OPTIMUM SEISMIC PROTECTION FOR NEW BUILDING CONSTRUCTION IN EASTERN METROPOLITAN AREAS

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ELASTIC RESPONSE OF MULTIDEGREE SYSTEMS UNDER EARTHQUAKE LOADING

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20 June 1973

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Comparisons are made between the elastic responses of buildings during earthquakes computed according to response spectrum analysis, random vibration analysis, and time history analysis. An 11-story RC moment resisting frame building, designed to resist a Zone 4 earthquake, is used as the hypothetical test model representing a typical apartment building. Eight earthquake records, four artificially created and four actual records from the 1971 San Fernando earthquake, are used in the study. The three methods of analysis are described and summarized in tabular form and conclusions are presented. Tables include: characteristics of the four artificial earthquakes; coefficients of variation of their response spectra; location and characteristics of real earthquakes; time history-response spectrum ratios; and time history-random vibration response ratios. Corresponding response spectra to both kinds of earthquakes are shown in graphic form.

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INTRODUCTION

Elastic responses of a structure to earthquakes may be obtained by at least three methods: (1) time history analysis, (2) response spectrum analysis, and (3) random vibration analysis. The time history analysis is done by step-by-step numerical integration of the system equations governing the dynamic behavior of the structure. The result is exact in the sense that the errors derived from numerical integration can be neglected, but the process is more expensive than the other two approximate methods. The response spectrum analysis utilizes the principle of modal superposition. The approximation arrises from the fact that the modal combination cannot be exact. The random vibration analysis is based on the assumptions that earthquake motions may be considered as (1) a Gaussian process with zero mean and (2) a time evolutionary non-stationary process with a unique frequency content.

The computations for response spectrum analysis and random vibration analysis are relatively easy with the tradeoff in the accuracy of the results. It is the intention of this report to make comparisons between the elastic responses of buildings during earthquakes computed according to the methods outlined above.

Due to the uncertainties involved in defining a strong ground motion for earthquake design, a "target" response spectrum and the corresponding artificial earthquake histories have been used to represent earthquake loadings in recent years. An artificial earthquake is usually generated in a way such that its response spectrum will match or envelop the "target" response spectrum and is generally obtained by a "trial and error" procedure. It is not feasible to produce an artificial earthquake and an infinite number of artificial earthquake which will match the "target" response spectrum exactly and an infinite number of artificial earthquakes may be obtained to simulate a "target" response spectrum. The question arises concerning how many artificial time histories should be used to represent the earthquake loading and which ones should be used. This question is also studied in this report.

DESCRIPTION OF TEST BUILDING

The building studied is one of the hypothetical buildings designed by Le Messurier Associates, Consulting Engineers, Cambridge, Mass. which were used previously (2). The building was designed to be typical of current engineering practice and represents the normal apartment building with a symmetrical and simple design. The methods used and considerations made in the design are described by Brennan et al. (3).

The structure is an 11-story RC moment resisting frame building. The lateral resistance is provided by the rigid frame action of the 11 frames which are not identical since the orientation of the exterior columns varies. Figure 1 shows the framing plan for the building with the column sizes and the overall dimensions. The story height is 9 feet. The building was designed to resist a zone 4 earthquake. Zone 4 is a special zone which doubles the lateral force requirement of zone 3 of UBC 1970.

The fundamental period of the building was 1.47 seconds. In order to study the effect of building periods on the results, the fundamental period of the building was changed to 1 second and 2 seconds by adjusting the mass without altering the mode shapes. The studies on the building with T_1 = 1.47, 1.0 and 2.0 seconds are designated as Case 1, 2, and 3, respectively.

EARTHQUAKE MOTIONS

Eight earthquake records were used in this study; four were artificially created and four are actual records from the San Fernando earthquake in 1971. The artificial time histories were created to match the same target response spectrum. The characteristics of the four artificial earthquakes are tabulated in Table 1 and the corresponding response spectra are shown in Figures 2 to 5. An average spectrum for the four artificial earthquakes is shown in Figure 6 and the lower bound smoothed spectrum for these earthquakes is superimposed on the response spectrum in Figure 3. The coefficients of variation of the response spectra generated by the artificial time histories are tabulated in Table 2 at some critical periods. The location and characteristics of the real earthquakes are shown in Table 3 and the corresponding response spectra are given in Figures 7 to 10.

METHODS OF ANALYSIS

All the analyses herein reported are limited to the elastic range with a linear model. All three methods of analysis, the time history analysis, response spectrum analysis and random vibration analysis, are performed in this study. The computer program used to perform the time history analysis is the one developed by S. Anagnostopoulous (1, 4). The building was considered to be of shear-type and modeled as a closed coupled spring system with the masses concentrated at floor levels. The spring constants and the yielding strength for each story were generated automatically by the computer by feeding the properties of the individual components into the program. The study was limited to one of the horizontal axes. Because of its symmetrical configuration, torsional effects present no problem in the content of this study.

Once the parameters for the dynamic model are computed, numerical integration is used at each time step of the earthquake motion to obtain a time history of the response of each floor of the building. The output response parameter used in this study was the maximum interstory displacement. It is believed that this parameter is a measure of the structural damage that will occur.

For response spectral analysis, a computer program developed by Garcia and Rosset (5) was used to generate the response spectra. The building periods, mode shapes and participation factors for each mode were obtained from the output of the time history analysis. To obtain the total response, the first five modes were then combined using the square root of the sum of the squares method. Again the interstory displacements were computed. In all cases considered, a damping of 5% of critical was used.

The method of random vibration analysis used here was developed by Chakravorty (6). The earthquake motion is assumed to be a time evolutional, non-stationary, zero-mean Gaussian process with a unique power spectrum. The maximum average response is the product somewhat similar to a root mean square factor and an amplification factor. Since the process is assumed non-stationary, the first factor is a function of the duration of the motion. It is also a function of the damping, modal frequencies, and the power spectrum ordinates at these frequencies. The amplification factor is a function of the average rate of "zero crossings," the duration of motion, the assumed probability, and the participation of the first mode. A medium value (50% probability) was used to represent the response. In any case the amplification factor generally falls in the range from 2.5 to 3.5. An extended treatment of this type of analysis appears in Anagnostopoulos and Roesset (4) and further discussion of some of the parameters in Garcia and Roesset (5).

DATA PRESENTATION

Types of analysis performed here are summarized in Table 4. Before present the results, several abbreviations must be defined.

T.H. - Time history solution

R.S. - Response spectrum solution

AVG. R.S. - Response spectrum solution using the average response spectrum of the four artificial earthquakes

L.B.R.S. - Response spectrum solution using the lower bound response spectrum which is obtained by eye-ball fitting of several straight segments to the response spectra of the artificial earthquakes

R.V. - Random vibration solution

The data are presented in terms of the ratios of the interstory displacement calculated by the exact method to that calculated by the approximate methods, i.e., T.H./R.S., T.H./AVG.R.S., T.H./L.B.R.S., and T.H./R.V. This is done for the purpose of studying the accuracy of the approximate methods. The results are shown in Tables 6 to 17 with an index of the tables given in Table 5. Shown in the tables are the ratio for each floor, the mean and standard deviation of the ratios for each floor under several earthquakes, the mean and standard deviation of the ratios for the building under each earthquake and the overall mean ratio and its standard deviation for the building under several earthquakes.

ANALYSIS OF THE RESULTS

A scrutiny of Tables 6 to 8 reveals that the response spectrum solution lies very close to the time history solution with a slight margin on the lower side. This applies equally well to the artificial earthquakes and the real ground motion records used in this study. The overall mean ratios of T.H./R.S. are 1.06, 1.02, and 1.12 for Case 1, 2, and 3 respectively. The reason for the higher mean ratio in Case 3 may be that the artificial earthquakes become less accurate in long period ranges. However, the results are readily acceptable for engineering purposes.

