Gibbs & Hill, Inc.

ENGINEERS DESIGNERS CONSTRUCTORS

DIRECT DIAL EXTENSION
(212) 760- 5167

November 30, 1979

LGH-NRC-70
File: 5.1.4

U.S. Nuclear Regulatory Commission
Standardization Branch
Washington, D.C. 20555

Subject: GIBBSSAR (STN-50-584),
Computer Verification Documents

Gentlemen:

Enclosed are the verification documents for Gibbs & Hill, Inc., in-house computer programs SCONV, SPECTA, QUAKE, and TIME for your review. This additional information supports our response to NRC Question 131.63.

If you have any questions or comments concerning this letter, we will be pleased to meet with you at your convenience.

Sincerely yours,

GIBBS & HILL, INC.

Robert Prieto

RP:lm
encs.

Robert Prieto
GIBBSSAR Assistant
Project Manager

cc: J. Conran
U.S. Nuclear Regulatory
Standardization Branch Commission
Washington, D.C.

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VERIFICATION OF

SCONV

COMPUTER PROGRAM

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VERIFICATION OF COMPUTER PROGRAM SCONV

I. PROGRAM FUNCTION

SCONV uses modal analysis time history method to determine the transient response of a linear elastic system subjected to support time history excitation. The convolution integration is used to obtain the analytical results. The input information of SCONV program includes the support time history excitation and the free vibration characteristics of the system, such as frequencies, mode shapes, weighted damping and participation factors, obtained by program QUAKE. Step-by-step integration by Simpson's rule is used. The theoretical part of this program is presented in Appendix A.

II. METHOD OF VERIFICATION

Continuous System Modeling Program (CSMP), which is an IBM program in the public domain and is independent of SCONV, is used to verify G&H proprietary program SCONV. CSMP uses the fourth order Runge-Kutta integration method with variable integration interval and the Simpon's rule for error estimate. The results from both programs compared to establish the validity of SCONV.

III. COMPARISON OF RESULTS

The dynamic analysis model of an auxiliary building of a PWR nuclear power plant shown in Figure 1 is used to verify SCONV. This model, which consists of five lumped masses or 30 dynamic degrees of freedom (Table 1), was analyzed by using both SCONV and CSMP for the same ground excitation as shown in Figure 2.

The absolute floor acceleration time history and the corresponding floor response spectra for the mass number 1, which produced most sensitive and critical response, are used for comparison. These results correspond to acceleration component in X direction due to Safe Shutdown Earthquake in X direction for the dynamic model with upper bound soil spring.

Figure 3 and Figure 4 are the absolute floor acceleration time histories obtained from SCONV and CSMP respectively. These time histories derived from both programs are almost identical. The equipment damping for the floor response Spectra shown in Figure 5 is 1 percent of the critical damping.

Plotted in Figure 5 are the floor response spectra case considered. It is obvious that the difference between two floor response spectra developed from SCONV and CSMP is negligibly small.

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TABLE 1 DEGREE OF FREEDOM
OF DYNAMIC MODEL

MASS POINT	DEGREE OF FREEDOM		
	1	Translation	X
	2	Translation	Y
	3	Translation	Z
1	4	Rotation	θx
	5	Rotation	θy
	6	Rotation	θz
	7	Translation	X
	8	Translation	Y
	9	Translation	Z
2	10	Rotation	θx
	11	Rotation	θy
	12	Rotation	θz
	13	Translation	X
	14	Translation	Y
	15	Translation	Z
3	16	Rotation	θx
	17	Rotation	θy
	18	Rotation	θz

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TABLE 1 DEGREE OF FREEDOM
OF DYNAMIC MODEL (Continued)

MASS POINT	DEGREE OF FREEDOM		
	19	Translation	X
	20	Translation	Y
	21	Translation	Z
4	22	Rotation	θx
	23	Rotation	θy
	24	Rotation	θz
	25	Translation	X
	26	Translation	Y
	27	Translation	Z
5	28	Rotation	θx
	29	Rotation	θy
	30	Rotation	θz

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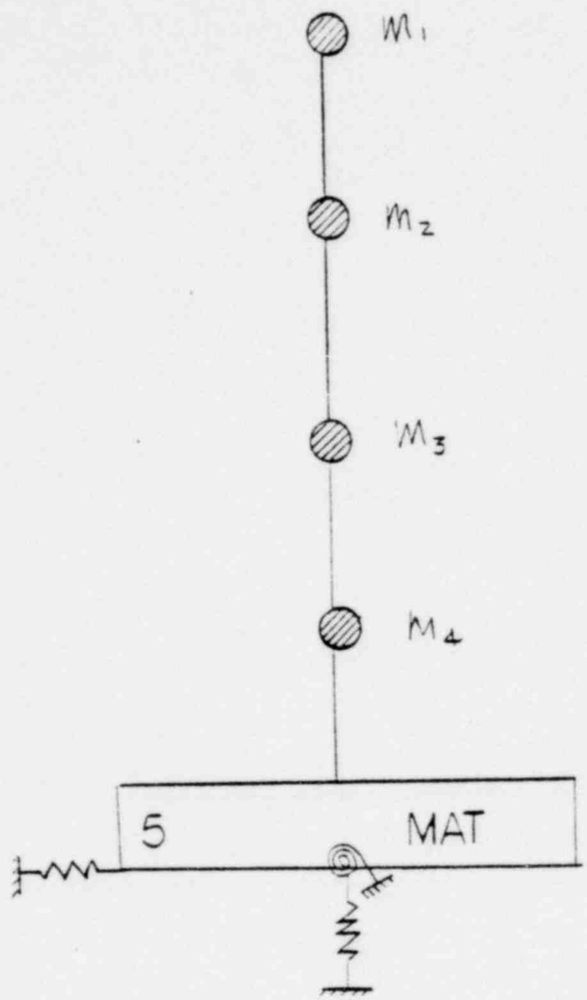

