STATISTICAL ANALYSIS OF THE COMPUTED RESPONSE OF STRUCTURAL RESPONSE RECORDERS (SRR) FOR ACCELEROGRAMS RECORDED IN THE UNITED STATES OF AMERICA

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SYNOPSIS

Since only a few strong-motion accelerograms have been recorded in India so far, there are not enough data at this time to compare characteristics of strong earthquakes there with related experiences in the U. S., Japan and elsewhere. Such comparisons would enable one not only to understand better the nature of strong earthquake ground motion in India, but would also provide a basis for the transfer and use of strong-motion data which have been recorded in other seismic regions for earthquake resistant design on the Indian continent. As a first step in the direction of establishing some basis for such correlations in the future, the analysis of computed response of SRR is presented for excitations consisting of 186 digitized accelerograms which have been recorded in the Western U. S. during the period from 1933 to 1971. This is analogous to having 186 actual records on SRR for earthquakes recorded in the U. S.

INTRODUCTION

The Structural Response Recorder (SRR), which serves as a dynamic model of engineering structures, has been developed in India to record response spectrum amplitudes for strong earthquake ground motion there. It consists of six seismoscopes with natural periods equal to 0.40 sec, 0.75 sec and 1.25 sec and fractions of critical damping equal to 0.05 and 0.10 (Krishna and Chandrasekaran, 1965). Because the central period coincides with the nominal period of the seismoscope used in the U. S., it is possible to make comparisons with the response of the U. S. seismoscope directly.

When more SRR records of strong earthquakes in India become available, correlation of SRR amplitudes with local estimates of earthquake magnitude and the intensity levels at the recording stations may enable one to find the overall relative difference of such estimates made in India and in the U. S. These results will then allow one to transform the estimates of magnitude and intensity made in India to their approximate equivalents in the U. S. In this way various empirical scaling functions for strong ground motion amplitudes which depend on magnitude and Modified Mercalli Intensity can be computed from the U. S. data and transferred back to India for approximate prediction of strong-motion characteristics there.

The method described in this paper can be generalized to other types of instruments and to different measures of strong ground shaking. Systematic analysis of such relative scaling functions may eventually provide a more reliable basis for transfer of the experiences in earthquake engineering and strong-motion seismology from one country to another.

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CORRELATIONS OF SRR RESPONSE WITH MODIFIED MERCALLI INTENSITY

The data on synthetic amplitudes of SRR response for correlations with MMI have been computed by numerically integrating six pairs of differential equations for φ and ψ response (Trifunac, 1977) of six seismoscopes constituting SRR and for their nominal periods and equivalent viscous dampings (Krishna and Chandrasekaran, 1965). As in our previous work, the contributions of torsional and higher modes to the SRR response have been neglected. From the analogy of linearized differential equations describing six seismoscope responses and the linear equations describing the response of single-degree-of-freedom systems employed in the response spectrum calculations [eq. (2) of Trifunac, 1977], the maximum displacement spectrum amplitudes, S_d, have been computed. Fig. 1 shows an example of computed SRR responses for the excitation corresponding to the Imperial Valley, California, earthquake of 1940. Different scales (shown in the bottom right corner of Fig. 1) have been employed to improve the clarity of the computed response.

Detailed descriptions of 186 accelerograms which have been recorded in the United States, the corresponding Modified Mercalli Intensities at the recording stations, the geologic site conditions at the recording stations ($s = 0$ designating alluvium, $s = 1$ intermediate rocks and $s = 2$ igneous rocks), and other characteristics of earthquakes which produced these records can be found in papers referenced by Trifunac (1977) and will not be repeated here. To preserve the brevity of this paper, the emphasis is being placed on the presentation of data, leaving out numerous technical details, discussion of the methodology and additional references.

The averages and standard deviations of the computed maximum relative displacement amplitudes, S_d, on SRR, for different MMI at the recording stations, but disregarding the dependence of these reponses on the geologic site conditions are shown in Table I and Fig. 2. Table I also presents the coefficients a and b in $S_d(\text{cm}) = a \exp(b I_{MM})$ which can be used to characterize overall trends of S_d versus the Modified Mercalli Intensity, I_{MM}, for six SRR transducers and assuming that the descriptive levels I, II,..., XI and XII of the MMI scale can be assigned to a linear numerical scale ranging from 1 to 12. This arbitrary and nonphysical selection of the numerical values to be associated with different I_{MM} levels appears to be adequate for preliminary correlations with the computed SRR response and for the other approximate characterizations of different I_{MM} levels of shaking in terms of the measured characteristics of strong ground motion (Trifunac, 1977). The correlation coefficient r is also shown in Table I for the assumed exponential dependence of S_d on I_{MM}.