Comparisons of Tables 6 and 9, Tables 7 and 10, and Tables 8 and 11 suggest that the mean T.H./AVG. R.S. ratios closely parallel the mean

T.H./R.S. ratios while the difference in standard deviation is substantial, as expected. The coefficients of variation of the T.H./AVG. R.S. ratios are of the same order as the coefficients of variation of the artificial earthquake response spectra at the corresponding periods (Table 2). Even though both types of coefficients of variation have their maximum values at a period of 1 second, a general correlation between them is not observed.

Tables 12 to 14 show the values of T.H./L.B.R.S. ratios. All are between 1.20 to 1.80 with an average approximately 1.40 and a standard deviation of about 0.20. These figures illustrate the degree of conservativeness if an artificial earthquake which envelops a target response spectrum in the whole frequency range is used to represent the seismic demand of the target response spectrum. An observation on the values of T.H./AVG. R.S. ratio (Tables 9, 10, 11) suggests that the mean values of four time history responses can be used effectively to represent the effects of the target response spectrum. (Here the target response spectrum is assumed to be equivalent to the average response spectrum).

The random vibration method approaches the problem from a different angle. Tables 15 to 17 illustrate that the random vibration solution is generally larger than the time history solution. Since this is a new method without extensive verification, no definite conclusion can be made on its applicability to the elastic response analysis.

CONCLUSIONS

Based on the results obtained from this research, the following points may be concluded:

1. Response spectrum solution using SRSS (square root of the sum of the squares) method for model combination closely approximates the exact solution by time history analysis for elastic building dynamic response.
2. The use of a single artificial time history which envelops a target response spectrum in the full frequency range to represent the effects of the target response spectrum results in an overly conservative design. Instead, the response may be better estimated by using the average of the responses produced by several time histories for which the average resulting response spectrum closely approximates the target response spectrum.
3. Random vibration solution is generally larger than the time history solution. Further research is needed to verify its applicability for predicting dynamic response of an elastic system under earthquake loading.

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TABLE 1: Characteristics of the Artificial Earthquakes

EARTHQUAKE	DURATION (SEC.)	TIME INTERVAL (SEC.)	MAX ACCELERATION (g)
A1	20	0.01	0.29
A2	20	0.01	0.25
A3	20	0.01	0.28
A4	20	0.01	0.25

TABLE 2: Coefficients of Variation of the Four Artificial Earthquake Response Spectoral Ordinates at Some Periods

PERIOD (SEC)	COEFFICIENTS OF VARIATION
0.8	0.073
1.0	0.140
1.1	0.040
1.3	0.190
1.474	0.072
1.6	0.063
1.8	0.132
2.0	0.127
2.2	0.138

TABLE 3: Location and Characteristics of the Real Earthquakes

	LOCATION RECORDED	COMPONENT	PEAK ACCELERATION	DURATION (SEC.)	TIME INTERVAL (SEC.)
R1	250 E. First St. Basement	N36E	0.10g	52.32	0.02
R2	250 E. First St. Basement	N54W	0.125g	42.32	0.02
R3	445 Figueroa St. Sub-basement	N52W	0.15g	57.28	0.02
R4	445 Figueroa St. Sub-basement	S38W	0.12g	57.44	0.02

TABLE 4: Summary of the Analyses Performed

BUILDING CHARACTERISTICS		CASE 1 $T_1 = 1.47$ SEC			CASE 2 $T_1 = 1.0$ SEC			CASE 3 $T_1 = 2.0$ SEC		
TYPE OF ANALYSIS		T.H.	R.S.	R.V.	T.H.	R.S.	R.V.	T.H.	R.S.	R.V.
EARTHQUAKE	A1	X	X	X	X	X	X	X	X	X
	A2	X	X	X	X	X	X	X	X	X
	A3	X	X	X	X	X	X	X	X	X
	A4	X	X	X	X	X	X	X	X	X
	R1	X	X							
	R2	X	X							
	R3	X	X							
	R4	X	X							

TABLE 5: Index of Tables 6 to 17

TABLE	BUILDING	TYPE OF RATIO	EARTHQUAKES CONSIDERED
6	1	T.H./R.S.	A1 - A4, R1 - R4
7	2		A1 - A4
8	3		A1 - A4
9	1	T.H./AVG. R.S.	
10	2		
11	3		
12	1	T.H./L.B.R.S.	
13	2		
14	3		
15	1	T.H./R.V.	
16	2		
17	3		

TABLE 6: Ratio of Each Time History Response to Each Response Spectrum Response (T.H./R.S.) Case 1 (T_1 = 1.47 SEC)

EARTHQUAKE RECORDS

Floor	A1	A2	A3	A4	R1	R2	R3	R4	Mean	Standard Deviation
1	0.94	0.91	0.91	1.18	1.18	0.99	1.00	1.10	1.03	0.11
2	0.89	0.87	0.95	1.10	1.13	1.01	1.02	1.06	1.00	0.09
3	0.86	0.86	0.93	1.05	1.07	0.99	1.07	1.04	0.98	0.08
4	0.91	0.97	0.96	1.13	1.07	1.01	1.12	1.04	1.03	0.07
5	1.02	1.12	0.91	1.22	1.11	1.01	1.14	1.04	1.07	0.09
6	1.13	1.22	0.88	1.20	1.02	1.06	1.11	0.99	1.08	0.10
7	1.18	1.24	0.92	1.10	1.03	1.15	1.13	0.93	1.08	0.11
8	1.20	1.31	0.97	1.14	1.02	1.22	1.21	0.88	1.12	0.14
9	1.05	1.31	0.92	1.12	0.99	1.17	1.25	0.89	1.09	0.14
10	1.08	1.24	0.93	1.09	1.07	1.12	1.29	0.97	1.10	0.11
11	1.13	1.13	0.96	1.02	1.09	1.11	1.31	0.99	1.09	0.10
Mean	1.04	1.11	0.93	1.12	1.07	1.08	1.15	0.99		
Standard Deviation	0.11	0.17	0.02	0.06	0.05	0.08	0.10	0.07		

MEAN RATIO OVERALL - 1.06

STANDARD DEVIATION OVERALL - 0.11

TABLE 7 : Ratio of Each Time History Response to Each Response Spectrum Response (T.H./R.S.)

Case 2 (T_1 = 1.0 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
	EARTHQUAKE RECORD					
1	1.01	0.90	0.92	1.05	0.97	0.06
2	1.02	0.89	0.91	1.02	0.96	0.06
3	1.04	0.94	0.92	1.00	0.98	0.04
4	1.05	0.97	0.94	1.02	0.99	0.04
5	1.05	0.98	0.97	1.07	1.02	0.04
6	1.03	0.94	0.99	1.10	1.01	0.06
7	1.01	0.95	0.96	1.10	1.00	0.06
8	0.97	0.96	0.98	1.14	1.01	0.07
9	1.01	1.02	1.03	1.23	1.07	0.09
10	1.11	1.02	1.06	1.23	1.10	0.08
11	1.19	1.01	1.01	1.25	1.12	0.10
Mean	1.04	0.96	0.97	1.11		
Standard Deviation	0.06	0.04	0.04	0.09		

MEAN RATIO OVERALL - 1.02

STANDARD DEVIATION OVERALL - 0.08

TABLE 8 : Ratio of Each Time History Response to Each Response Spectrum Response (T.H./R.S.)

