertical conditions (I, II and III), lateral loading conditions (A and B), and earthquake spectrum or time history loadings. One card must be entered in this section for each different building load case; the total number of building load cases is controlled by the entry in card columns 16-20 of the CONTROL INFORMATION CARD. Omit this data if the analysis type code is set equal to one (1); six (6); eight (8); minus one (-1); minus six (-6); or, minus eight (-8). See note 56.

Columns	Note	Entry
1 - 10		Multiplier or vertical load case I.
11 - 20		Multiplier for vertical load case II.
21 - 30		Multiplier for vertical load case III.
31 - 40		Multiplier for lateral load case A.
41 - 50		Multiplier for lateral load case B.
51 - 55	(42)	Multiplier for spectrum 1 loading - SRSS modal combination.
56 - 60	(42)	Multiplier for spectrum 2 loading - Absolute Sum modal combination.
61 - 65+	(42,55)	Multiplier for spectrum 3 loading - DSM modal combination.
66 - 70+	(42,55)	Multiplier for spectrum 4 loading - CQC modal combination.
71 - 80	(43)	Multiplier for time history earthquake response.

8. NOTES

(1) Input data for frames with identical properties and vertical loading are given only once--see Section 5, FRAME LOCATION CARDS.

(2) Load conditions are defined as combinations of the seven (7) basic load cases--see Section 7, LOAD CASE DEFINITION CARDS.

(3) Mass properties of the structure are not required for analysis type "0".

(4) The number of frequencies must be less than the number of stories times the number of degrees of freedom per story.

(5) For symmetrical buildings, the capacity and speed of solution of the program is improved if the story rotation is set to zero; i.e., "1" or "2" in card column 35.

(6) The translational mass has units of force divided by acceleration (W/g). The rotational mass moment of inertia is not required if the allowable story degrees of freedom do not include rotation. Mass properties need not be supplied if this data case is for static loading only.

(7) The location of the center of mass (X_m, Y_m) need not be given if this data case is for static loads only.

(8) The external story stiffnesses act on lines through the center of mass. These stiffnesses can be used to represent restraints (or braces) at the story level or can be used to represent soil stiffness below the ground level.

(9) Frame identification numbers must be entered in numerical sequence, beginning with number one (1). This frame may be located (repeated) at different positions in the structure.

(10) If a frame does not extend the full height of the building, then only those story levels actually existing in the frame are input below.

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

(12) Column properties may be referenced to any number of columns in the frame.

(13) The number of beam property sets controls the number of cards to be read in Section 4.d, below.

(14) If no vertical static loads act on the structure, then omit this number, and skip Section 4.e, below.

(15) If no panel elements are included in this frame, then omit this entry, and skip Section 4.h, below.

(16) If no bracing elements are included in this frame then omit this entry, and skip Section 4.i, below.

(17) One card must be included for each column line in the frame. For frames with a single column line a second column line should be specified to define the major axis for column properties entered in Section 4.g.

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

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

(20) The rigid zone depth is used to reduce the effective length of the column about both axes.

(21) Usually zero unless beam extends above floor level.

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

(23) Torsional inertias may be omitted.

(24) Shearing deformations are ignored if shear areas are zero.

(25) The beam rigid zone lengths are used to reduce the effective length of the beam (girder).

(26) Load set numbers must be input in sequence.

(27) Reactions act on the beam ends and are positive as shown in Figure B5.

(28) Additional fixed-end forces due to the uniform load. w, are calculated using:

$$M = w\ell^2/12; \qquad V = w\ell/2$$

and are added to any specified fixed-end reactions. The forces due to w are exact only for prismatic beams.

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

(30) Beams with zero (0) stiffness (missing girders) may be input as having a property set number of zero; if the beam has finite stiffness, the set number must reference an existing property set defined previously in Section 4.d, above.

(31) The generation option can only be used to define girders within the current bay; a new bay must be started with a new beam card.

(32) The vertical loading sets defined in Section 4.e, above, are applied to the girders via the references in card columns 11-25. Three (3) independent vertical load distributions (I, II, and III) are allowed, and these distributions are combined with the lateral load case (A and B) and the earthquake analysis to form load cases for the complete building; see Section 7, below.

(33) Missing columns may be input as having a property set number of zero (0); if the column has finite stiffness, then the set number referenced must correspond to one of the property sets defined previously in Section 4.c, above.

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

(35) Generation is allowed only within the current column line; begin a new column line with a new column card.

(36) The foundation line is defined as level zero, and the roof level number is equal to the total number of stories in the building.

(37) Frame identification numbers may be repeated, but location cards must be input in frame identification number sequence.