The dependence of the averages and the standard deviations of S_d on the geologic characteristics of the recording stations ($s = 0$ for alluvium, $s = 1$ for intermediate and $s = 2$ for basement rocks) is summarized in Table II and Fig. 3. Large standard deviations and the limited number of data points for many entries in Table II limit the resolution of any possible systematic trends that might characterize average S_d for different site classifications. The small period range covered by the natural periods between 0.40 sec and 1.25 sec and the relative proximity of these periods to the central portion of the Fourier spectrum of strong ground motion where the effects of local geologic conditions are reversed (see last reference of Trifunac, 1977) may have both contributed to the lack of detectable systematic variations of S_d with the site conditions (Fig. 3).

CORRELATIONS OF THE RESPONSE OF SRR WITH MAGNITUDE

It has been suggested that the correlations between S_d amplitudes and the published earthquake magnitudes may provide valuable scaling methods which could be employed to (a) establish empirical correlations of reported earthquake magnitudes in different countries and (b) to augment the data on local magnitude determinations especially in the near field where conventional seismological instruments would go off scale (Trifunac, 1977). This correlation would take the form

$$M_{SRR} = \log_{10} S_d(\mathrm{cm}) - \log_{10} A_0(\Delta) - \log_{10} S_{d_0} \qquad (1)$$

where $\log_{10} A_0(\Delta)$ represents the distance dependent empirical attenuation function (Table III of Trifunac, 1977) and S_{d_0} depends on seismoscope period, damping, earthquake magnitude and local geologic conditions. M_{SRR} would then represent an estimate of the local magnitude based on the near-field recording on SRR. When a sufficient number of recordings on SRR become available, this method will make it possible to determine conversion factors between the local magnitude estimates in Southern California and similar estimates elsewhere. These conversion factors, together with the use of local attenuation laws similar to $\log_{10} A_0(\Delta)$ (Table III of Trifunac, 1977) will then provide a rational physical basis for more meaningful and reliable transfer and use of numerous correlations which have been developed between the magnitude, epicentral distance and recording site conditions with the parameters which characterize strong ground shaking in California, to India.

The averages and standard deviations of $\log_{10} S_{d_0}$ are shown in Fig. 4 and Table III, for different magnitudes and site classifications and for the six transducers of SRR. This function appears to be quite similar to other $\log_{10} S_{d_0}$ functions which have been computed for the Wilmot type seismoscope and the SBM seismometer (Trifunac, 1977) so that its detailed characteristics and the conditions under which it can be used to estimate local earthquake magnitude need not be repeated here. Finally, by replacing M_{SRR} by local magnitude and solving for S_d results in a formula which can be used directly for estimation of the relative displacement spectrum amplitudes when local magnitude, source to station distance, local attenuation law [analogous to $\log_{10} A_0(\Delta)$ which is valid for Southern California] and the local geologic conditions at a given station are known.

REFERENCES

Krishna, J. and A. R. Chandrasekaran (1965). Structural Response Recorders, Proc. World Conf. Earthquake Eng., 3rd, New Zealand, 143-150.

Trifunac, M. D. (1977). An Instrumental Comparison of the Modified Mercalli (M. M. I.) and Medvedev-Karnik-Sponheuer (M. K. S.) Intensity Scales, Proc. World Conf. Earthquake Eng., 6th, New Delhi, India.

TABLE I

AVERAGE SEISMOSCOPE RESPONSES COMPUTED FOR 186 ACCELERATION RECORDS AND THE RESULTING REGRESSION COEFFICIENTS IN $S_d(\text{cm}) = ae^{bI_{MM}}$