Figure 1. Dynamic Analysis Model

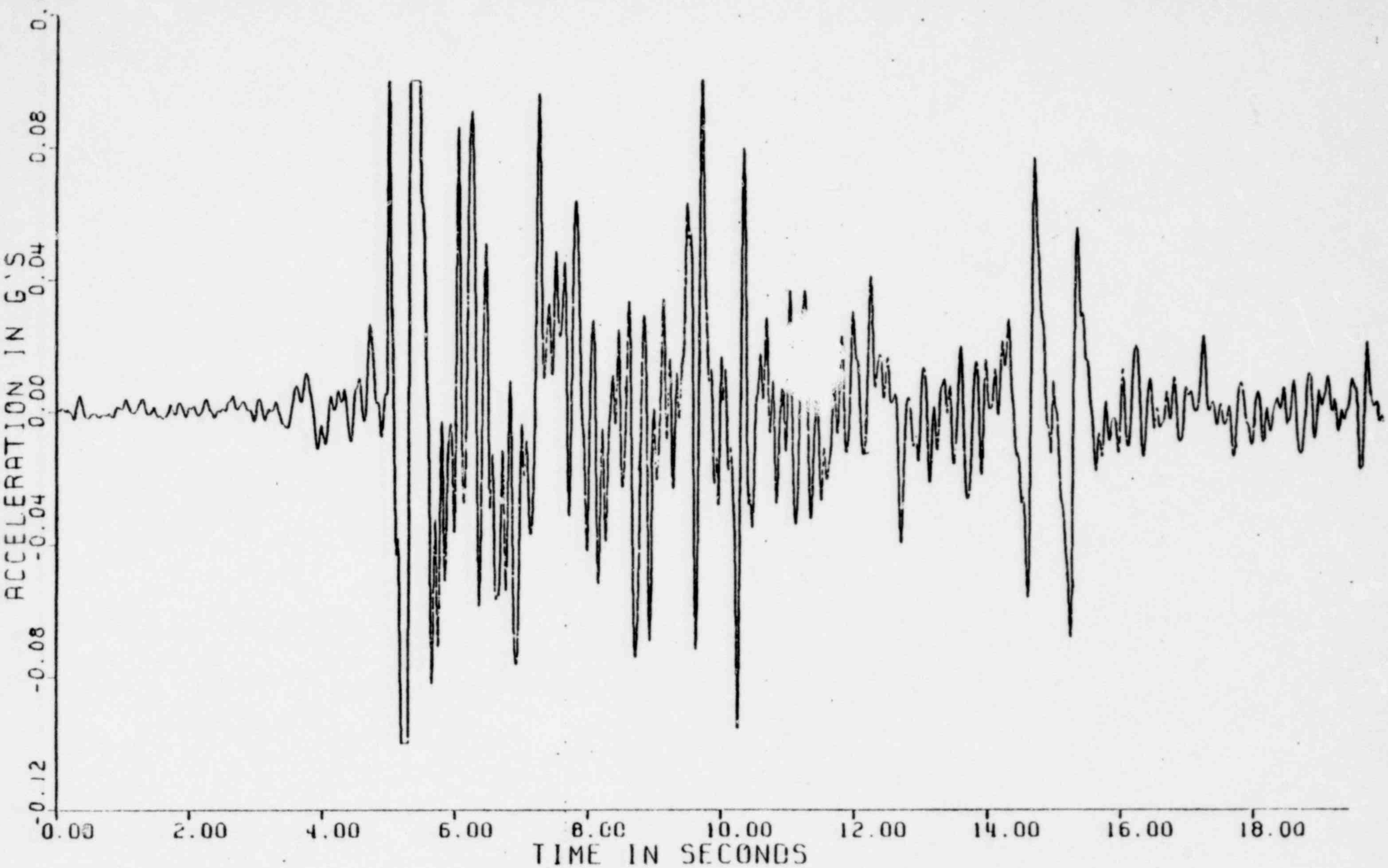

Figure 2. Time History Ground Motion

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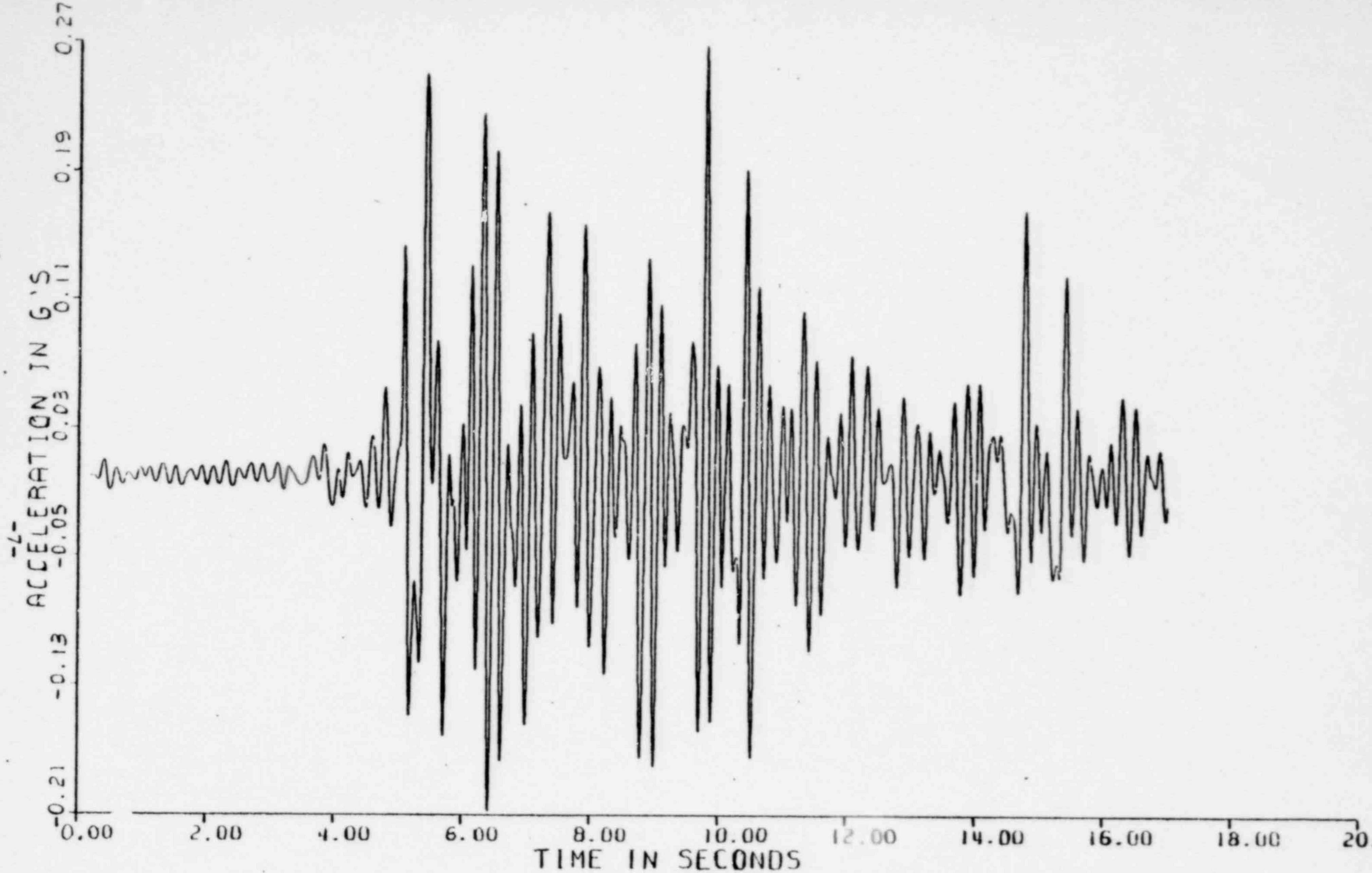

Figure 3. Time History Floor Motion Obtained from SCONV

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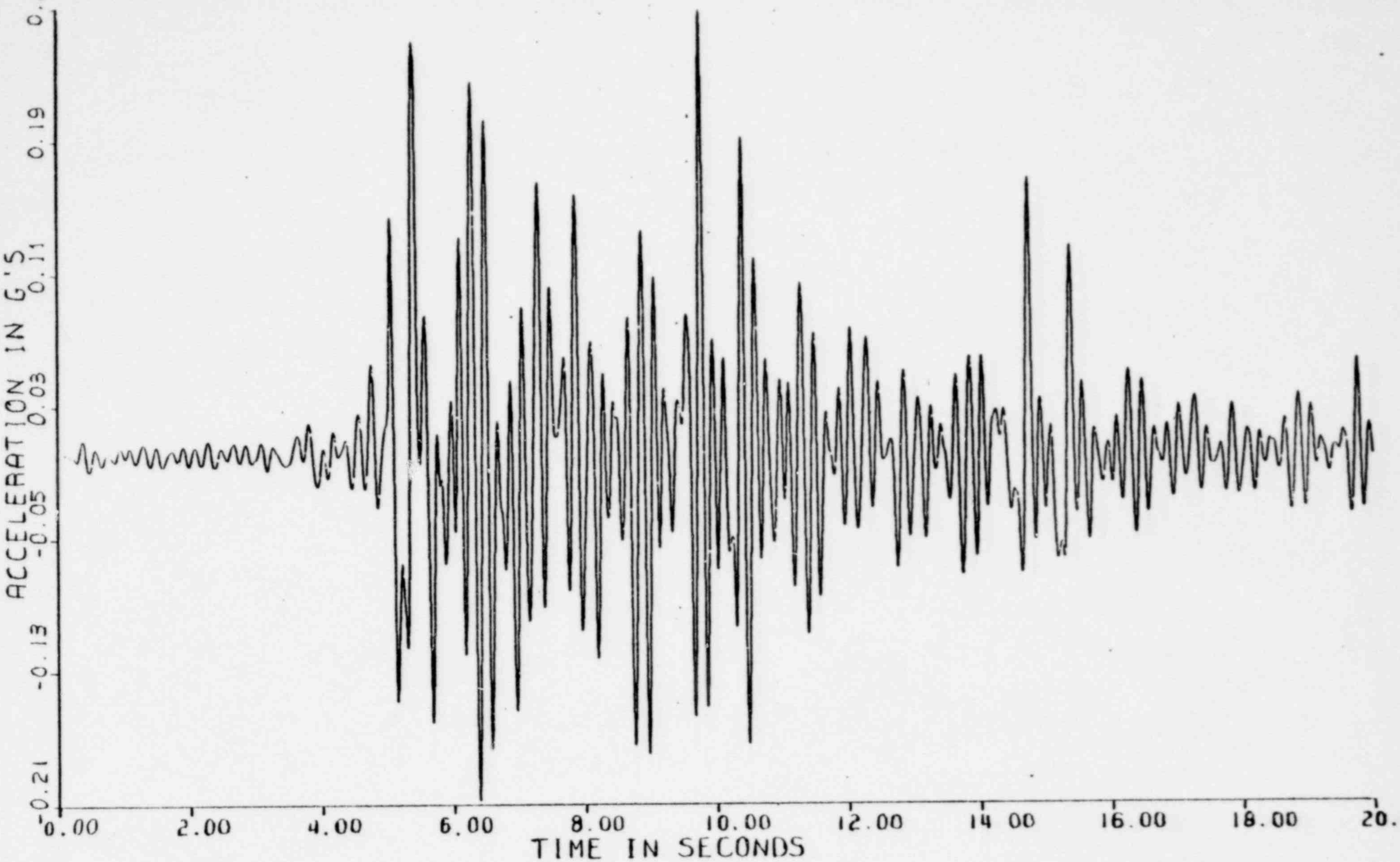

Figure 4. Time History Floor Motion Obtained from CSMP

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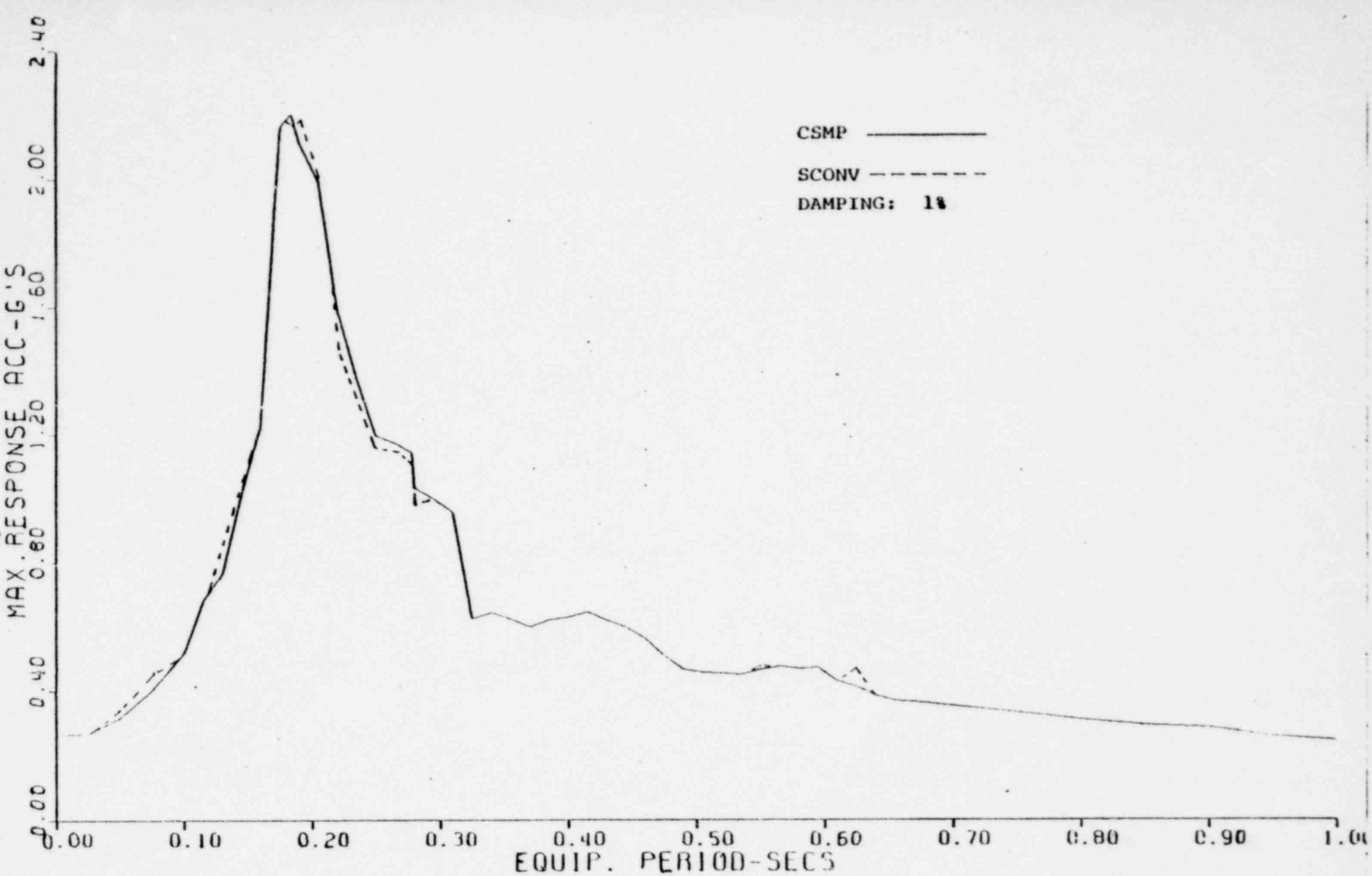

Figure 5. Horizontal Floor Response Spectra

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APPENDIX A

Computer Program (SCONV)

This program uses convolution integration to solve a general dynamic problem for a linear elastic system with the support time history excitation $R\ddot{S}_{(t)}$ where R is the scaling factor and $\ddot{S}_{(t)}$ time dependent support acceleration. For any linear elastic system, its governing equation for motions in matrix form

$$[m]\{\ddot{u}\} + [c]\{\dot{u}\} + [k]\{u\} = -[m]\{D\}R\ddot{S}(t) \quad (1)$$

can be decoupled into a system of second order differential equations:

$$\{\ddot{q}\} + 2[\beta][\omega]\{\dot{q}\} + [\omega^2]\{q\} = -\{\gamma\}R\ddot{S}_{(t)} \quad (2)$$

where $\{q\}$ is in normal coordinate, that is:

$\{u\} = [\phi]\ \{q\}$

and $[\beta]$, $[\omega]$, $\{\gamma\}$, $\{D\}$ and $[\phi]$ = the matrixes of coefficients of critical damping, circular frequencies, participation factors, direction vector, and eigenvectors, respectively.