Case 3 (T_1 = 2.0 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
	EARTHQUAKE RECORD					
1	0.93	0.98	1.09	0.99	1.00	0.06
2	0.94	1.03	1.11	1.03	1.03	0.06
3	0.97	1.08	1.13	1.02	1.05	0.06
4	1.07	1.06	1.09	1.03	1.06	0.02
5	1.22	1.04	1.13	1.15	1.13	0.06
6	1.17	1.01	1.12	1.36	1.16	0.13
7	1.09	1.02	1.08	1.43	1.15	0.16
8	1.16	0.96	1.12	1.36	1.15	0.14
9	1.13	1.10	1.06	1.35	1.16	0.11
10	1.19	1.29	1.00	1.41	1.22	0.15
11	1.24	1.42	1.01	1.35	1.26	0.16
Mean	1.10	1.09	1.08	1.22		
Standard Deviation	0.11	0.13	0.04	0.17		

MEAN RATIO OVERALL - 1.12

STANDARD DEVIATION OVERALL - 0.14

TABLE 9 : Ratio of Time History Response to

Average Spectrum Response (T.H./AVG. R.S.)

Case 1 (T_1 = 1.47 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
	EARTHQUAKE RECORD					
1	0.86	0.92	0.91	1.27	0.99	0.16
2	0.81	0.89	0.94	1.18	0.96	0.14
3	0.78	0.88	0.92	1.13	0.93	0.13
4	0.82	1.00	0.95	1.22	1.00	0.14
5	0.92	1.15	0.90	1.32	1.07	0.17
6	1.02	1.25	0.88	1.29	1.11	0.17
7	1.08	1.26	0.91	1.17	1.11	0.13
8	1.11	1.32	0.97	1.20	1.15	0.13
9	0.98	1.30	0.93	1.17	1.09	0.15
10	1.03	1.21	0.94	1.13	1.08	0.10
11	1.09	1.10	0.97	1.06	1.05	0.05
Mean	0.96	1.12	0.93	1.19		
Standard Deviation	0.12	0.16	0.03	0.07		

MEAN RATIO OVERALL – 1.05

STANDARD DEVIATION OVERALL – 0.15

TABLE 10: Ratio of Time History Response to

Average Spectrum Response (T.H./AVG. R.S.)

Case 2 (T_1 = 1.0 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
	EARTHQUAKE RECORD					
1	0.97	0.85	0.87	1.25	0.99	0.16
2	0.97	0.85	0.86	1.21	0.97	0.15
3	0.98	0.89	0.87	1.20	0.99	0.13
4	0.99	0.92	0.88	1.22	1.00	0.13
5	0.99	0.93	0.91	1.28	1.03	0.15
6	0.98	0.90	0.93	1.31	1.03	0.17
7	0.96	0.90	0.78	1.30	0.98	0.19
8	0.94	0.91	0.94	1.32	1.03	0.17
9	0.99	0.97	1.00	1.40	1.09	0.18
10	1.09	0.98	1.04	1.37	1.12	0.15
11	1.18	0.97	1.00	1.38	1.13	0.16
Mean	1.00	0.92	0.92	1.29		
Standard Deviation	0.07	0.04	0.07	0.07		

MEAN RATIO OVERALL - 1.03

STANDARD DEVIATION OVERALL - 0.17

TABLE 11: Ratio of Time History Response to

Average Spectrum Response (T.H./AVG. R.S.)

Case 3 (T_1 = 2.0 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
	EARTHQUAKE RECORD					
1	0.97	1.11	0.98	0.94	1.00	0.06
2	0.98	1.17	1.00	0.98	1.03	0.08
3	1.02	1.24	1.00	0.96	1.06	0.11
4	1.14	1.23	0.96	0.96	1.07	0.12
5	1.29	1.19	1.00	1.07	1.14	0.11
6	1.24	1.15	1.00	1.28	1.16	0.11
7	1.13	1.07	0.98	1.37	1.14	0.15
8	1.19	1.05	1.04	1.34	1.16	0.12
9	1.15	1.16	1.01	1.35	1.17	0.12
10	1.21	1.33	0.95	1.43	1.23	0.18
11	1.26	1.46	0.97	1.36	1.26	0.18
Mean	1.15	1.20	0.99	1.19		
Standard Deviation	0.11	0.11	0.02	0.19		

MEAN RATIO OVERALL - 1.13

STANDARD DEVIATION OVERALL - 0.15

TABLE 12: Ratio of Time History Response to

Lower Bound SpectrumResponse (T.H./L.B.R.S.)

Case 1 (T_1 = 1.47 SEC)

Floor	EARTHQUAKE RECORD A1	A2	A3	A4	Mean	Standard Deviation
1	1.13	1.22	1.97	1.67	1.30	0.21
2	1.07	1.18	1.25	1.56	1.27	0.18
3	1.03	1.17	1.22	1.50	1.23	0.17
4	1.09	1.32	1.26	1.62	1.32	0.19
5	1.22	1.52	1.19	1.74	1.42	0.23
6	1.35	1.64	1.16	1.70	1.46	0.22
7	1.43	1.67	1.20	1.55	1.46	0.17
8	1.47	1.74	1.28	1.59	1.52	0.17
9	1.29	1.70	1.22	1.53	1.43	0.19
10	1.32	1.57	1.22	1.46	1.39	0.13
11	1.38	1.40	1.23	1.35	1.34	0.06
Mean	1.25	1.47	1.22	1.57		
Standard Deviation	0.15	0.21	0.03	0.11		

MEAN RATIO OVERALL - 1.38

STANDARD DEVIATION OVERALL - 0.20

TABLE 13: Ratio of Time History Response to

Lower Bound Spectrum Response (T.H./L.B.R.S.)

Case 2 (T_1 = 1.0 SEC)

Floor	A1	A2	EARTHQUAKE RECORD A3	A4	Mean	Standard Deviation
1	1.34	1.18	1.20	1.73	1.36	0.22
2	1.34	1.18	1.20	1.68	1.35	0.20
3	1.37	1.25	1.21	1.67	1.37	0.18
4	1.38	1.29	1.22	1.70	1.40	0.19
5	1.38	1.30	1.27	1.79	1.44	0.21
6	1.36	1.25	1.29	1.82	1.43	0.23
7	1.33	1.24	1.08	1.79	1.36	0.27
8	1.28	1.25	1.29	1.81	1.40	0.23
9	1.33	1.31	1.35	1.89	1.47	0.24
10	1.45	1.30	1.38	1.82	1.49	0.20
11	1.56	1.29	1.33	1.84	1.50	0.22
Mean	1.37	1.26	1.25	1.78		
Standard Deviation	0.07	0.04	0.08	0.07		

MEAN RATIO OVERALL - 1.42

STANDARD DEVIATION OVERALL - 0.22

TABLE 14: Ratio of Time History Response to

Lower Bound Spectrum Response (T.H./L.B.R.S.)

Case 3 (T_1 = 2.0 SEC)

Floor	A1	A2	A3	A4	Mean	Standard Deviation
		EARTHQUAKE RECORD				
1	1.37	1.55	1.38	1.33	1.41	0.09
2	1.39	1.65	1.41	1.38	1.46	0.11
3	1.44	1.75	1.42	1.36	1.49	0.15
4	1.62	1.74	1.36	1.36	1.52	0.17
5	1.83	1.68	1.41	1.51	1.61	0.16
6	1.74	1.61	1.40	1.80	1.64	0.15
7	1.60	1.51	1.38	1.93	1.61	0.20
8	1.67	1.47	1.45	1.88	1.62	0.17
9	1.60	1.60	1.40	1.87	1.62	0.17
10	1.67	1.83	1.31	1.97	1.70	0.24
11	1.72	1.98	1.32	1.85	1.72	0.25
Mean	1.60	1.67	1.39	1.66		
Standard Deviation	0.14	0.14	0.04	0.25		

MEAN RATIO OVERALL - 1.58

STANDARD DEVIATION OVERALL - 0.20

TABLE 15: Ratio of Time History Response to Random Vibration Response (T.H./R.V.)

