HIGH-RISE BUILDING RESPONSE: DAMPING AND PERIOD NONLINEARITIES

by

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SYNOPSIS

Building modal damping and natural periods of vibration are estimated from several building response records obtained during the February 9, 1971, San Fernando Earthquake. Torsional natural frequencies are estimated and these modes are shown to be significant.

INTRODUCTION

The recorded response of fourteen southern California high-rise buildings during the February 9, 1971, San Fernando earthquake is summarized. Of particular interest are the general building response levels, ratio of earthquake to ambient natural periods, modal damping and torsional response of the buildings.

Table 1 presents a general summary of the building response. This table presents the peak floor accelerations and two general response parameters. The ten percent Time Function is the total time during which the absolute value of the recorded acceleration exceeded ten percent gravity The ten percent Peak Function is the total number of acceleration peaks which were greater, in absolute value, than ten percent gravity. In many cases the building strong motion instruments stopped recording when the building was still experiencing signficant motion. However, in all cases the peak motion at the time of machine shutoff was less than the ten percent threshold. That is why the ten percent acceleration level was selected. The ten percent time function is more meaningfully compared when it is divided by the corresponding building period. The number reflects the number of strong motion cycles the building experienced.

DAMPING IN BUILDING FUNDAMENTAL MODES

Structural damping is often irrationally chosen. This research attempts to provide some insight into its observed values in fundamental translational building mode response and its nonlinear variation with amplitude of ground motion.

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Damping estimates during the San Francisco earthquake are given in Table 1. Damping is assumed to be viscous and is obtained by evaluating the unsmoothed roof to basement transfer function at the building's fundamental period of vibration. This amplification is scaled by the building's modal participation factor. It was assumed that the floor masses are equal and the fundamental mode shape is a straight line.

Figure 1 shows a plot of the damping in the fundamental mode and principle direction versus basement Fourier modulus at the building period. It is apparent from this figure that a nonlinear trend exists. The scatter in the six steel buildings is considerably less than that in the seven concrete buildings. The figure shows best fit lines through the data that may be used to estimate damping for structural design.

EARTHQUAKE AND AMBIENT PERIODS

The ratio of earthquake to ambient building period, see Table 1, is fairly constant for all the modes in a particular building. It seems logical to assume that this ratio will be a function of some response parameter. Several parameters were studied and none were found to be adequate.

For the buildings located in Century City, the earthquake to ambient period ratio's were relatively constant. This suggests that the ratio depends upon site conditions in an as yet unpredictable manner. Intuitively it seems unacceptable that the variation in building periods can be completely explained by a degradation in structural stiffness.

TORSIONAL RESPONSE

Table 1 gives building torsional natural frequencies of vibration during earthquake and ambient excitations. Since the motion at any location on a floor is the sum of translational and torsional modes, it is important to establish the relative contribution to this motion of each mode. Herein, we compare for the most extreme point on the building's major axis the amplitudes of the acceleration and displacement Fourier spectra corresponding to the first minor axis translational and first torsional natural period. When the torsional participation ratios given in Table 1 are unity the amplitude of the spectra at the translational and torsional natural periods are equal.

CONCLUSIONS

The following conclusions are relevant:
(1) Modal damping increases approximately linearly with the value of the Fourier modulus amplitude at the building natural frequency;

(2) Building earthquake to ambient periods are not dependent upon any single common motion intensity parameter and site conditions seem to be important; (3) Two strong motion instruments per floor should be used in the future to insure reliable measurement of torsional building response — one instrument should be located away from the center of stiffness; (4) Torsional response of buildings during earthquakes is significant — especially in terms of floor acceleration.