The general solution of Equation (2) for any system is:

$$q_{n(t)} = C_{n(t)} - \frac{\gamma_n}{\omega_n^2} A_{n(t)} \quad (3)$$

where $$C_{n(t)} = e^{-\beta_n \omega_n t}\left(\frac{q_0 + \beta_n \omega_n q_0}{\bar{\omega}_n} \sin \bar{\omega}_n t + q_0 \cos \bar{\omega}_n t\right)$$

$$A_{n(t)} = \int_0^t \frac{\omega_n^2}{\bar{\omega}_n} e^{-\beta_n \omega_n (t-\tau)} R\ddot{S}_{(\tau)} \sin[\bar{\omega}_n (t-\tau)]\, d\tau \quad (4)$$

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and

$$\bar{\omega}_n = \sqrt{\omega_n^2 \left(1 - \beta_n^2\right)}$$

$q_{n(t)}$ is the relative displacement of nth mode at time t and $\dot{q}_0$ and q_0 are the initial velocity and displacement.

Differentiating Equation (3) once and twice, the relative velocity and acceleration are obtained.

$$\dot{q}_{n(t)} = -\beta_n \omega_n C_{n(t)} + D_{n(t)} + \frac{\gamma^n}{\omega_n^2}\left[\beta_n \omega_n A_{n(t)} - B_{n(t)}\right] \quad (5)$$

$$\ddot{q}_{n\,(t)} = -\left(\bar{\omega}_n^2 - \beta_n^2 \omega_n^2\right) C_{n\,(t)} - 2\beta_n \omega_n D_{n\,(t)} +$$

$$+ \frac{\gamma^n}{\omega_n^2}\left[\left(\omega_n^2 - 2\beta_n^2 \omega_n^2\right) A_{n(t)} + 2\beta_n \omega_n B_{n(t)}\right] - \gamma_n \ddot{RS}_{(t)} \quad (6)$$

where $$B_{n(t)} = \int_0^t \omega_n^2 \ddot{RS}_{(\tau)} e^{-\beta_n \omega_n (t-\tau)} \cos[\bar{\omega}_n (t - \tau)]\, d\tau \quad (7)$$

and $$D_{n(t)} = e^{-\beta_n \omega_n t} \left[(\dot{q}_0 + \beta_n \omega_n q_0) \cos \bar{\omega}_n t - q_0 \bar{\omega}_n \sin \bar{\omega}_n t \right]$$

The solution procedure is based upon the step-by-step method. The total time duration is divided into small time intervals or steps. Displacement and velocity from the previous step are used as initial condition for the next step. At each step, the relative displacement, velocity, and acceleration are calculated. The absolute acceleration is then combined by modal superposition.

$$\{\ddot{W}\} = [\phi]\,\{\ddot{q}\} + \{D\}\, \ddot{RS}_{(t)}$$

where $\{\ddot{W}\}$ = the column matrix of absolute accelerations.

The numerical method used for integration of Equations (4) and (7) is Simpson's rule.

1541 034

VERIFICATION OF

QUAKE

COMPUTER PROGRAM

1541 035

PROGRAM VERIFICATION OF QUAKE

I. PROGRAM FUNCTION

Program 'QUAKE' performs the dynamic analysis of a linear elastic lumped mass system using the response spectrum approach. First, the program determines the free vibration characteristics of the lumped mass system. Then, using the ground response spectra as loading input, the program computes the seismic response of the system due to base excitation. The analytical formulation of the program is described in Appendix A.

The capabilities of the program include:

(1) Extracting the eigenvalues (frequencies) and the corresponding eigenvectors (mode shapes) from the general equation of motion of the lumped mass system,

(2) Computing participation factors for three orthogonal directions of earthquake motion,

(3) Computing equivalent modal damping (or weighted damping, composite damping) according to the energy stored in each material component and in each vibration mode,

(4) Computing spectral accelerations, absolute modal accelerations, relative modal displacements and modal forces (or internal loads) using spectrum approach,

(5) Calculating modal shears and moments of statically determinate structures, and combining them by the square root of the sum of squares (SRSS).

II. METHOD OF VERIFICATION

The reactor building of a PWR nuclear power plant is used as a model to verify the program. The dynamic model consists of two components; one represents the containment and the other represents the internal structure (see Fig. 1). The nodal coordinates of the model are shown in Table 1. Each mass point has 6 degrees-of-freedom (3 translations and 3 rotations); the entire model has a total of 54 degrees-of-freedom. The effects of soil-structure interaction are simulated by soil springs attached to the foundation mat of the reactor building.

MRI/STARDYNE structural analysis system, which is available at Control Data Corporation Cybernet centers, is used to verify part of program 'QUAKE'. Hand calculation is used to verify other capabilities which are exclusive to 'QUAKE'.

Program 'STAR' of STARDYNE extracts eigenvalues and eigenvectors for all dynamic degrees of freedom of a structural system. Program 'DYNRE 4' of STARDYNE analyzes the response of lumped mass system subjected to a given shock spectra input. The ground response spectra, both horizontal and vertical, are input directly into the program in the form of user furnished spectra matrices. Hand calculations are used to verify the modal forces, and shears and bending moments.

IV. COMPARISON OF RESULTS

Very good agreement is found between analysis results from 'QUAKE' and 'STARDYNE'. It is also true for results from 'QUAKE' and hand calculations. The comparisons of results from computer runs and verification by hand calculations are presented in Tables 2 through 9 listed below. For comparison of results due to base excitation, the case of 1/2 SSE in X-direction is selected for demonstration. However, the conclusion from these selected comparisons holds true for the earthquakes in the other two orthogonal directions.

(a) Frequencies and weighted dampings (Table 2),

(b) Spectral accelerations (Table 3),

(c) Absolute modal accelerations for the first and second modes (Tables 4 and 5),

(d) Comparison of modal combination of accelerations, based on Regulatory Guide 1.92, from 'QUAKE' and hand calculations for the first and second degrees-of-freedom (Table 6),

(e) Relative modal displacements for the first mode (Table 7),

(f) Modal forces for the first and second modes (Table 8),

(g) Comparison of modal shear forces and base moments for the shield building through hand calculation for the two major coupling components (Table 9).

The comparison of modal participation factors computed from 'QUAKE' and 'STARDYNE' can not be made directly because the mode shapes obtained from the former were normalized with respect to mass matrix while the latter with respect to maximum modal displacement. Note that the absolute modal accelerations are equal to the product of participation factors, modal shapes and spectral accelerations. Since both the absolute modal accelerations and spectral accelerations were shown to be correct, it can be concluded that the participation factors are also correct.

SRSS combination of modal shear forces and base moments are computed through the same routine used in the combination of the absolute acceleration as shown in Table 6, the validity of the procedure is thus established without additional demonstration necessary.

With all the comparisons shown above, program 'QUAKE' can thus be considered a valid and reliable program.

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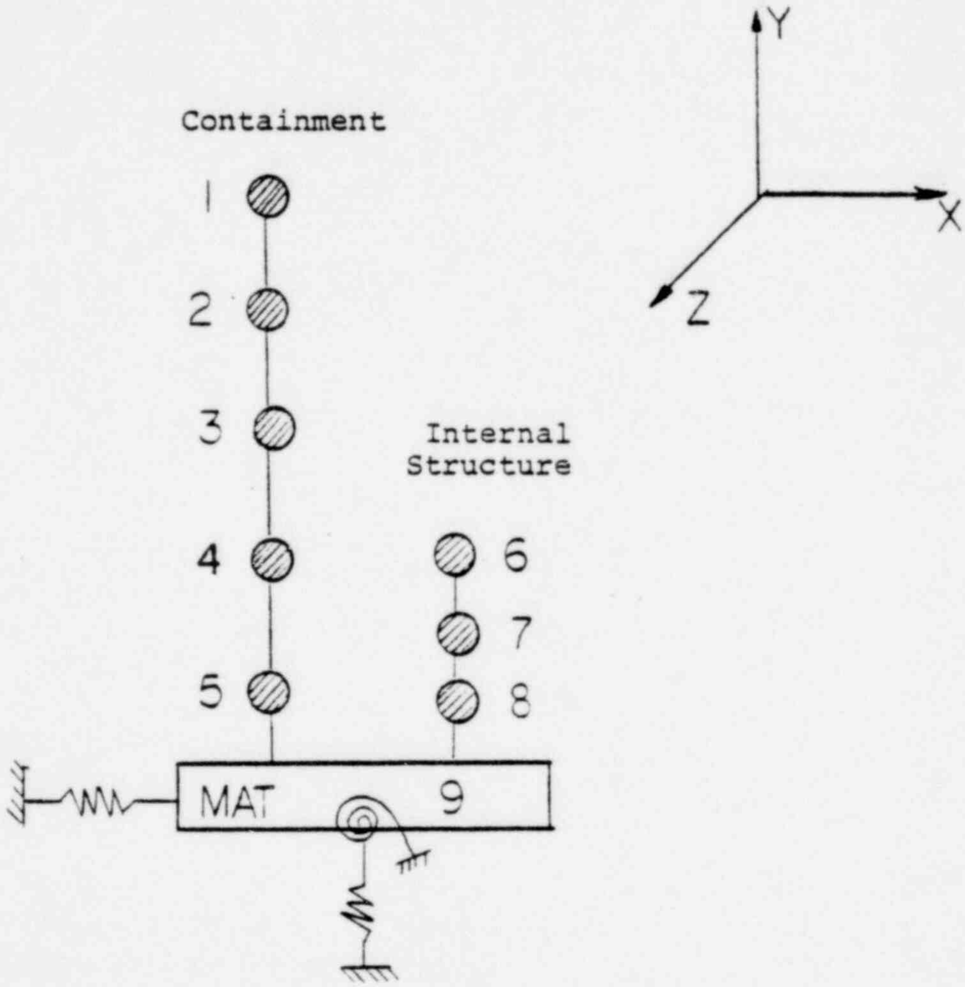

Fig. 1 Dynamic Model Of A PWR Nuclear Power Plant

TABLE 1 NODAL COORDINATES

Mass Point	X (ft)	Y (ft)	Z (ft)
1	0.	246.6	0.
2	0.	197.0	0.
3	0.	145.0	0.
4	0.	87.75	0.
5	0.	29.25	0.
6	9.45	89.83	4.44
7	-0.28	55.94	8.27
8	-5.87	26.98	2.42
9	2.40	-7.75	0.38
Soil Spring	0.	-18.85	0.