Case 1 (T_1 = 1.47 SEC)

Floor	EARTHQUAKE RECORD A1	A2	A3	A4	Mean	Standard Deviation
1	0.66	0.71	0.70	0.98	0.76	0.13
2	0.63	0.69	0.73	0.92	0.74	0.11
3	0.60	0.69	0.71	0.88	0.72	0.10
4	0.63	0.77	0.73	0.94	0.77	0.11
5	0.71	0.88	0.69	1.01	0.82	0.13
6	0.78	0.95	0.67	0.99	0.85	0.13
7	0.84	0.98	0.71	0.91	0.86	0.10
8	0.88	1.04	0.76	0.95	0.91	0.10
9	0.79	1.04	0.74	0.94	0.88	0.12
10	0.83	0.98	0.76	0.91	0.87	0.08
11	0.88	0.89	0.78	0.85	0.85	0.04
Mean	0.75	0.87	0.73	0.93		
Standard Deviation	0.10	0.13	0.03	0.04		

MEAN RATIO OVERALL - 0.82

STANDARD DEVIATION OVERALL - 0.12

TABLE 16: Ratio of Time History Response to

Random Vibration Response (T.H./R.V.)

Case 2 (T_1 = 1.0 SEC)

	EARTHQUAKE RECORD					
Floor	A1	A2	A3	A4	Mean	Standard Deviation
1	0.85	0.75	0.77	1.10	0.87	0.14
2	0.86	0.76	0.77	1.08	0.87	0.13
3	0.88	0.81	0.78	1.08	0.89	0.12
4	0.90	0.84	0.79	1.11	0.91	0.12
5	0.88	0.83	0.81	1.14	0.92	0.13
6	0.87	0.80	0.82	1.16	0.91	0.15
7	0.85	0.79	0.69	1.15	0.87	0.17
8	0.82	0.80	0.83	1.16	0.90	0.15
9	0.85	0.83	0.85	1.20	0.93	0.15
10	0.92	0.82	0.88	1.15	0.94	0.12
11	0.98	0.81	0.83	1.15	0.94	0.14
Mean	0.88	0.80	0.80	1.14		
Standard Deviation	0.04	0.03	0.05	0.04		

MEAN RATIO OVERALL - 0.90

STANDARD DEVIATION OVERALL - 0.14

TABLE 17: Ratio of Time History Response to

Random Vibration Response (T.H./R.V.)

Case 3 (T_1 = 20 SEC)

Floor	EARTHQUAKE RECORD A1	A2	A3	A4	Mean	Standard Deviation
1	0.69	0.79	0.70	0.67	0.72	0.04
2	0.70	0.83	0.71	0.70	0.74	0.06
3	0.73	0.89	0.72	0.69	0.75	0.08
4	0.82	0.88	0.69	0.68	0.77	0.08
5	0.92	0.85	0.71	0.76	0.81	0.08
6	0.88	0.82	0.71	0.91	0.83	0.08
7	0.81	0.77	0.70	0.99	0.82	0.10
8	0.87	0.77	0.76	0.98	0.84	0.09
9	0.86	0.87	0.76	1.02	0.88	0.09
10	0.94	1.03	0.74	1.10	0.95	0.14
11	0.99	1.15	0.76	1.07	0.99	0.14
Mean	0.84	0.88	0.72	0.87		
Standard Deviation	0.09	0.11	0.02	0.16		