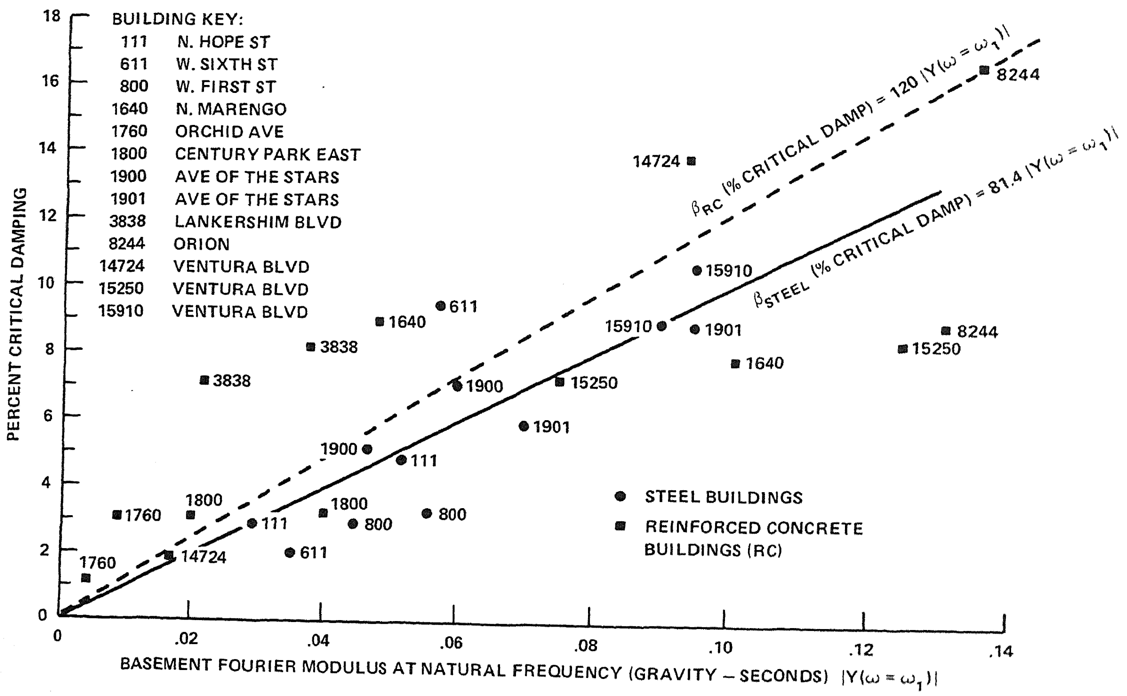

Figure 1. Building Damping in Fundamental Mode Versus Amplitude

Table 1
SEISMIC RESPONSE OF HIGH RISE BUILDINGS

LOCATION (Direction)	EPICENTRAL DISTANCE	PEAK ACCELERATION (g)			TIME RESPONSE FUNCTION (sec)			PEAK RESPONSE FUNCTION			BUILDING PERIOD (sec)						DAMPING IN 1st LATERAL MODE	TORSIONAL PARTICIPATION			
											(Earthquake)			(Ambient)				(Earthquake)		(Ambient)	
		B*	M	R	B	M	R	B	M	R	1st	2nd	3rd	1st	2nd	3rd		Disp.	Acc.	Disp.	Acc.
•8244 ORION (7RC)	20																				
North		.27	.18	.39	2.5	4.0	6.5	30	35	53	1.49	–	–	0.58	–	–	8.7	–	–	1.00	1.00
West		.14	.24	.31	0.6	2.7	5.4	12	31	48	1.26	–	–	0.63	–	–	16.4	1.00	1.00	–	–
Torsion (6/72)**		–	–	–	–	–	–	–	–	–	1.09	–	–	0.47	–	–	–	0.46	0.60	0.66	1.02
•15250 VENTURA (12RC)	28																				
NIIE		.23	.25	.26	1.3	5.7	9.1	26	72	60	2.38	0.67	0.49	1.62	0.50	0.29	7.1	1.00	1.00	–	–
N79W		.14	.21	.18	0.5	4.0	7.5	11	44	47	2.94	0.98	0.59	2.00	0.60	0.34	8.2	–	–	–	–
Torsion (4/71)		–	–	–	–	–	–	–	–	–	1.89	–	–	–	–	–	–	0.65	0.95	–	–
•14724 VENTURA (12RC)	28																				
N78W		.19	.27	.21	1.1	2.2	4.6	28	46	61	1.14	–	–	0.95	–	–	1.9	–	–	–	–
S12W		.26	.36	.32	1.8	3.8	5.2	25	56	66	1.19	–	–	0.86	–	–	13.7	1.00	1.00	1.00	1.00
Torsion (10/72)		–	–	–	–	–	–	–	–	–	0.63	–	–	0.57	–	–	–	0.61	1.76	0.74	1.72
•15910 VENTURA (17ST)	28																				
S09W		.13	.18	.22	0.2	1.7	6.7	4	16	23	3.34	1.17	–	2.18	0.73	–	8.9	1.00	1.00	1.00	1.00
S8IE		.15	.13	.23	0.2	0.5	6.6	3	6	25	3.28	1.10	–	1.94	0.70	0.42	10.5	–	–	–	–
Torsion (6/72)		–	–	–	–	–	–	–	–	–	1.71	0.73	–	1.48	0.52	–	–	0.08	0.30	0.18	0.39
•3838 LANKERSHIM (20RC)	30																				
North		.18	–	.10	0.1	–	0.1	2	–	1	2.09	–	–	1.35	–	–	7.1	–	–	1.00	1.00
West		.13	–	.21	0.4	–	1.1	8	–	17	2.27	–	–	1.47	0.47	–	8.2	1.00	1.00	–	–
Torsion (1/72)		–	–	–	–	–	–	–	–	–	1.83	–	–	1.22	–	–	–	0.28	0.41	0.41	0.50
•1760 ORCHID (22RC)	34																				
South		.16	.08	.11	0.4	–	0.1	10	–	2	2.00	–	–	1.49	0.48	–	3.1	1.00	1.00	–	–
East		.13	.14	.20	0.1	–	0.5	3	–	9	2.17	–	–	1.42	0.47	–	1.2	–	–	1.00	1.00
Torsion (6/72)		–	–	–	–	–	–	–	–	–	1.83	–	–	1.31	0.43	–	–	1.16	1.36	0.54	0.69
•1800 CENTURY PARK (15RC)	38																				
S36E		.08	.21	.28	0.0	1.7	2.7	0	25	32	1.04	0.34	0.22	0.95	0.30	0.17	3.1	–	–	–	–
N54E		.10	.22	.28	0.0	1.7	3.0	2	22	32	1.55	0.47	0.30	1.29	0.40	0.24	3.2	–	–	1.00	1.00
Torsion (7/71)		–	–	–	–	–	–	–	–	–	–	–	–	0.72	–	–	–	–	–	0.31	0.98

