AN INSTRUMENTAL COMPARISON OF THE MODIFIED MERCALLI (M. M. I.) AND MEDVEDEV-KARNIK-SPONHEUER (M. K. S.) INTENSITY SCALES

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SYNOPSIS

For many parts of the world scales similar to the Modified Mercalli intensity scale, which is employed in the United States, are still widely used for mapping the descriptive characteristics of the effects of strong earthquake ground motion on man-made structures and near-surface rocks and soil. In spite of the fact that these intensity maps depend in an important way on the methods employed to prepare them and on the type of construction in the shaken area, in many seismic regions this information on the earthquake generated effects still represents the useful data which are available for seismic risk analysis. As instrumental data on strong shaking are now becoming available, primarily for the Western United States and Japan, it is possible to correlate the reported intensity levels with different characteristics of recorded accelerograms and thus derive empirical relationships that may be useful for approximate estimation of strong-motion amplitudes in terms of the Modified Mercalli Intensity or its equivalent. The results of this analysis show that, although in the intensity range between IV and VIII M. K. S. and M. M. I. scales have very similar definitions, the actual assigned intensity levels can differ by approximately one intensity unit for the average instrumental strength of shaking as measured by the SBM seismometer.

RESPONSE OF THE SBM SEISMOMETER

The SBM seismometer (Medvedev, 1965) is similar in construction to the widely used Wilmot type seismoscope (Hudson, 1958). It consists of a conical pendulum with static magnification of 1. 1 and records on spherical smoked glass by means of a needle attached to the pendulum base. Peak displacement amplitudes recorded on an SBM seismometer during earthquake shaking, blasts and machine vibrations have been correlated with the Medvedev-Karnik-Sponheuer (M. K. S.) intensity scale (Medvedev and Sponheuer, 1969) and a range of maximum recorded amplitudes has been assigned to different intensity levels (Medvedev, 1965). This correlation represents one of the first attempts to provide an empirical instrumental basis for the MKS scale, which, like the Modified Mercalli Intensity (M. M. I.) scale, represents only a qualitative shorthand description of earthquake effects on man-made structures and surficial geology. Deflections φ and ψ (Fig. 1) of the SBM pendulum can be described by the nonlinear coupled differential equations (Trifunac and Brady, 1975a)

$$\ddot{\varphi} + 2\omega_n\zeta\dot{\varphi} + \omega_n^2 \sin\varphi \cos\psi = -(\omega_n^2/g)(\cos\varphi\ddot{x} + \sin\varphi\ddot{z}) \qquad (1a)$$

$$\ddot{\psi} + 2\omega_n\zeta\dot{\psi} + 2\omega_n^2 \sin\psi \cos\varphi = -(\omega_n^2/g)(\cos\psi\ddot{y} + \sin\psi\ddot{z})$$

where $\omega_n = 2\pi/T_n \approx 25.13$ and g represents acceleration of gravity. $\ddot{x}$, $\ddot{y}$ and $\ddot{z}$ (Fig. 1) represent absolute components of acceleration for the

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pendulum support. Here we are neglecting the contributions to φ and ψ that result from torsional and higher modes of pendulum response.

The analogy between the linearized form of Eqs. (1) and the equation describing the relative displacement response of a single-degree-of-freedom viscously damped system can be shown (Hudson and Cloud, 1967) to give the maximum relative displacement S_d as

$$S_d = (g\, T_n^2/4\pi^2)\,\alpha_{max} \tag{2}$$

for a given excitation, where α_{max} is the largest angular deflection of the SBM pendulum relative to the z axis. This shows that the maximum response of the SBM seismometer provides one point on the relative displacement response spectrum at $T_n = 0.25$ sec and $\zeta = 0.08$. Eq. (2) is valid only for small φ and ψ deflections.

CORRELATIONS OF SBM SEISMOMETER RESPONSE WITH MODIFIED MERCALLI INTENSITY

To develop correlations between the maximum relative displacement response, S_d, computed from the response of an SBM seismometer, and the Modified Mercalli Intensity, for different site conditions and for earthquake motions recorded in the United States of America, synthetic SBM responses have been calculated for 186 strong-motion accelerograph records (Trifunac and Brady, 1975b). These accelerograms are representative of earthquakes with magnitudes ranging from $M = 4$ to about $M = 7.5$ and the Modified Mercalli Intensity levels IV through VIII. Most of these accelerograph records have been recorded at stations underlain by alluvium or "soft" sedimentary deposits ($s = 0$), about 30% have been recorded on "intermediate" sedimentary type rocks ($s = 1$) and only a few records are now available for sites on igneous basement rocks ($s = 2$).