Intensity I_{MM}	T = 0.40 sec				T = 0.75 sec				T = 1.25 sec				Number of Data Points
	ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		
	$\overline{S}$(cm)	σ	$\overline{S}$(cm)	σ	$\overline{S}$(cm)	σ	$\overline{S}$(cm)	σ	$\overline{S}$(cm)	σ	$\overline{S}$(cm)	σ	
III	0.15	—	0.05	—	0.45	—	0.25	—	1.05	—	0.75	—	1**
IV	0.22	—	0.15	—	0.62	—	0.48	—	0.98	—	0.68	—	3
V	0.41	0.30	0.31	0.22	0.73	0.51	0.56	0.41	1.24	1.12	0.94	0.85	34**
VI	0.72	0.69	0.56	0.54	1.49	1.19	1.18	0.98	2.67	2.24	2.11	1.82	66**
VII	1.50	0.69	1.13	0.51	3.16	1.87	2.52	1.30	6.86	3.24	5.22	2.52	75
VIII	1.88	0.78	1.50	0.70	4.20	2.36	3.40	1.76	6.72	3.48	5.32	2.51	6
X	18.2*	—	11.5*		18.8*	—	17.4*	—	49.9*	—	39.6*		1
a	0.0158		0.00699		0.0675		0.0373		0.110		0.0747		
b	0.660		0.723		0.540		0.593		0.567		0.585		
r^2	0.965		0.983		0.972		0.981		0.923		0.932		

*linearized response.

**see footnote for the following table.

TABLE II

AVERAGE SEISMOSCOPE RESPONSES COMPUTED FOR 186 ACCELERATION RECORDS AND DIFFERENT SITE CLASSIFICATIONS

Intensity I_{MM}	Site Classification	T = 0.40 sec				T = 0.75 sec				T = 1.25 sec				Number of Data Points
		ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		
		S(cm)	σ	S(cm)	σ	S(cm)	σ	S(cm)	σ	S(cm)	σ	S(cm)	σ	
III	0	0.15		0.05		0.45		0.25		1.05		0.75		1
IV	0	0.25		0.15		1.05		0.85		1.65		1.25		1
IV	1	0.20		0.15		0.40		0.30		0.65		0.40		2
V	0	0.36	0.28	0.28	0.20	0.73	0.48	0.58	0.44	1.32	1.37	0.99	1.02	17
V	1	0.48	0.34	0.36	0.24	0.70	0.50	0.53	0.35	1.20	0.81	0.94	0.64	15**
V	2	0.40		0.30		0.85		0.65		0.90		0.60		2
VI	0	0.66	0.75	0.51	0.59	1.34	0.96	1.06	0.79	2.76	2.15	2.13	1.71	43
VI	1	0.89	0.63	0.68	0.49	1.76	1.46	1.40	1.23	2.24	1.85	1.84	1.61	16**
VI	2	0.66	0.33	0.56	0.25	1.75	1.60	1.41	1.26	3.06	3.25	2.56	2.67	7
VII	0	1.49	0.52	1.11	0.38	2.95	1.20	2.41	0.93	6.97	2.87	5.27	2.16	49**
VII	1	1.46	0.81	1.10	0.59	3.79	2.83	2.90	1.87	7.20	3.90	5.53	3.18	21**
VII	2	1.73	1.26	1.39	1.00	2.57	1.58	1.97	1.09	4.43	2.46	3.47	1.82	5
VIII	0	1.83	0.78	1.50	0.70	4.20	2.36	3.40	1.76	6.72	3.48	5.32	2.51	6
X	2	18.2*		11.5*		18.8*		17.4*		49.9*		39.6*		1

*linearized response.

**In Table V of Trifunac and Brady [1975b (referenced in Trifunac (1977)] the "number of data" listed for intensities V-1, VI-1, VII-0 and VII-1 are 14, 17, 50 and 20 rather than those shown above. These changes reflect the latest improvements in the classification of the basic data set and in no way affect the results and inferences presented in this or our previous paper.