(38) A frame force calculation code of one (1) will suppress output for the frame.

(39) Distance from structure (Global) axis to origin of frame (local) axis.

(40) Angle is input in degrees and decimal fractions; e.g. 36 12' entered as 36.2.

(41) The angle ϕ is measured positively clockwise between the global Y-direction and the line of action of the earthquake direction; see Figure B8.

(42) Four different response spectrum modal combination methods are available. See discussion in Part A regarding situations where the DSM or CQC methods should be used.

(43) Multipliers should be specified either for response spectrum analysis or for time history analysis as specified in Section 1, CONTROL INFORMATION CARD as only one of these analysis types may be performed in a single program execution.

(44) The total time span of the computed response is equal to the number of time steps multiplied by the time increment Δt. Output is given at each time step. Since explicit integration is used in computing the response, numerical instability problems are never encountered and the time increment may be any desired sampling value.

(45) A zero (0) value for the moment of inertia selects the pure shear deformation panel model. The pure shear panel uses the gross sectional area, <u>not</u> the effective shear area, to calculate stiffness and stress values.

(46) The DSC and CQC matrices are used for combining the individual modal responses to estimate the total response. If DSC and/or CQC of modal responses are not requested, leave this entry blank.

(47) Envelope values of maximum and minimum response values, and

the associated times of occurence are always printed when using analysis types 8 or 9.

(48) If force generation requested, then the generated forces replace any entries in these columns.

(49) No default value.

(50) The user must ensure that values of C, S, C*S are within code specified limits.

(51) No default value, if zero then geometric stiffness (P-Δ) effects not included in stiffness and response calculation.

(52) See Part A for description of stress ratio equation.

(53) No default value. If less than or equal to zero (blank), stress ratios will not be calculated for members with this property set.

(54) If DSC and/or CQC is required for type 3 analysis, enter the value one (1) in the appropriate columns. When blank or zero, the DSC and/or CQC element response calculations are skipped and are not available for use in load case definition (see LOAD CASE DEFINITION CARDS), whereas the SRSS and ABS element responses may be calculated irrespective of their output codes. The purpose of this key is to omit unnecessary internal DSC and/or CQC calculations when these combination types are not used. Note, for type seven (7) analysis, if DSC/CQC element response is requested, the CSC/CQC gross response must also be output.

(55) If DSC and/or CQC is requested, then the appropriate key must be set in the EARTHQUAKE ACCELERATION SPECTRUM CARDS (Control Card, Columns 42-43).

(56) The gross response quantities from lateral static and dynamic analyses cannot be combined to form new load cases. The results from each lateral static and/or dynamic analysis are output separately.

(57) Note that when using the empirical rule to automatically generate mode shapes in approximate analysis, irregularities in higher mode shapes may result if a large number of modes is included in the analysis. The user should use only that number of modes which insures that the smallest internodal distance (h) of the highest mode (NFQ) will be greater than the typical story height for the building.

(58) In analysis type 4, only peak envelope member response values are printed.

(59) For 3-D approximate analysis, the order of mode generation is as follows: first X translational, first Y translational, first torsional, second X translational, second Y translational, second torsional, etc. Therefore, period values must be input according to this pattern. Also, in 3-D mode generation, the number of modes NFQ must be a multiple of three (3).

Analysis Type	Periods and Mode Shapes		Macro (Gross) Building Response			Detailed (Elements) Building Response			
	Eigen Solution	Approx.	Static	Response Spectrum	Time History	Static	Response Spectrum	Time Hist. (Envelopes)	Time History
0			X			X			
1	X		X						
-1		X	X						
2	X		X			X			
3	X		X			X	X		
4	X		X			X		X	
5									
6	X		X	X					
-6		X	X	X					
7	X		X	X		X	X		
8	X		X		X				
-8		X	X		X				
9	X		X		X	X		X	