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TABLE 2 COMPARISON OF FREQUENCIES AND WEIGHTED DAMPINGS

	FREQUENCIES (HZ)		WEIGHTED DAMPINGS	
MODE	QUAKE	STARDYNE	QUAKE	STARDYNE
1	3.289	3.2894	0.04282	0.04282
2	3.290	3.2904	0.04280	0.04280
3	6.317	6.3165	0.04320	0.04320
4	7.002	7.0019	0.04472	0.04472
5	7.462	7.4616	0.04102	0.04102
6	9.019	9.0186	0.04106	0.04106
7	9.673	9.6730	0.06347	0.06347
8	10.238	10.2380	0.04319	0.04319
9	10.252	10.2517	0.04295	0.04295
10	14.684	14.6841	0.05879	0.05879
11	15.220	15.2198	0.05055	0.05055
12	16.665	16.6648	0.05875	0.05875
13	18.524	18.5237	0.04218	0.04218
14	18.765	18.7656	0.04183	0.04183
15	19.172	19.1725	0.04177	0.04177
16	19.576	19.5761	0.04328	0.04328
17	20.119	20.1187	0.04211	0.04211
18	20.626	20.6256	0.04018	0.04018
19	20.960	20.9596	0.04094	0.04094
20	22.379	22.3791	0.04582	0.04582
21	23.356	23.3563	0.05377	0.05377
22	23.820	23.8203	0.05050	0.05050
23	24.903	24.9027	0.04253	0.04253
24	26.171	26.1711	0.04313	0.04313
25	26.250	26.2502	0.04214	0.04214
26	27.499	27.4987	0.04779	0.04779
27	27.618	27.6179	0.04988	0.04988
28	28.317	28.3166	0.04130	0.04130
29	28.706	28.7060	0.04193	0.04193
30	28.817	28.8167	0.04487	0.04487
31	29.251	29.2507	0.05185	0.05185
32	30.477	30.4768	0.04462	0.04462
33	31.293	31.2935	0.04331	0.04331
34	33.302	33.3019	0.04178	0.04178
35	33.645	33.6448	0.04705	0.04705
36	35.726	35.7262	0[illegible]503	0.04503
37	37.197	37.1965	0.[illegible]4029	0.04029
38	38.628	38.6280	0.04065	0.04065
39	39.501	39.5[illegible]	0.04048	0.04048
40	39.997	39.9969	0.04059	0.04059
41	40.155	40.1549	0.04043	0.04043
42	41.576	41.5756	0.04211	0.04211
43	42.259	42.2596	0.04056	0.04056
44	44.259	44.2591	0.04030	0.04030
45	49.081	49.0810	0.04034	0.04034
46	52.966	52.9656	0.04028	0.04028
47	53.047	53.0469	0.04028	0.04028
48	54.012	54.0111	0.04034	0.04034
49	56.816	56.8157	0.04010	0.04010

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TABLE 2 COMPARISON OF FREQUENCIES AND WEIGHTED DAMPINGS

MODE	FREQUENCIES (HZ) QUAKE	STARDYNE	WEIGHTED DAMPINGS QUAKE	STARDYNE
50	56.854	56.8545	0.04012	0.04012
51	59.112	59.1113	0.04011	0.04011
52	69.698	69.6981	0.04005	0.04005
53	73.706	73.7060	0.04004	0.04004
54	81.125	81.1249	0.04003	0.04003

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TABLE 3 SPECTRAL ACCELERATIONS (in G's)

MODE	HORIZONTAL (X AND/OR Z) QUAKE	STARDYNE	VERTICAL (Y) QUAKE	STARDYNE
1	0.189770	.190220E+00	0.180343	.178495E+00
2	0.189786	.190237E+00	0.180415	.178567E+00
3	0.172822	.172880E+00	0.173567	.172803E+00
4	0.168370	.168417E+00	0.168873	.168361E+00
5	0.171861	.171773E+00	0.172133	.171735E+00
6	0.167134	.166930E+00	0.166988	.166930E+00
7	0.135579	.135232E+00	0.135669	.135232E+00
8	0.148869	.148770E+00	0.148756	.148770E+00
9	0.148972	.148865E+00	0.148859	.148865E+00
10	0.104819	.104624E+00	0.104834	.104624E+00
11	0.105857	.105960E+00	0.105827	.105960E+00
12	0.096080	.959297E-01	0.096092	.959297E-01
13	0.094284	.942425E-01	0.094248	.942425E-01
14	0.093445	.934019E-01	0.093410	.934019E-01
15	0.091904	.918623E-01	0.091870	.918623E-01
16	0.089972	.899461E-01	0.089942	.899461E-01
17	0.088400	.883667E-01	0.088371	.883667E-01
18	0.087197	.871536E-01	0.087169	.871536E-01
19	0.085899	.858619E-01	0.085873	.858619E-01
20	0.080621	.806233E-01	0.080603	.806233E-01
21	0.076845	.768246E-01	0.076840	.768246E-01
22	0.076217	.762488E-01	0.076208	.762488E-01
23	0.074744	.747296E-01	0.074730	.747296E-01
24	0.071841	.718310E-01	0.071830	.718310E-01
25	0.071773	.717603E-01	0.071762	.717603E-01
26	0.068784	.687938E-01	0.068777	.687938E-01
27	0.068417	.684373E-01	0.068412	.684373E-01
28	0.067693	.676841E-01	0.067686	.676841E-01
29	0.066931	.669240E-01	0.066925	.669240E-01
30	0.066567	.665658E-01	0.066562	.665658E-01
31	0.065494	.654967E-01	0.065492	.654967E-01
32	0.063779	.637772E-01	0.063775	.637772E-01
33	0.062523	.625210E-01	0.062521	.625210E-01
34	0.060000	.600000E-01	0.060000	.600000E-01
35	0.060000	.600000E-01	0.060000	.600000E-01
36	0.060000	.600000E-01	0.060000	.600000E-01
37	0.060000	.600000E-01	0.060000	.600000E-01
38	0.060000	.600000E-01	0.060000	.600000E-01
39	0.060000	.600000E-01	0.060000	.600000E-01
40	0.060000	.600000E-01	0.060000	.600000E-01
41	0.060000	.600000E-01	0.060000	.600000E-01
42	0.060000	.600000E-01	0.060000	.600000E-01
43	0.060000	.600000E-01	0.060000	.600000E-01
44	0.060000	.600000E-01	0.060000	.600000E-01
45	0.060000	.600000E-01	0.060000	.600000E-01
46	0.060000	.600000E-01	0.060000	.600000E-01
47	0.060000	.600000E-01	0.060000	.600000E-01
48	0.060000	.600000E-01	0.060000	.600000E-01
49	0.060000	.600000E-01	0.060000	.600000E-01

TABLE 3 SPECTRAL ACCELERATIONS (in G's)

MODE	HORIZONTAL (X AND/OR Z) QUAKE	STARDYNE	VERTICAL (Y) QUAKE	STARDYNE
50	0.060000	.600000E-01	0.060000	.600000E-01
51	0.060000	.600000E-01	0.060000	.600000E-01
52	0.060000	.600000E-01	0.060000	.600000E-01
53	0.060000	.600000E-01	0.060000	.600000E-01
54	0.060000	.600000E-01	0.060000	.600000E-01

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TABLE 4 MODAL ACCELERATION COMPARISON - Mode 1 (in G's)

DOF	QUAKE	STARDYNE
1	0.174543E-02	0.174525E-2
2	-0.160066E-05	-0.160235E-5
3	0.233091E-01	0.233358E-1
4	0.786848E-04	0.787749E-4
5	-0.245330E-07	-0.245642E-7
6	-0.589219E-05	-0.589158E-5
7	0.139659E-02	0.139644E-2
8	-0.157366E-05	-0.157529E-5
9	0.186507E-01	0.186720E-1
10	0.788243E-04	0.789145E-4
11	-0.242828E-07	-0.243138E-7
12	-0.590264E-05	-0.590202E-5
13	0.101904E-02	0.101894E-2
14	-0.155626E-05	-0.155789E-5
15	0.136089E-01	0.136244E-1
16	0.738709E-04	0.739555E-4
17	-0.237756E-07	-0.238061E-7
18	-0.553172E-05	-0.553114E-5
19	0.580324E-03	0.580264E-3
20	-0.151635E-05	-0.151795E-5
21	0.775012E-02	0.775899E-2
22	0.594585E-04	0.595266E-4
23	-0.225085E-07	-0.225373E-7
24	-0.445249E-05	0.445203E-5
25	0.186918E-03	0.186899E-3
26	-0.145628E-05	-0.145781E-5
27	0.249649E-02	0.249935E-2
28	0.321236E-04	0.321604E-4
29	-0.205209E-07	-0.205471E-7
30	-0.240561E-05	-0.240536E-5
31	0.175045E-03	0.175043E-3
32	-0.832334E-04	-0.833121E-4
33	0.233840E-02	0.234108E-2
34	0.169495E-04	0.169689E-4
35	-0.188876E-05	-0.189094E-5
36	-0.148701E-05	-0.148716E-5
37	0.114839E-03	0.114829E-3
38	-0.131871E-03	-0.132020E-3
39	0.159738E-02	0.159921E-2
40	0.164543E-04	0.164731E-4
41	-0.127531E-05	-0.127680E-5
42	-0.140895E-05	-0.140907E-5
43	0.764824E-04	0.764773E-4
44	-0.289521E-04	-0.289927E-4
45	0.100841E-02	0.100956E-2
46	0.152328E-04	0.152502E-4
47	-0.402359E-06	-0.402836E-6
48	-0.126107E-05	-0.126109E-5
49	0.302338E-04	0.302308E-4

1541 045

TABLE 4 MODAL ACCELERATION COMPARISON - Mode 1 (in G's)

DOF	QUAKE	STARDYNE
50	-0.903831E-05	-0.904547E-5
51	0.404266E-03	0.404729E-3
52	0.136146E-04	0.136301E-4
53	-0.192120E-07	-0.192366E-7
54	-0.101963E-05	-0.101952E-5