MEAN RATIO OVERALL - 0.83

STANDARD DEVIATION OVERALL - 0.13

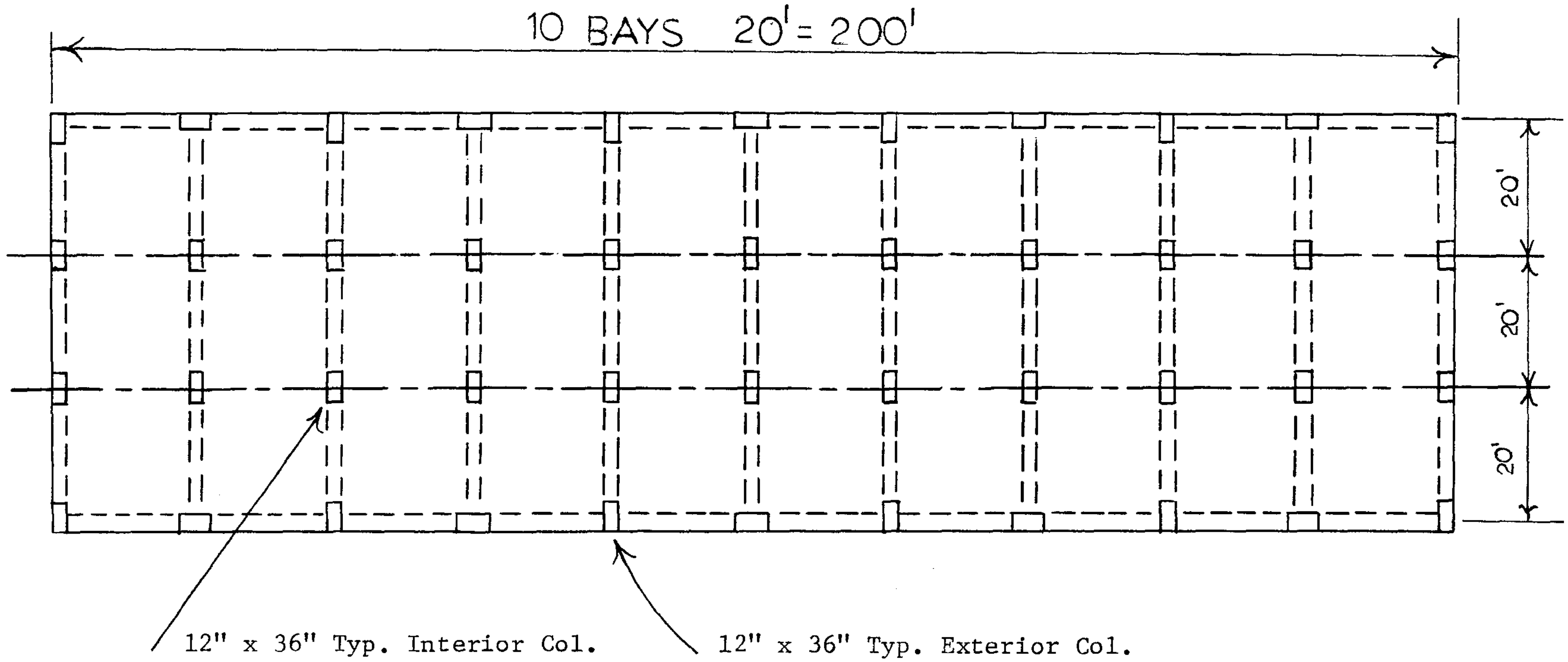


FIGURE 1. TYPICAL FRAMING PLAN FOR 11-STORY RC FRAME BUILDING

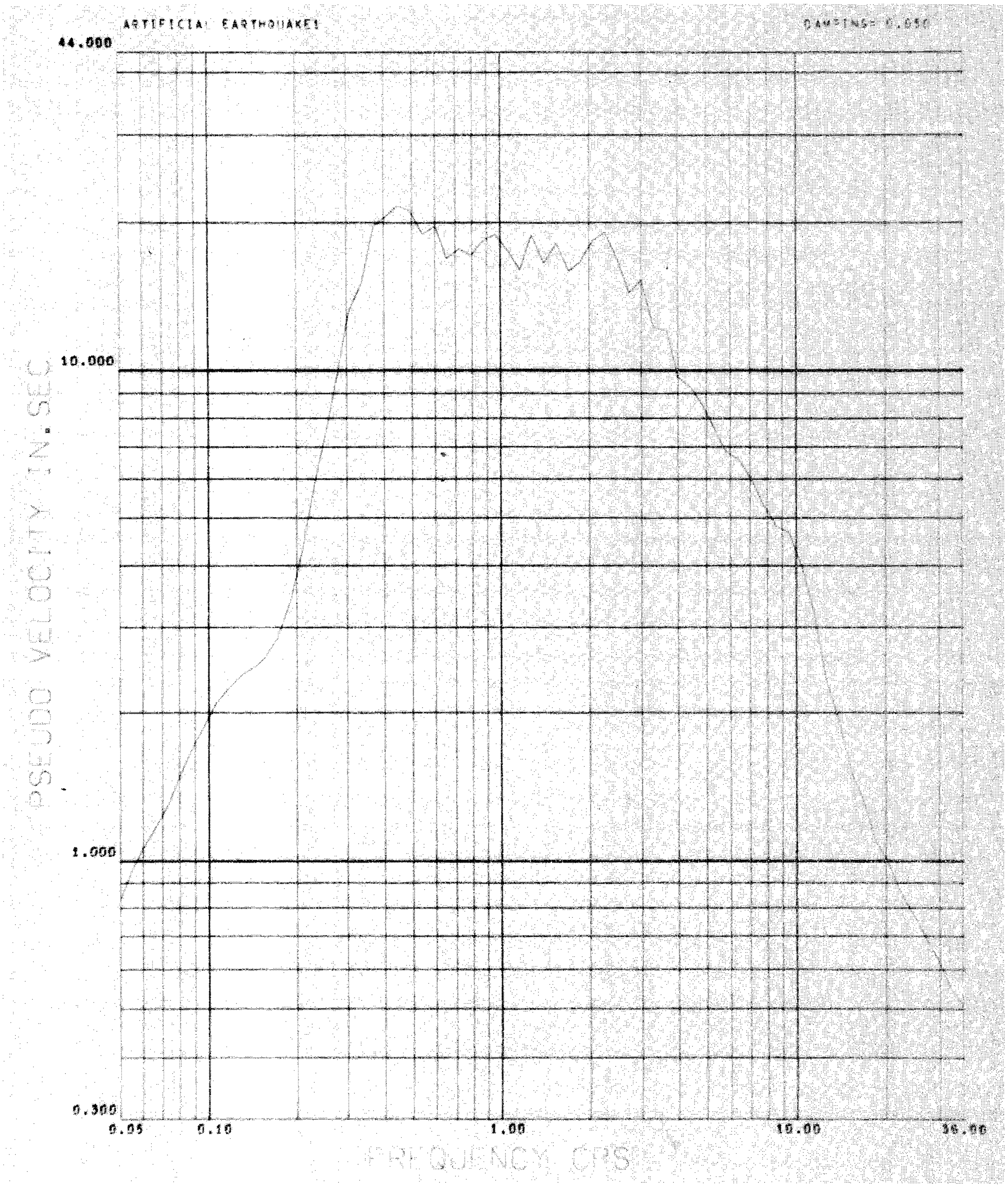


Figure 2. Response spectrum of artificial earthquake 1.

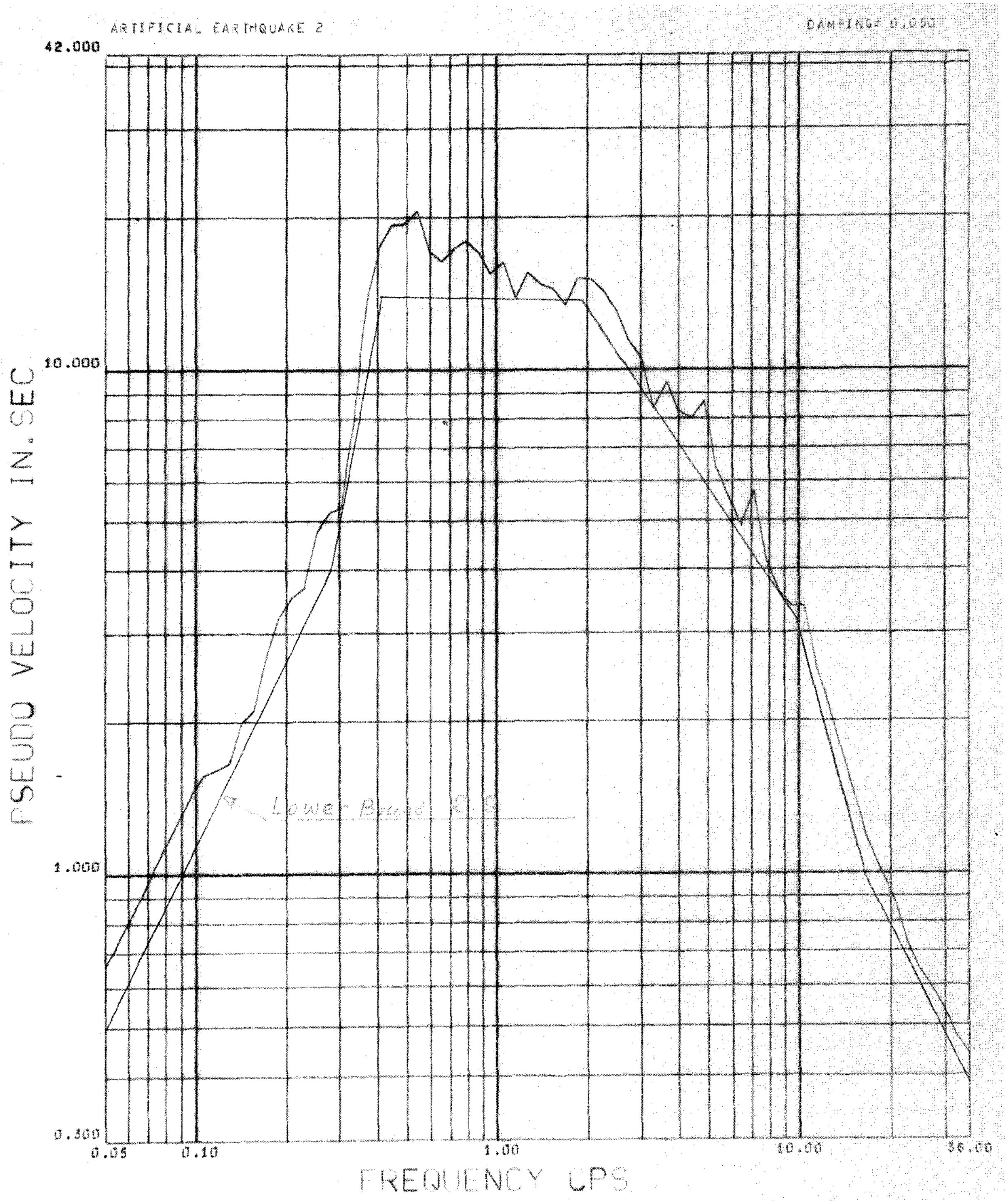


Figure 3. Response spectrum of artificial earthquake 2 and the lower bound response spectrum.