Figure B1: Analysis Types

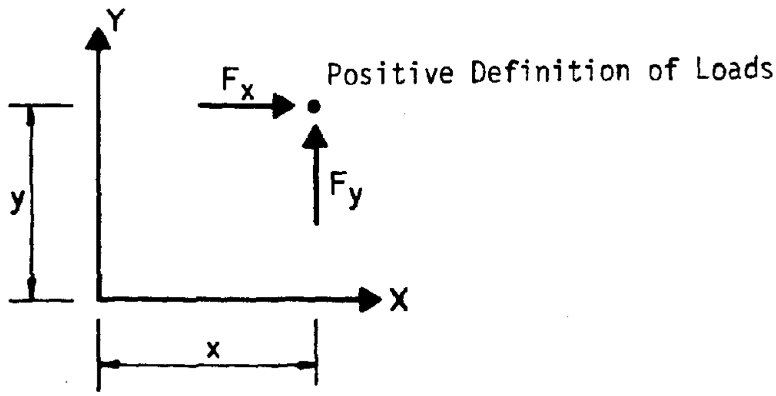

Figure B2: Definition of Positive Loads

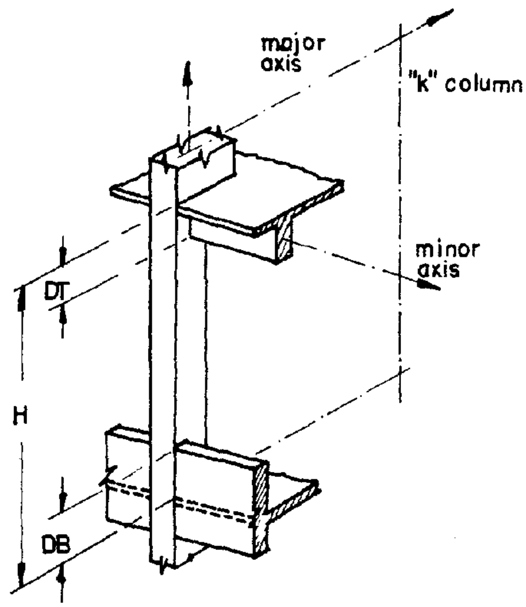

Figure B3: Column Geometry

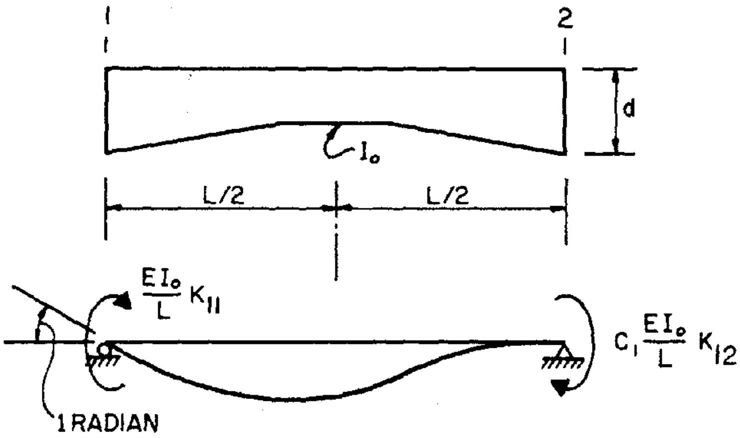

Figure B4: Beam Stiffness Factors

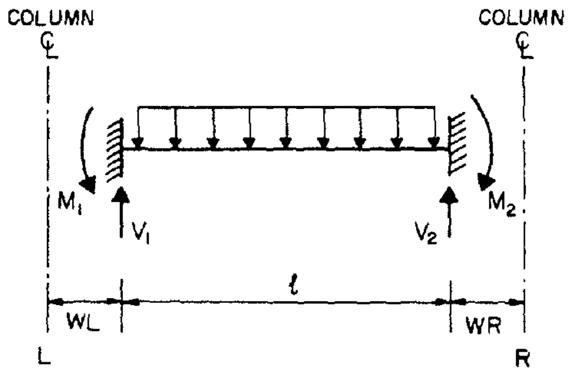

Figure B5: Beam Fixed End Forces