TABLE III

DEPENDENCE OF $\log_{10}(S_{d_0})$ ON MAGNITUDE AND SITE CONDITIONS

Magnitude Range	Site Classification	T = 0.40 sec				T = 0.75 sec				T = 1.25 sec				Number of Data Points*
		ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		ζ = 0.05		ζ = 0.10		
		$\log_{10}S_{d_0}$	σ	$\log_{10}S_{d_0}$	σ	$\log_{10}S_{d_0}$	σ	$\log_{10}S_{d_0}$	σ	$\log_{10}S_{d_0}$	σ	$\log_{10}S_{d_0}$	σ	
4-4.9	0	-3.171	0.145	-3.241	0.138	-2.819	0.081	-2.885	0.077	-2.668	0.196	-2.766	0.207	3
4-4.9	1	-3.194	0.302	-3.284	0.272	-3.086	0.297	-3.186	0.296	-3.029	0.314	-3.081	0.335	2
5-5.9	0	-3.543	0.504	-3.649	0.495	-3.217	0.466	-3.330	0.453	-3.001	0.493	-3.119	0.480	23
5-5.9	1	-3.549	0.354	-3.660	0.336	-3.340	0.354	-3.446	0.330	-3.236	0.359	-3.322	0.348	15
5-5.9	2	-3.419	0.523	-3.503	0.501	-3.488	0.352	-3.522	0.344	-3.179	0.550	-3.269	0.478	2
6-6.9	0	-3.870	0.259	-3.991	0.257	-3.539	0.309	-3.635	0.309	-3.201	0.323	-3.318	0.317	83
6-6.9	1	-3.930	0.238	-4.054	0.241	-3.585	0.292	-3.689	0.284	-3.302	0.308	-3.419	0.298	33
6-6.9	2	-4.193	0.385	-4.281	0.382	-3.864	0.480	-3.974	0.463	-3.668	0.381	-3.762	0.369	10
7-7.9**	0	-4.827	0.141	-4.931	0.143	-4.350	0.264	-4.444	0.255	-4.079	0.257	-4.195	0.252	7

*The calculated seismoscope records not included in this table either had the assigned magnitude less than 4.0 or no magnitude information was available.

**For most earthquakes used in this work the magnitude has been calculated from the Wood-Anderson seismograph records and represents, by definition, the local Richter magnitude M_L. For earthquakes larger than about 6.5-7.0, local stations usually go off scale and the "magnitude" has to be determined from other teleseismic seismograms. For this reason, there may be systematic deviations between the magnitude estimates for shocks less than and greater than 6.5-7.0.