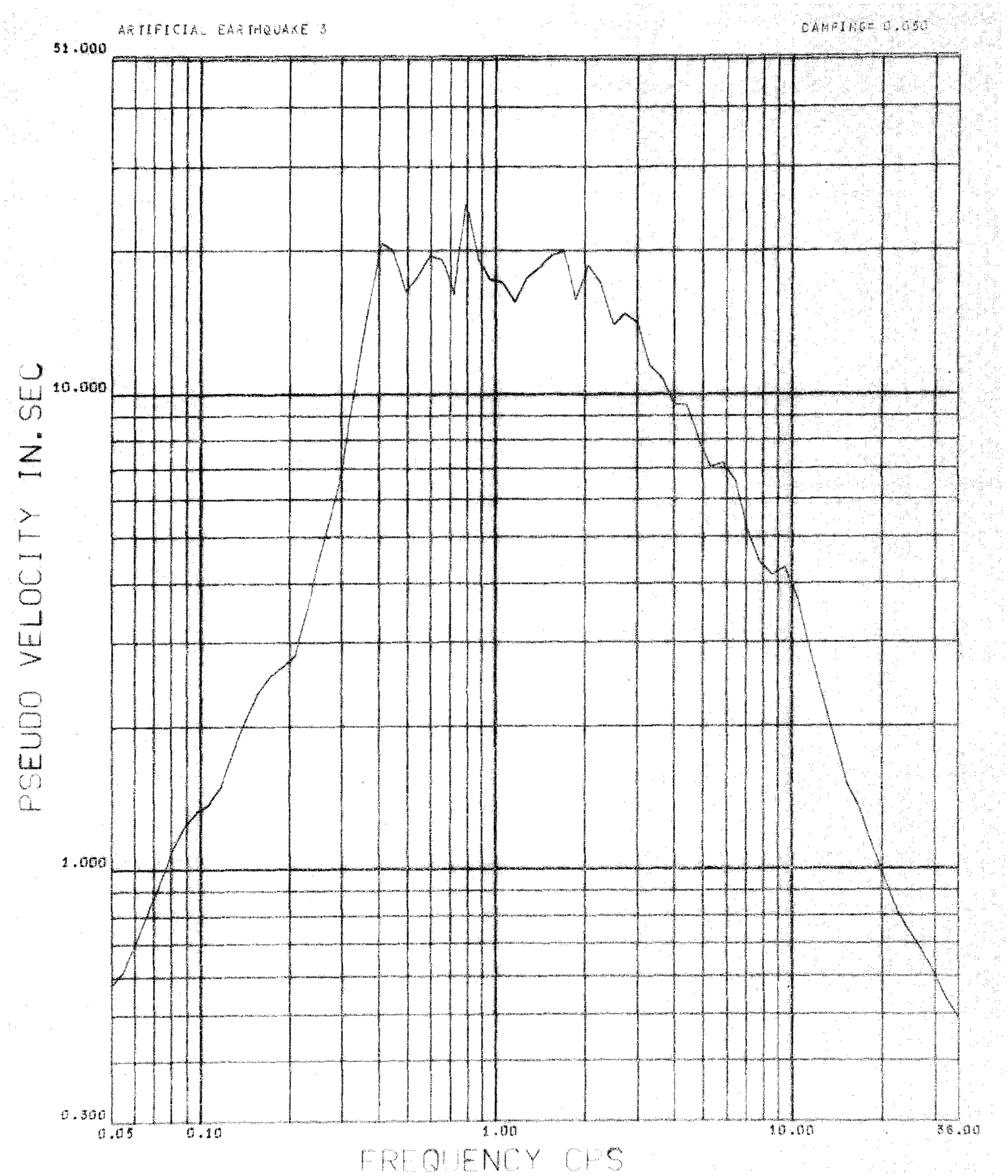


Figure 4. Response spectrum of artificial earthquake 3.

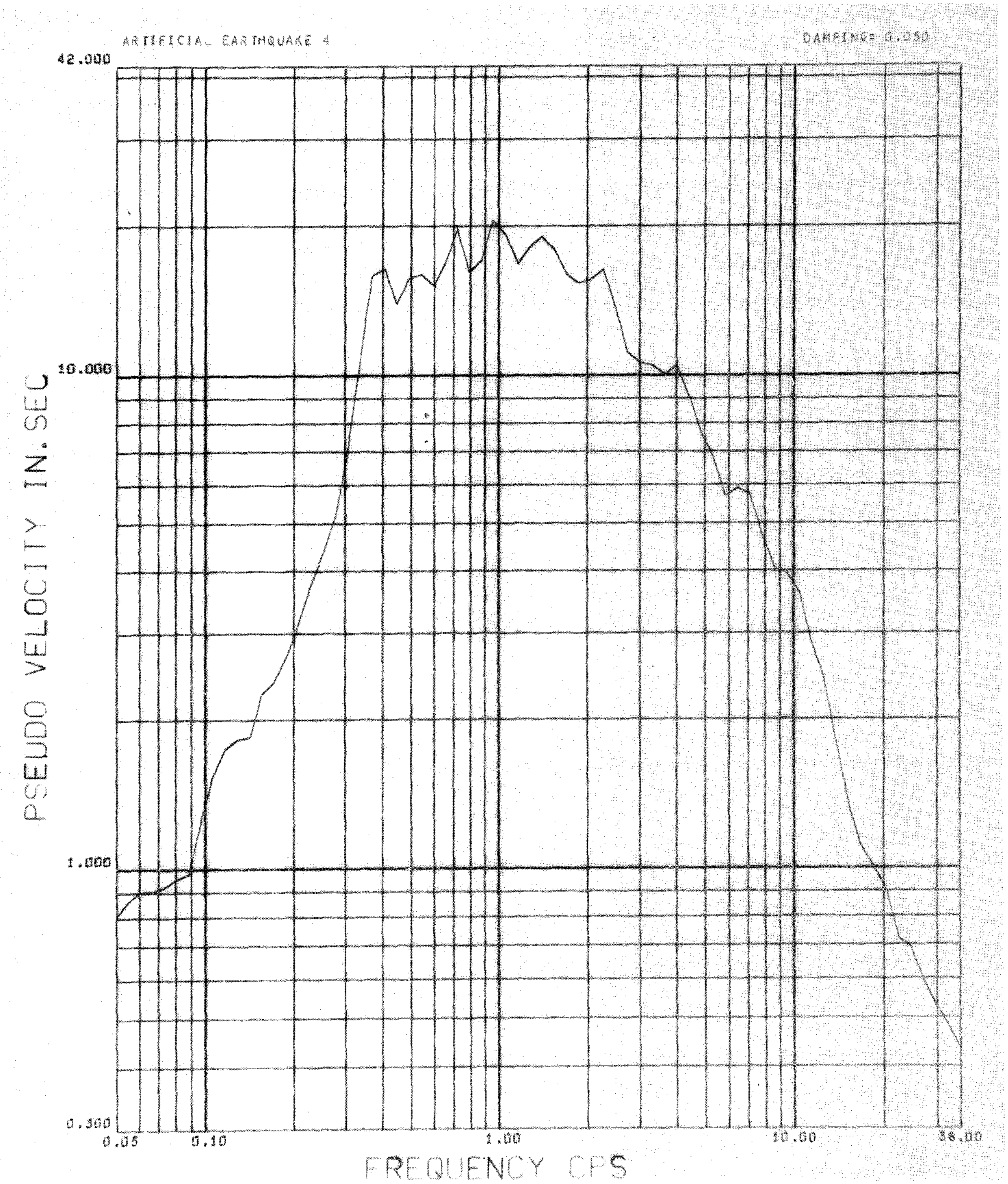


Figure 5. Response spectrum of artificial earthquake 4.