1541 046

TABLE 5 MODAL ACCELERATION COMPARISON - Mode 2 (in G's)

DOF	QUAKE	STARDYNE
1	0.310599E+00	0.311341E+0
2	-0.214465E-04	-0.214999E-4
3	-0.232555E-01	-0.232821E-1
4	-0.785024E-04	-0.785921E-4
5	0.518279E-06	0.519490E-6
6	-0.104850E-02	-0.105101E-2
7	0.248518E+00	0.249111E+0
8	-0.210783E-04	-0.211302E-4
9	-0.186074E-01	-0.186286E-1
10	-0.786416E-04	-0.787314E-4
11	0.512989E-06	0.514187E-6
12	-0.105036E-02	-0.105287E-2
13	0.181326E+00	0.181760E+0
14	-0.208448E-04	-0.208966E-4
15	-0.135767E-01	-0.135922E-1
16	-0.736966E-04	-0.737808E-4
17	0.502269E-06	0.503441E-6
18	-0.984314E-03	-0.986668E-3
19	0.103246E+00	0.103493E+0
20	-0.203102E-04	-0.203606E-4
21	-0.773068E-02	-0.773952E-2
22	-0.593087E-04	-0.593764E-4
23	0.475478E-06	0.476586E-6
24	-0.792150E-03	-0.794045E-3
25	0.332367E-01	0.333162E-1
26	-0.195049E-04	-0.195534E-4
27	-0.248893E-02	-0.249178E-2
28	-0.320207E-04	-0.320572E-4
29	0.433460E-06	0.434467E-6
30	-0.427695E-03	-0.428718E-3
31	0.288000E-01	0.288689E-1
32	-0.228943E-02	-0.229500E-2
33	-0.224332E-02	-0.224577E-2
34	-0.143306E-04	-0.143438E-4
35	0.467390E-05	0.468269E-5
36	-0.221383E-03	-0.221913E-3
37	0.202740E-01	0.203225E-1
38	-0.590659E-04	-0.593705E-4
39	-0.153119E-02	-0.153287E-2
40	-0.140853E-04	-0.140985E-4
41	0.598524E-05	0.599792E-5
42	-0.212995E-03	-0.213505E-3
43	0.132020E-01	0.132336E-1
44	0.110297E-02	0.110556E-2
45	-0.984814E-03	-0.985914E-3
46	-0.134569E-04	-0.134702E-4
47	0.299470E-05	0.300134E-5
48	-0.202454E-03	-0.202939E-3

TABLE 5 MODAL ACCELERATION COMPARISON - Mode 2 (in G's)

DOF	QUAKE	STARDYNE
49	0.536445E-02	0.537728E-2
50	-0.448052E-03	-0.449131E-3
51	-0.403068E-03	-0.403528E-3
52	-0.135438E-04	-0.135592E-4
53	0.405787E-06	0.406732E-6
54	-0.180921E-03	-0.181354E-3

1541 048

TABLE 6 MODAL COMBINATION COMPARISON

(Check Accelerations for First Two D.O.F.'s)

MODE	FREQUENCY (Hz)	GROUP NO.	FIRST D.O.F. MODAL ACC. (G)	FIRST D.O.F. GROUP SUM SQUARE*	SECOND D.O.F. MODAL ACC. (G)	SECOND D.O.F. GROUP SUM SQUARE*
1	3.289		.174543E-2		-.160066E-5	
2	3.290	1	.310599E 0	9.7559E-2	-.2214465E-4	5.3117E-10
3	6.317	2	.329135E-4	1.0833E-9	-.102472E-4	1.0501E-10
4	7.002		-.467814E-1		-.174962E-2	
5	7.462	3	-.294389E-3	2.2161E-3	-.106245E-4	3.0985E-6
6	9.019		-.313862E-3		.458347E-4	
7	9.673	4	-.332767E-3	4.1815E-7	.933138E-2	8.7932E-5
8	10.238		-.106221E-1		-.593546E-3	
9	10.252	5	-.987398E-1	1.1960E-2	-.329356E-2	1.5108E-5
10	14.684		.349282E-2		-.248641E-1	
11	15.220	6	.639873E-4	1.2650E-5	-.687655E-3	[illegible].5289E-4
12	16.665	7	.289821E-1	8.3996E-4	.295999E-1	8.7615E-4
13	18.524		.193434E-3		-.143106E-3	
14	18.765		.536154E-2		-.158420E-2	
15	19.172		-.581545E-3		.542822E-4	
16	19.576		.708787E-3		-.201251E-3	
17	20.119	8	.282031E-1	1.2284E-3	-.742782E-3	7.4290E-6
18	20.626		-.376743E-3		-.734061E-4	
19	20.960		.301979E-4		-.204669E-4	
20	22.379	9	-.271671E-2	9.7572E-6	-.108798E-1	1.2042E-4
21	23.356		-.143886E-4		-.364792E-4	
22	23.820		-.336823E-1		.276438E-2	
23	24.903	10	-.725651E-3	1.1850E-3	-.939570E-2	1.4880E-4
24	26.171		-.980660E-3		.984709E-2	
25	26.250		-.169391E-4		.469699E-3	
26	27.499		.105736E-1		.695947E-2	
27	27.618		.716228E-2		.106847E-2	
28	28.317		-.129457E-4		-.160336E-4	
29	28.706	11	-.561036E-3	3.7278E-4	.491361E-3	3.5540E-4
30	28.817		-.182691E-2		.504823E-3	
31	29.251		-.433310E-2		-.774133E-2	
32	30.477		.202638E-3		.440079E-5	
33	31.293	12	.218277E-3	4.3309E-5	-.180205E-3	7.1078E-5

1541 049

TABLE 6 MODAL COMBINATION COMPARISON

(Check Accelerations for First Two D.O.F.'s)

MODE	FREQUENCY (Hz)	GROUP NO.	FIRST D.O.F. MODAL ACC. (G)	FIRST D.O.F. GROUP SUM SQUARE*	SECOND D.O.F. MODAL ACC. (G)	SECOND D.O.F. GROUP SUM SQUARE*
34	33.302		.644488E-5		.776371E-5	
35	33.645		-.391534E-4		-.745290E-4	
36	35.726	13	-.391811E-3	1.9133E-7	.295403E-3	1.4265E-7
37	37.197		-.121[illegible]2E-4		.685940E-4	
38	38.628		.192484E-4		-.316540E-3	
39	39.501		.671180E-3		.162576E-3	
40	39.997		.959826E-4		.609032E-4	
41	40.155	14	.300691E-6	6.3810E-7	.159994E-6	3.7060E-7
42	41.576		.413844E-6		.142499E-6	
43	42.259		.688781E-5		.356304E-6	
44	44.259	15	-.109058E-5	7.0430E-11	.271022E-5	1.0298E-11
45	49.081		.747342E-5		.219735E-4	
46	52.966		-.354846E-4		.134476E-4	
47	53.047	16	-.125383E-3	2.8339E-8	.610884F-4	9.3141E-9
48	54.012		-.113180E-4		-.880168E-4	
49	56.816		.459657E-5		-.692842E-6	
50	56.854		.641094E-4		-.929218E-5	
51	59.112	17	.145388E-6	6.4271E-9	.136767E-4	1.2472E-8
52	69.698		.221186E-7		-.766261E-7	
53	73.706	18	.604236E-9	5.1633E-16	-.458925E-8	6.5959E-15
54	81.125	19	.867458E-9	7.5248E-19	.324068E-8	1.0502E-17
			Σ =	1.1543E-1		2.3389E-3
			SRSS=(Σ) 1/2	3.3975E-1		4.8362E-2
			SRSS FROM QUAKE	3.39747E-1		4.83617E-2

1541 050

* Based on the grouping method, Section 1.2.1, NRC Regulatory Guide 1.92, February 1976

TABLE 7 RELATIVE MODEL DISPLACEMENTS (IN FT AND RADIAN) - MODE 1

DOF	QUAKE	STARDYNE
1	0.131459E-03	0.131558E-03
2	-0.120556E-06	-0.120786E-06
3	0.175556E-02	0.175907E-02
4	0.592626E-05	0.593811E-05
5	-0.184774E-08	-0.185167E-09
6	-0.443779E-06	-0.444112E-06
7	0.105186E-03	0.105265E-03
8	-0.118522E-06	-0.118747E-06
9	0.140470E-02	0.140751E-02
10	0.593677E-05	0.594864E-06
11	-0.182889E-08	-0.183279E-09
12	-0.444565E-06	-0.444899E-06
13	0.767508E-04	0.768084E-04
14	-0.117212E-06	-0.117434E-06
15	0.102497E-02	0.102702E-02
16	0.556369E-05	0.557482E-05
17	-0.179069E-08	-0.179452E-08
18	-0.416629E-06	-0.416942E-06
19	0.437079E-04	0.437407E-04
20	-0.114206E-06	-0.114424E-06
21	0.583711E-03	0.584879E-03
22	0.447820E-05	0.448716E-05
23	-0.169526E-08	-0.169888E-08
24	-0.335345E-06	-0.335597E-06
25	0.140780E-04	0.140885E-04
26	-0.109682E-06	-0.109891E-06
27	0.188027E-03	0.188403E-03
28	0.241943E-05	0.242427E-05
29	-0.154556E-08	-0.154886E-08
30	-0.181182E-06	-0.181318E-06
31	0.131838E-04	0.131949E-04
32	-0.626884E-05	-0.628013E-05
33	0.176120E-03	0.176472E-03
34	0.127658E-05	0.127912E-05
35	-0.142254E-06	-0.142540E-06
36	-0.111996E-06	-0.112103E-06
37	0.864929E-05	0.865587E-06
38	-0.993283E-05	-0.995180E-05
39	0.120309E-03	0.120549E-03
40	0.123928E-05	0.124175E-05
41	-0.960515E-07	-0.962461E-07
42	-0.106117E-06	-0.106217E-06
43	0.576038E-05	0.576492E-05
44	-0.218056E-05	-0.218549E-05
45	0.759498E-04	0.761017E-04
46	0.114728E-05	0.114957E-05
47	-0.303042E-07	-0.303661E-07
48	-0.949789E-07	0.950618E-07
49	0.227710E-05	0.227882E-05

1541 051

TABLE 7 RELATIVE MODEL DISPLACEMENTS (IN FT AND RADIAN) - MODE 1

DOF	QUAKE	STARDYNE
50	-0.680733E-06	-0.681854E-06
51	0.304479E-04	0.305087E-04
52	0.102540E-05	0.102745E-05
53	-0.144698E-08	-0.145007E-08
54	-0.767945E-07	-0.768525E-07

1541 052

TABLE 8 MODEL FORCE COMPARISON (IN KIP AND KIP-FT)