*B = Basement, M = Midheight, R = Roof; **Date of Ambient Vibration Test

Table 1 (continued)
SEISMIC RESPONSE OF HIGH RISE BUILDINGS

LOCATION (Direction)	EPICENTRAL DISTANCE	PEAK ACCELERATION (g)			TIME RESPONSE FUNCTION (sec)			PEAK RESPONSE FUNCTION			BUILDING PERIOD (sec)						DAMPING IN 1st LATERAL MODE	TORSIONAL PARTICIPATION			
											(Earthquake)			(Ambient)				(Earthquake)		(Ambient)	
		B*	M	R	B	M	R	B	M	R	1st	2nd	3rd	1st	2nd	3rd		Disp.	Acc.	Disp.	Acc.
•1880 CENTURY PARK (16ST)	38																				
N54E		.11	.10	.10	0.1	0.0	–	1	0	–	3.43	–	–	2.35	.82	–	–	–	–	1.00	1.00
N36W		.13	.14	.12	0.4	0.3	–	11	7	–	2.85	0.95	–	2.08	.775	–	–	–	–	–	–
Torsion (10/72)		–	–	–	–	–	–	–	–	–	–	–	–	1.83	–	–	–	–	–	.60	.95
•1900 AVE OF STARS (27ST)	38																				
S46E		.08	–	.15	0.0	–	0.0	0	–	1	4.26	–	–	3.54	1.21	0.72	7.0	–	–	–	–
N44E		.10	–	.12	0.0	–	1.0	0	–	11	4.27	1.42	–	3.66	1.17	0.68	5.1	–	–	1.00	1.00
Torsion (7/71)		–	–	–	–	–	–	–	–	–	–	–	–	2.39	0.83	–	–	–	–	0.40	0.94
•1901 AVE OF STARS (19ST)	38																				
N46W		.12	.18	–	0.1	0.5	–	3	9	–	3.41	0.81	0.40	2.78	0.71	0.36	5.9	1.00	1.00	–	–
S44W		.17	.11	–	0.2	0.1	–	5	2	–	3.43	1.39	0.78	2.84	0.97	0.56	8.8	–	–	–	–
Torsion (7/71)		–	–	–	–	–	–	–	–	–	3.28	–	–	2.58	–	–	–	0.60	1.20	–	–
•5900 WILSHIRE (32ST)	38																				
S07W		.07	.10	.14	0.0	–	1.6	0	–	10	4.86	1.95	–	4.46	1.58	0.87	–	–	–	1.00	1.00
N83W		.07	.12	.17	0.0	–	1.4	0	–	7	5.50	1.90	–	4.66	1.56	0.90	–	–	–	–	–
Torsion (6/72)		–	–	–	–	–	–	–	–	–	–	–	–	3.64	1.26	–	–	–	–	.06	.60
•611 WEST 6TH ST (43ST)	41																				
N52W		.10	–	.11	0.0	–	0.1	0	–	2	5.40	–	–	5.71	1.65	.97	9.4	–	–	–	–
N38E		.11	–	.18	0.1	–	0.5	1	–	7	6.06	–	–	6.35	1.9	1.11	3.0	–	–	1.0	1.0
Torsion (1/72)		–	–	–	–	–	–	–	–	–	–	–	–	5.02	1.71	1.04	–	–	–	.715	.895
•800 WEST 1ST ST (31ST)	41																				
N53W		.15	.18	.28	0.1	1.2	7.6	2	10	39	2.90	1.07	0.60	2.14	0.87	–	3.2	–	–	–	–
N37E		.09	.11	.18	0.0	0.5	3.4	0	10	23	3.38	1.19	0.68	2.56	0.90	0.50	2.9	–	–	1.00	1.00
Torsion (1/72)														1.65	.625	.369		–	–	0.70	1.55
•1640 MARENGO (7RC)	42																				
N38W		.14	.20	.24	0.1	0.7	2.0	3	13	24	1.03	–	–	0.60	0.21	–	9.0	1.00	1.00		
S52W		.14	.26	.44	0.6	2.9	5.7	11	37	42	1.17	–	–	0.57	0.21	–	7.8	–	–	1.00	1.00
Torsion (6/72)		–	–	–	–	–	–	–	–	–	0.90	–	–	0.46	–	–	–	.78	1.01	1.12	1.68