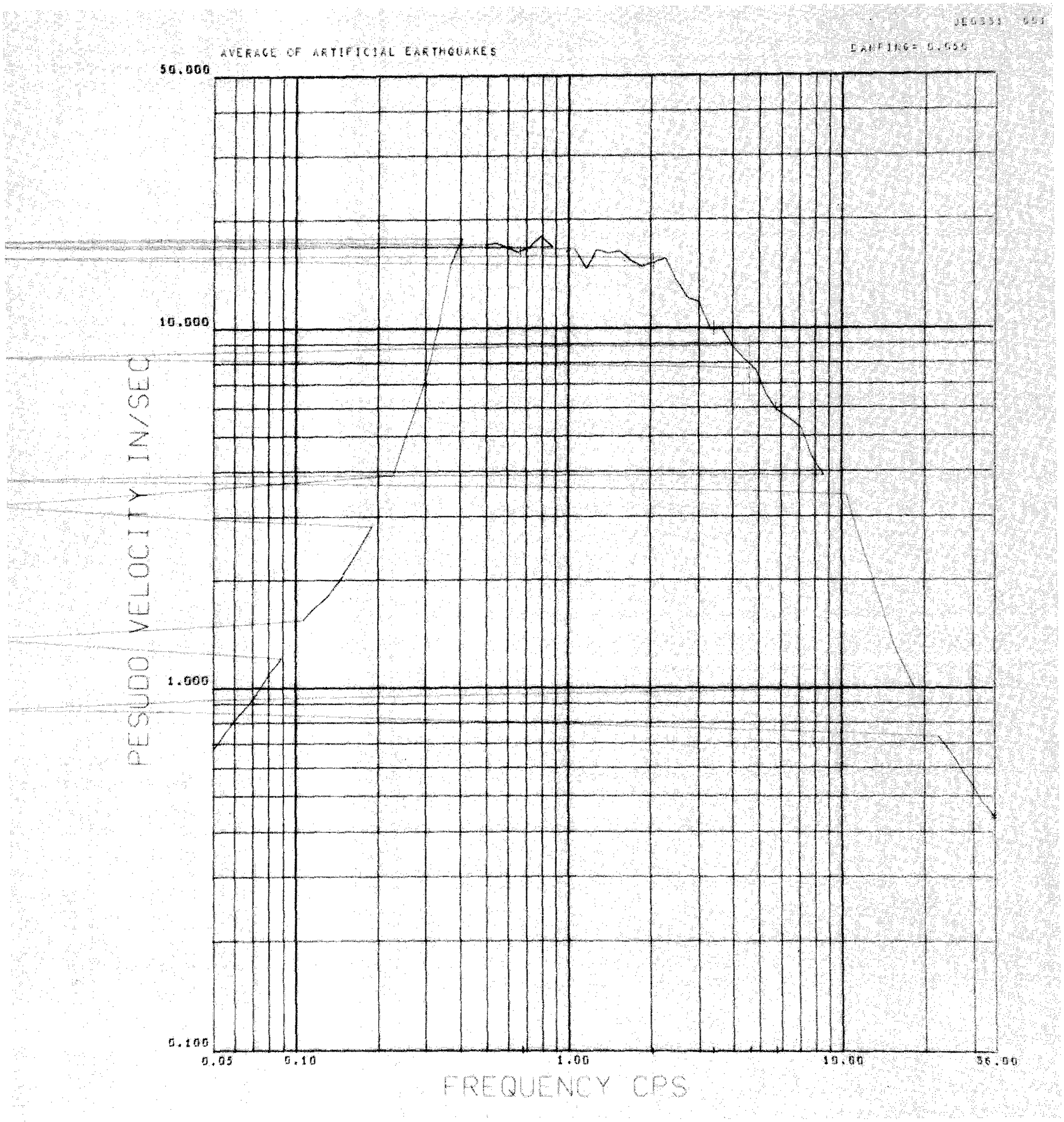


Figure 6. Average response spectrum of the artificial earthquakes.

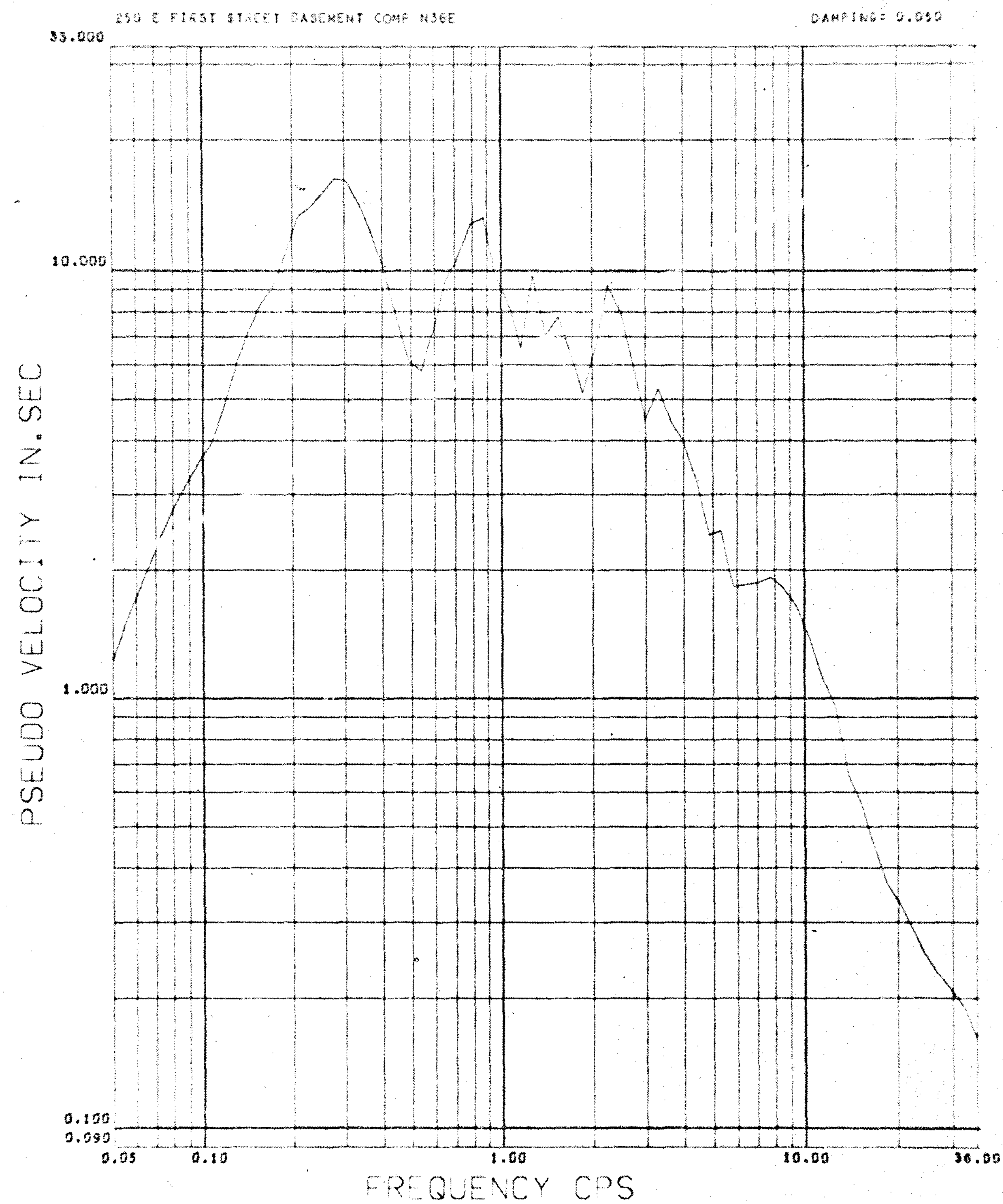
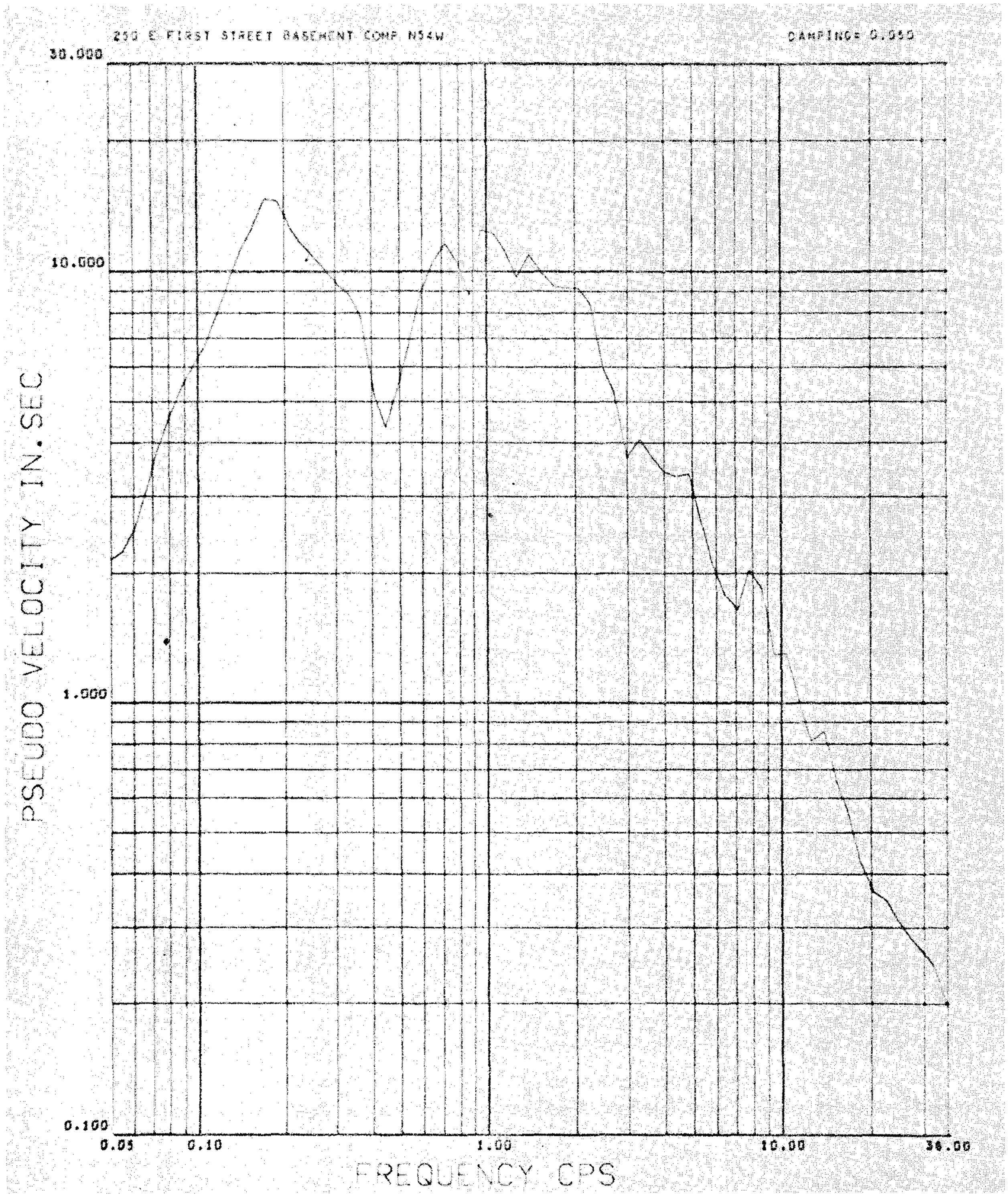