Table I and Fig. 2 present the averages and standard deviations of the S_d computed from maximum SBM responses for different Modified Mercalli Intensities and disregarding any possible dependence on the recording site conditions. As Table I shows, the number of computed responses is possibly adequate to define S_d for MMI levels V, VI and VII only. Assuming that the descriptive levels of the MMI scale can be assigned to a linear numerical scale (Trifunac, 1976a), the rough trend of the average S_d responses in Table I can be characterized by $S_d = 0.00667 \exp(0.609\, I_{MM})$ for the range IV $\le I_{MM} \le$ VIII. Table II and Fig. 3 present the averages and standard deviations of S_d for different recording site conditions ($s = 0$, 1 and 2) and show that the number of recorded accelerograms is not adequate to provide reliable estimates for $\overline{S}_d$ for all levels of shaking and all site conditions. Systematic studies of spectral amplitudes (Trifunac, 1976b) have shown that there is a tendency for amplitudes of high frequency waves to be slightly larger for $s = 2$ than for $s = 0$. The data in Fig. 3 and Table II, however, do not show such systematic trends.

COMPARISON OF THE M.K.S. AND M.M.I. SCALES

Differences in the building design practices, methods of reporting the levels of shaking and the subsequent analysis of the observed damage can vary substantially from one seismic zone to the next and from one country to another. The methods of presentation and routine data reporting can, for example, lead to systematic and possibly significant differences in the reported intensity levels even when the same intensity scale is employed in two different countries (Lomnitz, 1970). In spite of these difficulties, it appears that the intensity scales contain useful information on the levels of historic seismicity and in many parts of the world still represent the only available data for seismic risk analysis and the estimation of possible future levels of shaking. Therefore, for seismic regions where little or no recorded strong-motion data are available and where the reports on strong shaking employ intensity scales only, it is useful to provide even rough estimates of the characteristics of strong motion in terms of the expected intensity levels at a point. To do this it is necessary to develop acceptable conversion functions which will permit one to convert the intensity scales employed in the areas where strong-motion data are now becoming available to the scales in those regions where no adequate recordings now exist. The preliminary correlations of peak acceleration, velocity and displacement (Trifunac, 1976a) suggest that, as a first approximation, a linearly increasing scale which corresponds numerically to the levels I, II,..., XII might be adopted as an interim vehicle for preliminary correlations, before more refined analysis becomes feasible.

To compare MKS and MMI scales we employ the correlations between the computed response of the SBM seismometer for 186 accelerograms recorded in the United States and the respective range of response for the same instrument but subject to shaking which is characterized by the MKS scale in the U. S. S. R. (Medvedev, 1965). Fig. 2 shows both the correlations of the SBM seismometer response computed for 186 accelerograms in the United States and the range of its amplitudes corresponding to different levels on the MKS scale. By comparing the average of computed responses in the United States (Table I) with the averages corresponding to different MKS levels for MM Intensities V, VI, VII and VIII, it is possible to find the four points which are connected with the dashed line in Fig. 2. This dashed line shows that the average MKS intensity levels VI, VII, VIII$^-$ and VIII$^+$ correspond to MMI levels V, VI, VII and VIII. Thus, the correlations with the SBM seismometer suggest that in the interval of MMI between IV and VIII the average reported MKS intensity would tend to be about one intensity level higher than the MMI scale. The correlations of recorded peak accelerations with MMI and MKS (Trifunac and Brady, 1975b; where it has been assumed that MMI and MKS intensity levels are identical), suggested that the average peak accelerations recorded in the United States would be systematically higher than those expected in the U. S. S. R. However, if it is assumed that the above correlations based on the SBM seismometer response do characterize systematic differences between MMI and MKS scales in the high frequency range, then employing these correlations essentially eliminates all systematic differences between the average trend of peak accelerations recorded in the U. S. and those expected in the U. S. S. R. for the corrected equivalent MKS intensity levels.

CORRELATIONS OF THE RESPONSE OF THE SBM SEISMOMETER WITH MAGNITUDE

At epicentral distances (typically less than 50 km to 100 km) the amplitudes of ground shaking even during small and moderate earthquakes, may excite conventional seismographs well beyond their recording amplitude range. Under those conditions peak amplitudes recorded by a considerably less sensitive seismoscope (Trifunac & Brady, 1975a) or by a SBM seismometer, for example, may prove to be of use in filling in additional information on the amplitudes of shaking close to the earthquake. To this end by rewriting eq. (6) of Trifunac & Brady (1975a) in the new form

$$M_{\text{SBM seismometer}} = \log_{10} S_d(\text{cm}) - \log_{10} A_0(\Delta) - \log_{10} S_{d_0} \qquad (3)$$