DOF	MODE 1 QUAKE	MODE 1 CALCULATED	MODE 2 QUAKE	MODE 2 CALCULATED
1	0.971477E+01	0.971478E+1	0.172874E+04	0.172874E+4
2	-0.890901E-02	-0.890902E-2	-0.119368E+00	-0.119368E+0
3	0.129735E+03	0.129735E+3	-0.129436E+03	-0.129436E+3
4	0.471869[illegible]+03	0.471869E+3	-0.470775E+03	-0.470775E+3
5	-0.268753E+00	-0.268752E+0	0.567761E+01	0.56776[illegible]E+1
6	-0.353352E+02	-0.353352E+2	-0.628781E+04	0.628781E+4
7	0.168494E+02	0.168494E+2	0.299829E+04	0.299829E+4
8	-0.189857E-01	-0.189857E-1	-0.254303E+00	-0.254303E+0
9	0.225015E+03	0.225015E+3	-0.224492E+03	-0.[illegible]4492E+3
10	0.244975E+04	0.244975E+4	-0.244407E+04	-0.244407E+4
11	-0.135466E+01	-0.135466E+1	0.286182E+02	0.286182E+2
12	-0.183446E+03	-0.183446E+3	-0.326438E+05	-0.326437E+5
13	0.177696E+02	0.177695E+2	0.316188E+04	0.316187E+4
14	-0.277882E-01	-0.277882E-1	-0.372200E+00	-0.372199E+0
15	0.237305E+03	0.237305E+3	-0.236743E+03	-0.236743E+3
16	0.331537E+04	0.331537E+4	-0.330755E+04	-0.330755E+4
17	-0.191995E+01	-0.191995E+1	0.405597E+02	0.405597E+2
18	-0.248267E+03	-0.248267E+3	-0.441767E+05	-0.441766E+5
19	0.100447E+02	0.100447E+2	0.178707E+04	0.178706E+4
20	-0.262462E-01	-0.262462E-1	-0.351545E+00	-0.351545E+0
21	0.134145E+03	0.134145E+3	-0.133809E+03	-0.133809E+3
22	0.279862E+04	0.279861E+4	-0.279156E+04	-0.279156E+4
23	-0.189583E+01	-0.189583E+1	0.400484E+02	0.400484E+2
24	-0.209571E+03	-0.209571E+3	-0.372852E+05	-0.372852E+5
25	0.323532E+01	0.323532E+1	0.575288E+03	0.575287E+3
26	-0.252065E-01	-0.252064E-1	-0.337607E+00	-0.337606E+0
27	0.432113E+02	0.432112E+2	0.430805E+02	0.430804E+2
28	0.151200E+04	0.151200E+4	-0.150716E+04	-0.150716E+4
29	-0.172843E+01	-0.172843E+1	0.365093E+02	0.365093E+2
30	-0.113228E+03	-0.113228E+3	-0.201309E+05	-0.201309E+5
31	0.247792E+01	0.247792E+1	0.407690E+03	0.407690E+3
32	-0.117824E+01	-0.117824E+1	-0.324090E+02	-0.324089E+2
33	0.331022E+02	0.331022E+2	-0.317562E+02	-0.317562E+2
34	0.327076E+03	0.327075E+3	-0.276538E+03	-0.276538E+3
35	-0.597026E+02	-0.597027E+2	0.147739E+03	0.147739E+3
36	-0.205524E+02	-0.205524E+2	-0.305980E+04	-0.305980E+4
37	0.261583E+01	0.261582E+1	0.461805E+03	0.461804E+3
38	-0.225283E+01	-0.225283E+1	-0.100906E+01	-0.100906E+1
39	0.364881E+02	0.364881E+2	-0.349763E+02	-0.349762E+2
40	0.432182E+03	0.432182E+3	-0.369959E+03	-0.369959E+3
41	-0.456251E+02	-0.456252E+2	0.214127E+03	0.214127E+3
42	-0.282675E+02	-0.282674E+2	-0.427327E+04	-0.427327E+4
43	0.148130E+01	0.148130E+1	0.255695E+03	0.255694E+3
44	-0.596134E+00	-0.596135E+0	0.227106E+02	0.227106E+2
45	0.195307E+02	0.195307E+2	-0.190737E+02	-0.190737E+2
46	0.216074E+03	0.216075E+3	-0.190884E+03	-0.190884E+3
47	-0.127481E+02	-0.127481E+2	0.948826E+02	0.948825E+2
48	-0.238642E+02	-0.238643E+2	-0.383122E+04	-0.383121E+4

1541 053

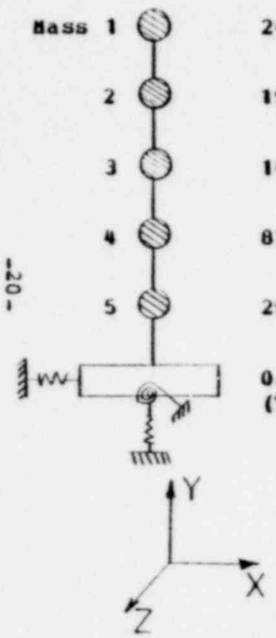
TABLE 8 MODEL FORCE COMPARISON (IN KIP AND KIP-FT)

49	0.177128E+01	0.177128E+1	0.314282E+03	0.314282E+3
50	-0.569643E+00	-0.569648E+0	-0.282389E+02	-0.282389E+2
51	0.236844E+02	0.236844E+2	-0.236142E+02	-0.236142E+3
52	0.922021E+03	0.922023E+3	-0.917229E+03	-0.917228E+3
53	-0.240378E+01	-0.240378E+1	0.507716E+02	0.507716E+2
54	-0.711516E+02	-0.711519E+2	-0.126251E+05	-0.126251E+5

1541 054

TABLE 9 COMPARISON OF SHEAR FORCES AND BASE MOMENTS

(INTERNAL LOADS) MODE 1



	Containment Elevation (ft)	Calculated Modal Force (KIP & KIP-ft)	Calculated Modal Shear & Base Moment (Kip & Kip-ft)	QUAKE Result (KIP & KIP-ft)
Mass 1	246.60	Fx: 9.71478	9.71478	9.7148
		Mz: -35.3352	-35.3352	-35.335
2	197.00	Fx: 16.8494	9.71478 + 16.8494 = 26.56418	26.564
		Mz: -183.446	-9.71478 x 49.6-35.3352-183.446=-700.634	-700.63
3	145.00	Fx: 17.7695	26.56418+17.7695=44.33368	44.334
		Mz: -248.267	-700.634-26.56418x52-248.267=-2330.2384	-2330.23
4	87.75	Fx: 10.0447	44.33368+10.0447=54.37838	54.379
		Mz: -209.571	-2330.2384-44.33368x57.25-209.571=-5077.9126	-5077.9
5	29.25	Fx: 3.2352	54.37838+3.2352=57.61358	57.614
		Mz: -113.228	-5077.9126-54.37838x58.5-113.228=-8372.2758	-8372.3
	0.0 (Top of Mat)	Fx: 57.61358		57.64
		Mz: 8372.2758-57.61358x29.25=-100057.4731		-10057.0

1541 055

APPENDIX A

I. Computer Program (QUAKE)

This program performs the dynamic analysis of a lumped mass system. The input information includes mass data, structural stiffness, soil spring constants, structure and soil damping values and other data related to the dynamic analysis model. Program "QUAKE" has the following capabilities:

(1) Extracting the eigenvalues and the corresponding eigenvectors from the following equation,

$$\left(\frac{1}{\omega^2} [I] - [\delta][m]\right) \{\phi\} = 0 \qquad (1)$$

where

$[I]$ = the unit matrix

ω = the natural circular frequency

$[m]$ = the mass matrix

$[\delta]$ = the flexibility matrix

$\{\phi\}$ = the column matrix of eigenvectors

Equation (1) can be written in terms of the stiffness matrix $[k]$ as follows:

$$\left([k] - \omega^2 [m]\right) \{\phi\} = 0 \qquad (2)$$

In order to extract eigenvalues and eigenvectors, equation (1) is converted into the following form:

$$[m] = [U]^T [U] \qquad (3)$$

In general, matrix $[U]$ consists of diagonal and upper-diagonal elements only.

Substitution of $[m]$ from equation (3) and $\{\phi\}$ from equation $\{\phi\} = [U]^{-1} \{\bar{\Phi}\}$ into equation (2) yields:

$$\left([k][U]^{-1} - \omega^2 [U]^T [U][U]^{-1}\right) \{\bar{\Phi}\} = 0 \qquad (4)$$

1541 056

Premultiplication of Equation (4) by $[U][k]^{-1}$ yields the Equation:

$$\left(\frac{1}{\omega^2}[I] - [U][\delta][U]^T\right)\{\bar{\Phi}\} = 0 \qquad (5)$$

The matrix product $[U][\delta][U]^T$ is a symmetric matrix. The eigenvalues and eigenvectors are extracted from Equation (5) using a subroutine called EIGEN of IBM. This subroutine uses an algorithm known as the Jacobi Diagonalization method.

The mode shapes $[\phi]$ as corresponding eigenvectors of Equation (1) are obtained from the following equation:

$$[\phi] = [U]^{-1}[\bar{\Phi}] \qquad (6)$$

(2) Computing participation factors Γ using matrix manipulation in the following manner:

$$\{\Gamma\}_j = [M]^{-1}[\phi]^T[m]\{D\}_j \qquad (7)$$

where

$$[M] = [\phi]^T[m][\phi] \qquad (8)$$

and

$[\phi]$ = the matrix of mode shapes

$[\phi]^T$ = the transpose of mode shape matrix

$\{\Gamma\}_j$ = the column matrix of participation factors for seismic motion in the jth direction

$\{D\}_j$ = the column matrix governed by the seismic motion in jth direction

$[m]$ = the mass matrix

The normalization and orthogonality conditions are represented by the matrix equation (8)

(3) Computing equivalent modal damping (or composite modal damping) according to the energy stored in each component and in each vibration mode.

Each component, such as concrete structures, steel structures and systems, and foundation materials, can have different damping properties. The effective damping in any vibration mode of the total system depends upon the degree of participation of these materials in the modal response.

The flexibility matrices $[\delta]_r$ for each component r that have inherently different damping properties are formed. The summation of these flexibility matrices yields the total flexibility matrix of the composite system $[\delta]$.

where,

$$[\delta] = \sum_{1}^{N} [\delta]_r \qquad (9)$$

After the free vibration characteristics are generated using flexibility matrix $[\delta]$, obtained according to Equation (9), the stiffness matrix $[k]$ of the entire system is obtained by the inversion of flexibility matrix as follows:

$$[k] = [\delta]^{-1} \qquad (10)$$

Then the fictitious force matrix $[f]$ is obtained as a product of the stiffness matrix and mode shape matrix $[\phi]$ as follows:

$$[f] = [k][\phi] \qquad (11)$$

The mode shape matrix $[\phi]_r$ for each component r is generated as follows:

$$[\phi]_r = [\delta]_r [f] \qquad (12)$$

The stiffness matrix for each component r is obtained by inverting the corresponding flexibility matrix as shown by equation,

$$[k]_r = [\delta]_r^{-1} \qquad (13)$$

For foundation components, that is, for each foundation spring constant, the stiffness matrix $[k]_r$ has a single value on the diagonal.