Figure 7. Response spectrum of real earthquake 1.


250 E FIRST STREET BASEMENT COMP N54W
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10.000
1.000
0.100
0.05
0.10
1.00
10.00
30.00
PSEUDO VELOCITY IN. SEC
FREQUENCY CPS

Figure 8.

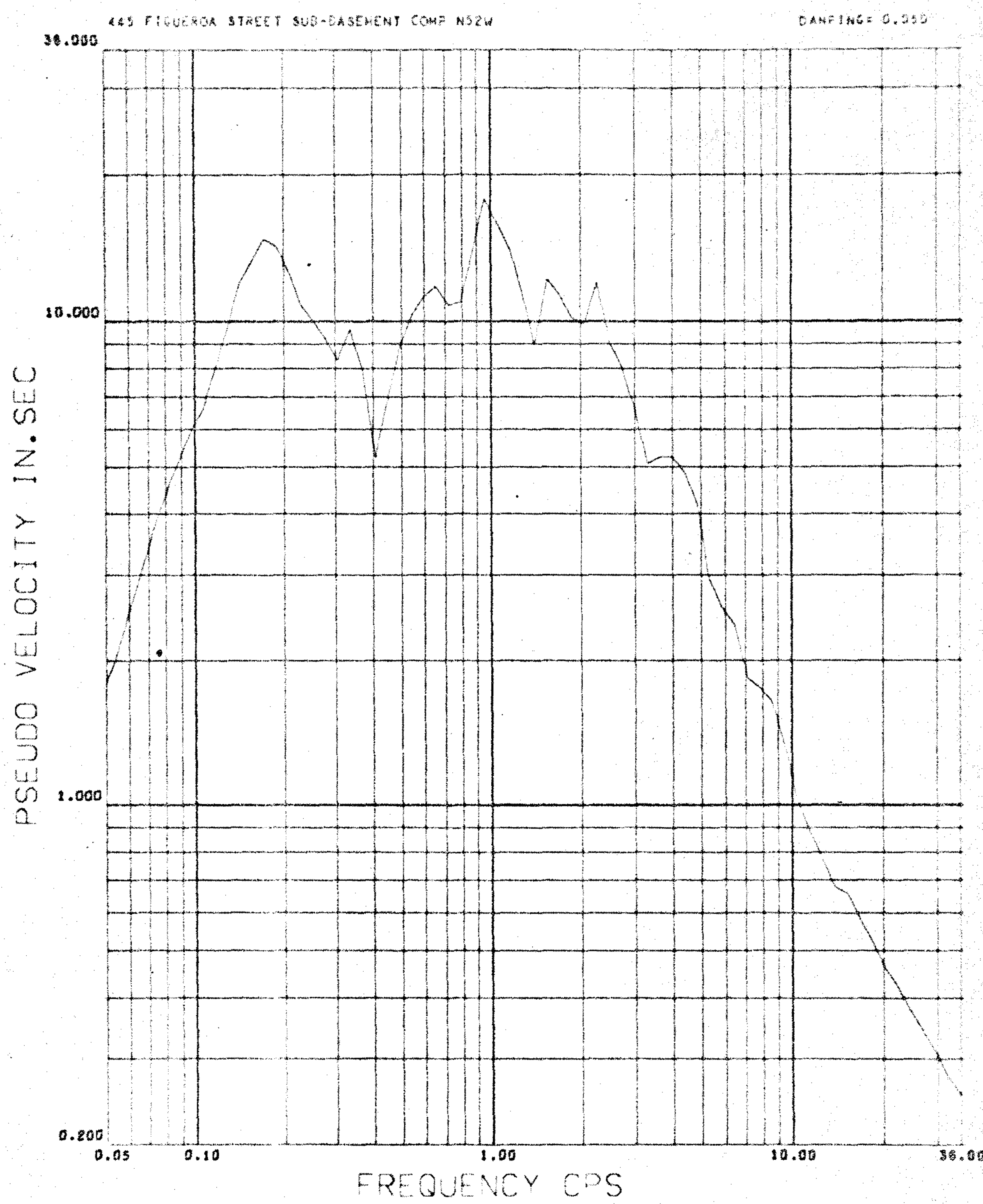
445 FIGUEROA STREET SUB-BASEMENT COMP N52W
DAMPING= 0.050
30.000
10.000
1.000
0.200
PSEUDO VELOCITY IN.SEC
0.05
0.10
1.00
10.00
30.00
FREQUENCY CPS

Figure 10.