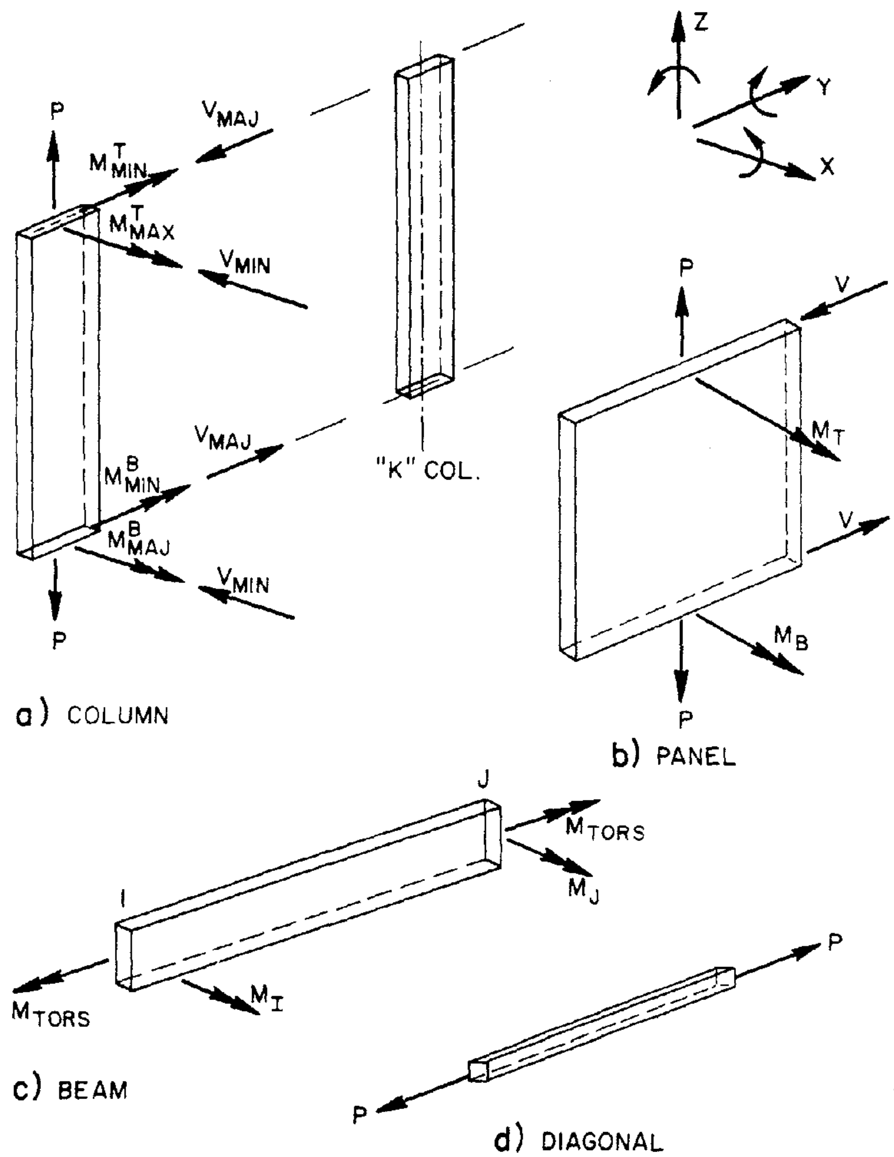

Figure B6: Sign Convention for Member Forces

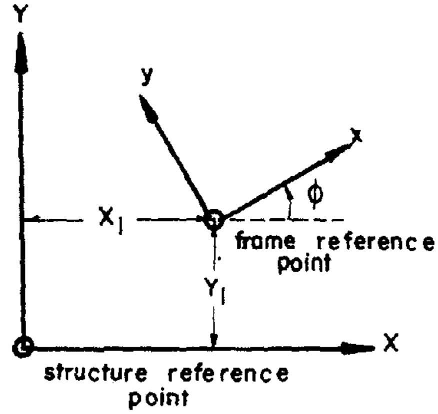

Figure B7: Frame Location Procedure

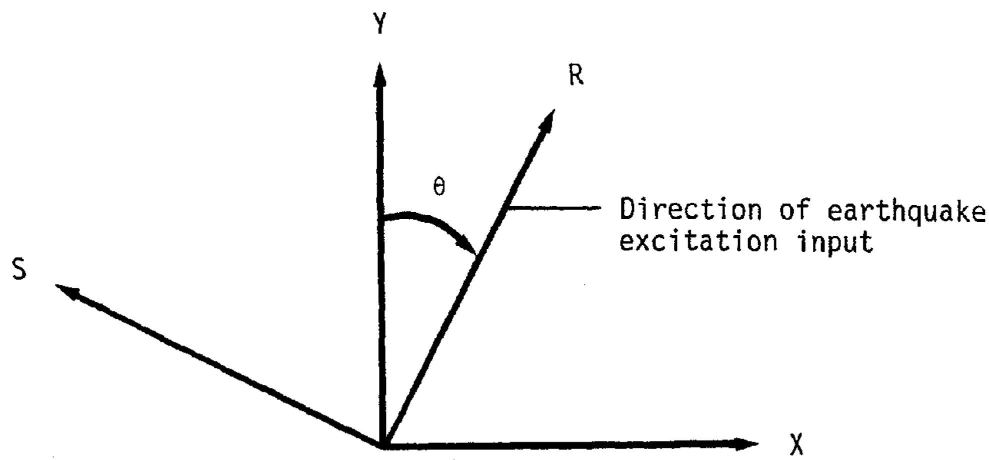

Figure B8: Orientation of (R,S) Coordinate System with respect to Global (X,Y) Coordinate System