Matrix $[K]_r$ which represents the energy stored in each mode of component r is calculated from the following equation in matrix form:

$$[K]_r = [\phi]_r^T [k]_r [\phi]_r \qquad (14)$$

Matrix [2E] which represents the total energy stored in the entire system is obtained as follows:

$$[2E] = [M][\omega^2] \qquad (15)$$

where

$[M] = [\phi]^T [m][\phi]$ = the generalized mass matrix

ω = the circular natural frequency

$[m]$ = the mass matrix

$[\phi]$ = the mode shape matrix

$[\phi]^T$ = the transpose of mode shape matrix

Energy matrix corresponding to the last component N is generated as presented in the following equation in matrix form:

$$[K]_N = [2E] - \sum_{r=1}^{r=N-1} [K]_r \qquad (16)$$

Then the column matrix of weighted modal damping ratios {D} is calculated from the following equation:

$$\{D\} = [2E]^{-1} \left[\sum_{r=1}^{r=N} [K]_r \{D\}_r \right] \qquad (17)$$

where

$\{D\}_r$ = the column matrix of damping ratios for component r.

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Fraction of modal energy components is generated as follows:

$$\{MEC\}_r = [2E]^{-1}[K]_r\{1\} \qquad (18)$$

Then, as a check, total summation of these fractions is obtained, which is equal unity:

$$\sum_{r=1}^{r=N} \{MEC\} = \{1\} \qquad (19)$$

(4) Computing absolute modal accelerations, relative displacements and inertia loads using spectrum approach.

The matrix of maximum modal absolute accelerations $[\ddot{W}]$ is obtained from the following equation in matrix form:

$$[\ddot{W}] = [\phi][Sa][\Gamma] \qquad (20)$$

where

$[\phi]$ = the mode shape matrix

$[Sa]$ = the diagonal matrix of maximum modal spectral accelerations

$[\Gamma]$ = the diagonal matrix of modal participation factors

The matrix of maximum modal relative displacements $[d]$ is computed by

$$[d] = [\ddot{W}]\left[\frac{1}{\omega^2}\right] \qquad (21)$$

where

$\left[\frac{1}{\omega^2}\right]$ = the diagonal matrix of eigenvalues, if the flexibility matrix is used in the equation for the extraction of eigenvalues and eigenvectors.

The matrix of maximum modal inertia forces $[F]$ is the product of mass matrix $[m]$ and maximum modal acceleration matrix $[\ddot{W}]$.

$$[F] = [m][\ddot{W}] \qquad (22)$$

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The maximum modal inertia forces [F] are combined by the square root of the sum of the squares (in accordance with NRC Regulatory Guide 1.92), by absolute sum and by algebraic sum.

(5) Calculation of modal shears and moments of statically determinate structures, and combining them by the square root of the sum of the squares of modal values, by absolute sum and by algebraic sum.

The matrix of modal shears and bending moments [Q] is computed from:

$$[Q]^T = [F]^T [J] \qquad (23)$$

where

$[F]^T$ = the transpose of the matrix of inertia forces and inertia moment

$[J]$ = summation matrix

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VERIFICATION OF

SPECTRA

COMPUTER PROGRAM

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VERIFICATION OF COMPUTER PROGRAM SPECTRA

I. PROGRAM FUNCTION

This is a two-part computer program which stores both the horizontal and vertical ground (acceleration) design response spectra, as given by NRC Regulatory Guide 1.60, in the form of polynomial functions. The program can also compute the spectral value for a given pair of frequency and damping value.

Basically, the program divides into two parts. The first part of the program is to find, for each control frequency, a polynomial expression for the spectral amplification curve which is a function of damping values as determined from Regulatory Guide 1.60. This is done by using the least square fitting method described in References 1 and 2. A total of six curves, with three each for horizontal and vertical directions, are being fitted in such a manner. The polynomial expression so established are then built into the second part of the program which calculates spectral accelerations between the control frequencies for a given damping value in accordance with linear variations with frequencies in the log field. Thus, for a given pair of frequency and damping the spectral acceleration can be computed from one of the polynomial functions or from interpolation of the spectral values so computed.

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II. METHOD OF VERIFICATION

Six polynomial functions are established to fit the six sets of the NRC design response spectral acceleration values at six control points: the horizontal spectra at 0.25, 2.5 and 9 Hz, and the vertical spectra at 0.25, 3.5 and 9 Hz. Using these functions, the program can compute and interpolate in log-field the spectral value for a given frequency and damping value. These program calculated values are then compared with the values obtained from Regulatory Guide 1.60.

III. COMPARISON OF RESULTS

The spectral accelerations for various frequency and damping pairs calculated by the program are listed in Tables 1 and 2. The corresponding spectral values according to NRC Regulatory Guide 1.60 are also listed for comparison. Based on the closeness of the results, the program 'SPECTRA' can be considered satisfactory.

References:

1. Kelly, L.G., Handbook of Numerical Methods and Application, Addison - Wesley.

2. Library of Mathematical Subprograms, Reference Manual, Control Data Company.

TABLE 1

HORIZONTAL GROUND (ACCELERATION) DESIGN RESPONSE SPECTRA

Percent of Critical Damping	Freq. (cps)	NRC Values	Program Calculated Values	Percent of Critical Damping	Freq. (cps)	NRC Values	Program Calculated Values
	0.25	0.74	0.73		0.25	0.43	0.43
	1.0	2.59	2.58		1.0	1.31	1.31
0.5	2.5	5.95	5.93	7.0	2.5	2.72	2.72
	5.0	5.39	5.37		5.0	2.47	2.46
	9.0	4.96	4.94		9.0	2.27	2.26
	20.0	1.85	1.85		20.0	1.37	1.37
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.65	0.66		0.25	0.41	0.41
	1.0	2.25	2.28		1.0	1.24	1.24
	2.5	5.10	5.18		2.5	2.55	2.54
1.0	5.0	4.62	4.69	8.0	5.0	2.31	2.30
	9.0	4.25	4.31		9.0	2.13	2.12
	20.0	1.75	1.76		20.0	1.34	1.34
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.58	0.58		0.25	0.39	0.39
	1.0	1.89	1.92		1.0	1.13	1.13
2.0	2.5	4.25	4.25	10.0	2.5	2.28	2.28
	5.0	3.85	3.85		5.0	2.07	2.07
	9.0	3.54	3.54		9.0	1.90	1.91
	20.0	1.63	1.63		20.0	1.28	1.28
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.53	0.53				
	1.0	1.72	1.71				
	2.5	3.75	3.73				
3.0	5.0	3.41	3.39				
	9.0	3.15	3.12				
	20.0	1.56	1.55				
	33.0	1.00	1.00				
	0.25	0.47	0.47				
	1.0	1.47	1.48				
5.0	2.5	3.13	3.14				
	5.0	2.84	2.85				
	9.0	2.61	2.62				
	20.0	1.45	1.45				
	33.0	1.00	1.00				

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TABLE 2

VERTICAL GROUND (ACCELERATION) DESIGN RESPONSE SPECTRA

Percent of Critical Damping	Freq. (cps)	NRC Values	Program Calcu- lated Values	Percent of Critical Damping	Freq. (cps)	NRC Values	Program Calculated Values
	0.25	0.49	0.49		0.25	0.29	0.29
	1.0	1.77	1.77		1.0	0.91	0.91
0.5	3.5	5.67	5.65	7.0	3.5	2.59	2.58
	5.0	5.39	5.37		5.0	2.46	2.46
	9.0	4.96	4.94		9.0	2.27	2.26
	20.0	1.85	1.85		20.0	1.37	1.37
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.43	0.44		0.25	0.28	0.28
	1.0	1.54	1.57		1.0	0.87	0.86
	3.5	4.86	4.94		3.5	2.43	2.42
1.0	5.0	4.62	4.69	8.0	5.0	2.31	2.30
	9.0	4.25	4.31		9.0	2.13	2.12
	20.0	1.75	1.76		20.0	1.34	1.34
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.38	0.38		0.25	0.26	0.26
	1.0	1.33	1.32		1.0	0.79	0.79
2.0	3.5	4.05	4.05		3.5	2.17	2.18
	5.0	3.85	3.85	10.0	5.0	2.06	2.07
	9.0	3.54	3.54		9.0	1.90	1.91
	20.0	1.63	1.63		20.0	1.28	1.28
	33.0	1.00	1.00		33.0	1.00	1.00
	0.25	0.35	0.35				
	1.0	1.20	1.19				
	3.5	3.60	3.56				
3.0	5.0	3.42	3.39				
	9.0	3.15	3.12				
	20.0	1.56	1.55				
	33.0	1.00	1.00				
	0.25	0.31	0.32				
	1.0	1.02	1.03				
5.0	3.5	2.98	2.99				
	5.0	2.83	2.85				
	9.0	2.61	2.62				
	20.0	1.45	1.45				
	33.0	1.00	1.00				

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VERIFICATION OF

TIME

COMPUTER PROGRAM

1541 067

VERIFICATION OF COMPUTER PROGRAM TIME

I. PROGRAM FUNCTION

The program TIME is a routine used to develop floor response spectra for various equipment damping values from the floor time histories of a building under either ground excitation or force vibration. The program can also develop floor response spectra for soft floor condition by assuming the floor being a single degree of freedom system itself.

The program solves the uncoupled equations of motion using the method of LaPlace transforms. Exact solutions are obtained for these second order differential equations by assuming the forcing function (i.e., floor time history) to be linear between each time step. The analytical formulation of the problem is given in Reference 1.

II. METHOD OF VERIFICATION

The analysis results of a BWR nuclear power plant are chosen for the verification of this program. The dynamic model shown in Figure 1 is associated with a cracked concrete condition, unflooded case and upper bound soil springs. The model was subjected to a Safe Shutdown Earthquake in X-direction. The floor response spectra in X-direction at the top node (node 47) of reactor vessel for 2 and 3 percent equipment damping are obtained by using two different approaches. First, the floor response spectra are developed by TIME, then they are again developed by DYNRES of STARDYNE which is an established and well known program in public domain developed by Mechanics Research Incorporated (MRI). The results obtained by the latter approach, therefore, is used as the benchmark for verification of the program TIME.