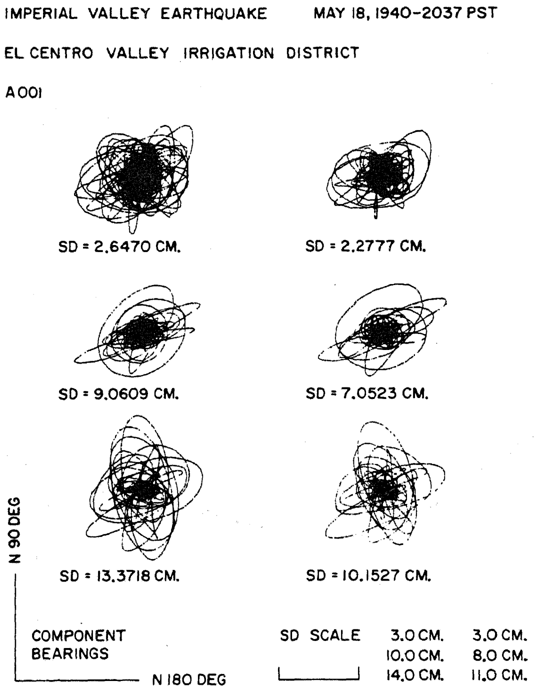

Figure 1

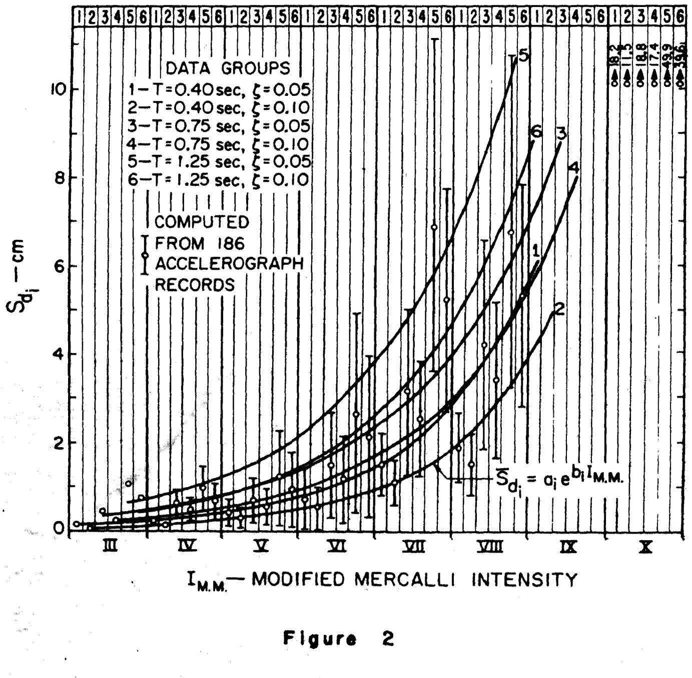

Figure 2

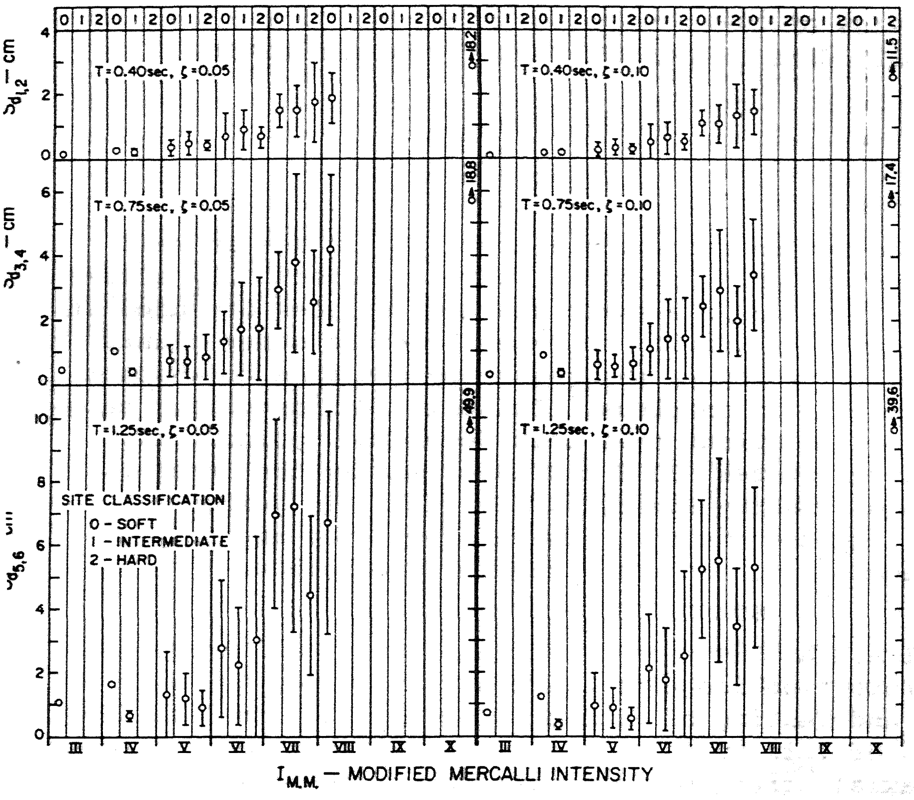

Figure 3

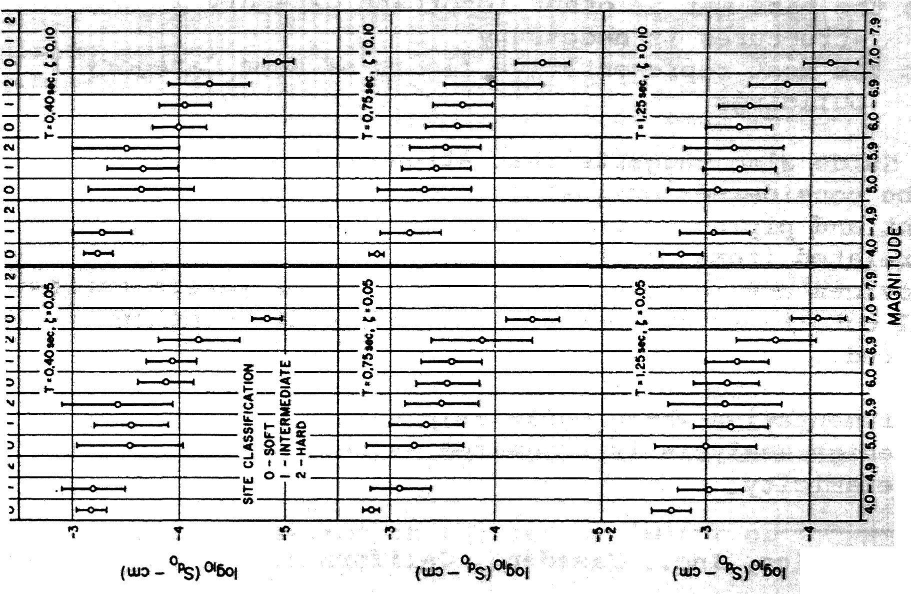

Figure 4