III. COMPARISON OF RESULTS

The floor response spectra obtained for node 47 of the reactor vessel from programs TIME and DYNRES are shown in Table 1 for 2 and 3 percent equipment damping values. As can be seen from the comparison, the results from both programs agree exactly for periods above 0.10; however, the discrepencies, which range from 1 to 6 percent, are observed for the spectral values below that period. It is to be noted that the spectral values obtained from TIME are exact as mentioned previously, while the results obtained from DYNRES, though exact theoretically, are amenable to round-off approximation due to the integration technique used, particularly in

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the higher frequency range. For the spectral values which are obtained by TIME and differ from those obtained by DYNRE5 over 2 percent, are further verified by the program DYNRE1 of STARDYNE. The results from TIME and DYNRE1 are exactly the same as shown in Table 1. It can, therefore, be concluded that the program TIME is correct and dependable.

References:

1. D. Vancouvering, DYNRE1 Technical Description, Theoretical Manual of MRI/STARDYNE, pp. C-400-C-480.

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TABLE 1 COMPARISON OF FLOOR RESPONSE SPECTRA

Period (sec)	Spectral Acceleration (g)					
	2% equipment damping			3% equipment damping		
	TIME	DYNRES	DYNRE1	TIME	DYNRES	DYNRE1
0.0100	0.7669	0.7777		0.7670	0.7812	
0.0143	0.7560	0.7756	0.7560	0.7564	0.7752	0.7564
0.0200	0.7668	0.7765		0.7668	0.7766	
0.0222	0.7701	0.7796		0.7701	0.7796	
0.0250	0.7755	0.7842		0.7752	0.7840	
0.0263	0.7766	0.7859		0.7766	0.7858	
0.0278	0.7783	0.7872		0.7785	0.7874	
0.0303	0.7865	0.7945		0.7862	0.7944	
0.0333	0.7932	0.8058		0.7928	0.8052	
0.0364	0.7976	0.8110	0.7976	0.7975	0.8110	0.7975
0.0385	0.8057	0.8184		0.8048	0.8178	
0.0400	0.8108	0.8230		0.8108	0.8238	
0.0435	0.9272	0.9330		0.9089	0.9105	
0.0455	0.9847	0.9847		0.9577	0.9577	
0.0476	0.9560	0.9678		0.9316	0.9544	
0.0500	1.0170	1.0631	1.0170	1.0009	1.0270	1.0009
0.0526	1.2583	1.2583		1.1383	1.1883	
0.0556	1.3943	1.3943		1.3021	1.3021	
0.0588	1.5135	1.5135		1.3488	1.3488	
0.0606	1.5037	1.5903	1.5037	1.3556	1.4380	1.3556
0.0625	1.5162	1.5163		1.3862	1.3862	
0.0667	1.3885	1.4437	1.3885	1.1978	1.2497	1.1979
0.0690	1.4080	1.4080		1.3037	1.3114	
0.0714	1.5321	1.5569	1.5321	1.4084	1.4291	1.4084

Period (sec)	Spectral Acceleration (g)					
	2% equipment damping			3% equipment damping		
	TIME	DYNRE5	DYNRE1	TIME	DYNRE5	DYNRE1
0.0741	1.5607	1.5695		1.4546	1.4546	
0.0769	1.4678	1.5567	1.4678	1.3889	1.4192	1.3889
0.0800	1.5216	1.5216		1.4334	1.4334	
0.0833	2.1793	2.1793		1.8582	1.8608	
0.0870	1.9997	2.0243		1.8192	1.8337	
0.0909	1.8859	1.8859		1.5661	1.5858	
0.0952	1.7714	1.8091	1.7714	1.6160	1.6338	1.6160
0.1000	1.8304	1.8304		1.7602	1.7602	
0.1042	2.1360	2.1360		1.9823	1.9823	
0.1075	2.3906	2.3906		2.1645	2.1645	
0.1111	2.4647	2.4647		2.1469	2.1469	
0.1176	1.9994	1.9994		1.7935	1.7935	
0.1250	2.5742	2.5742		2.2998	2.2998	
0.1290	3.2954	3.2954		2.7776	2.7776	
0.1333	3.7542	3.7542		2.9873	2.9873	
0.1379	3.5311	3.5311		2.8838	2.8838	
0.1429	3.2579	3.2579		2.9290	2.9290	
0.1481	4.8062	4.8063		4.0953	4.0953	
0.1515	5.6867	5.6867		4.6958	4.6958	
0.1538	5.6070	5.6070		4.7719	4.7720	
0.1613	6.5735	6.5734		5.7952	5.7951	
0.1667	8.7033	8.7034		6.6873	6.6873	
0.1695	6.8596	6.8596		5.8582	5.8582	
0.1818	4.0481	4.0481		3.5149	3.5149	
0.1905	4.1172	4.1172		3.4990	3.4990	

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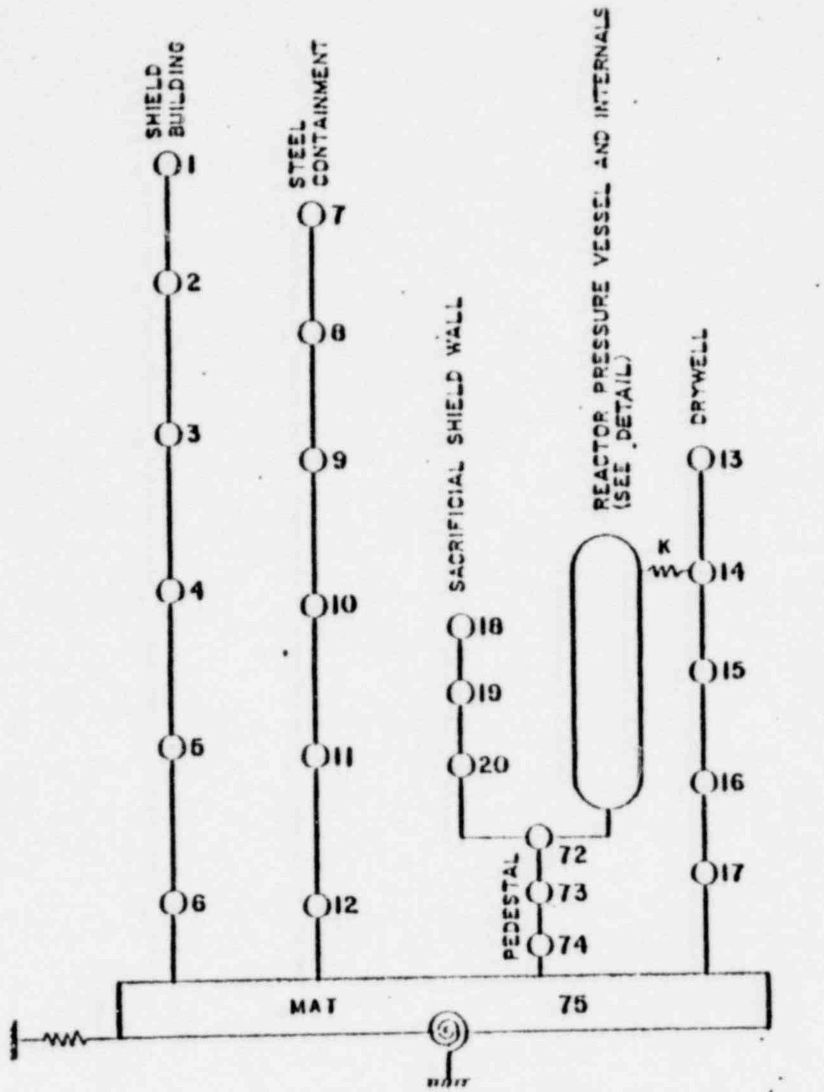
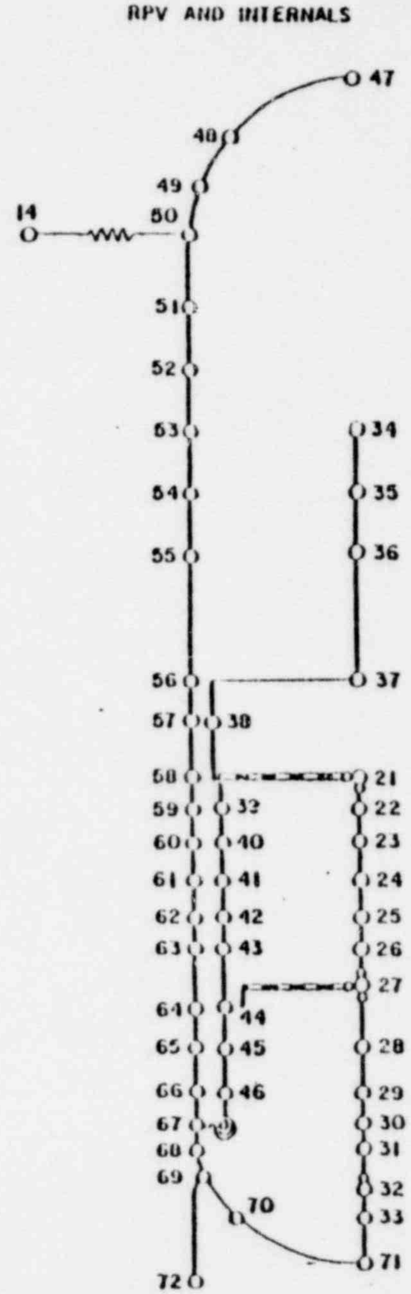
Period (sec)	Spectral Acceleration (g)			
	2% equipment damping		3% equipment damping	
	TIME	DYNRES	TIME	DYNRES
0.2000	5.7318	5.7318	4.6577	4.6577
0.2083	5.0152	5.0151	4.0309	4.0309
0.2174	3.1199	3.1199	2.7205	2.7206
0.2222	2.6946	2.6947	2.4514	2.4514
0.2273	2.4151	2.4151	2.2294	2.2294
0.2381	2.4698	2.4698	2.1699	2.1699
0.2500	1.5553	1.5553	1.4919	1.4919
0.2632	1.6646	1.6646	1.4922	1.4922
0.2778	2.4781	2.4780	2.0004	2.0004
0.2941	2.0811	2.0811	1.8997	1.8997
0.3125	2.2204	2.2204	1.8821	1.8821
0.3333	1.7806	1.7805	1.4784	1.4784
0.3704	1.6777	1.6777	1.4821	1.4821
0.4000	1.7672	1.7672	1.5651	1.5652
0.4444	1.2379	1.2379	1.1917	1.1917
0.5000	0.9557	0.9557	0.9143	0.9144
0.5714	0.7112	0.7112	0.6834	0.6834
0.6667	0.6126	0.6126	0.5609	0.5609
1.0000	0.3689	0.3690	0.3262	0.3262





NOTE: 'K' REPRESENTS REFUELING BELLOW SPRING STIFFNESS
K = 12,000 K/FT

Figure 1 DYNAMIC MODEL OF A BWR PLANT