it becomes possible to determine the empirical scaling function $\log_{10} S_{d_0}$ so that the estimates of the local magnitude $M_{\text{SBM seismometer}}$ for all earthquakes which resulted in 186 accelerograms used here to compute S_d agrees with the published magnitudes for these earthquakes. Table IV and Fig. 4 present the dependence of average $\overline{\log_{10} S_{d_0}}$ versus magnitude for different site classifications. The large and overlapping standard deviations of $\log_{10} S_{d_0}$ versus magnitude make it difficult to use this method for computation of $M_{\text{SBM seismometer}}$ (Trifunac and Brady, 1975a) unless the most likely range of earthquake magnitude is known from other sources. Thus, for the determination of local magnitudes the above eq. (3) is probably useful only when employed to fill in the gaps in other more distant recordings. The $\log_{10} A_0(\Delta)$ in eq. (3) describes empirically the attenuation of peak amplitudes in Southern California. By using the same form of this eq. (3) elsewhere, by substituting for the equivalent of $\log_{10} A_0(\Delta)$ in the respective seismic region and by carrying through an analysis of $\log_{10} S_{d_0}$ for the magnitudes determined by the local instruments in the same region, it becomes possible to "calibrate" systematic differences between the estimates of local magnitude scale in California and the estimates of local magnitudes in all regions where SBM seismometers have been deployed.

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TABLE I

Average Seismoscope Response Computed from 186 Acceleration Records

Intensity I_{MM}	S_d (cm)	σ (cm)	Number of Data Points
III	0.05		1**
IV	0.05		3**
V	0.16	0.11	34**
VI	0.31	0.31	66**
VII	0.52	0.25	75**
VIII	0.70	0.31	6
X	3.10*		1

TABLE II

Average Seismoscope Response Computed from 186 Acceleration Records and for Different Site Classifications

Intensity I_{MM}	Site Classification	S_d (cm)	σ (cm)	Number of Data Points
III	0	0.05		1
IV	0	0.05		1
	1	0.05		2
V	0	0.14	0.11	17
	1	0.18	0.12	15**
	2	0.15	0.10	2
VI	0	0.25	0.27	43
	1	0.44	0.42	16**
	2	0.38	0.12	7
VII	0	0.51	0.23	49**
	1	0.51	0.19	21**
	2	0.73	0.50	5
VIII	0	0.70	0.31	6
X	2	3.10*		1

TABLE IV

Dependence of $\log_{10}(S_{d_0})$ on Magnitude and Site Classification

Magnitude Range	Site Classification	$\log_{10}(S_{d_0})$ (cm)	σ	Number of Data Points†
4-4.9	0	-3.775	0.126	4
	1	-3.490	0.275	3
5-5.9	0	-3.945	0.471	23
	1	-3.917	0.279	15
	2	-3.690	0.380	3
6-6.9	0	-4.343	0.267	83
	1	-4.362	0.239	33
	2	-4.507	0.355	11
7-7.9***	0	-5.313	0.140	7

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[*] Linearized response.

[**] In Table V of Trifunac and Brady (1975b) the "number of data points" listed for intensities V-1, VI-1, VII-0 and VII-1 are 14, 17, 50 and 20 rather than those shown here. 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.

[***] 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.

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

TABLE III

Logarithms* of the Amplitudes A_0 (in millimeters) with which a Standard Torsion Seismometer (T_0 = 0.8, V = 2800, h = 0.8) Should Register an Earthquake of Magnitude Zero

Δ (km)	$-\log A_0$	Δ (km)	$-\log A_0$	Δ (km)	$-\log A_0$	Δ (km)	$-\log A_0$	Δ (km)	$-\log A_0$
0	1.4	70	2.8	190	3.5	330	4.2	470	4.7
5	1.4	80	2.9	200	3.5	340	4.2	480	4.7
10	1.5	85	2.9	210	3.6	350	4.3	490	4.7
15	1.6	90	3.0	220	3.65	360	4.3	500	4.7
20	1.7	95	3.0	230	3.7	370	4.3	510	4.8
25	1.9	100	3.0	240	3.7	380	4.4	520	4.8
30	2.1	110	3.1	250	3.8	390	4.4	530	4.8
35	2.3	120	3.1	260	3.8	400	4.5	540	4.8
40	2.4	130	3.2	270	3.9	410	4.5	550	4.8
45	2.5	140	3.2	280	3.9	420	4.5	560	4.9
50	2.6	150	3.3	290	4.0	430	4.6	570	4.9
55	2.7	160	3.3	300	4.0	440	4.6	580	4.9
60	2.8	170	3.4	310	4.1	450	4.6	590	4.9
65	2.8	180	3.4	320	4.1	460	4.6	600	4.9

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[*] Since A_0 is less than 1, its logarithm is negative, and the table shows values for $-\log A_0$.

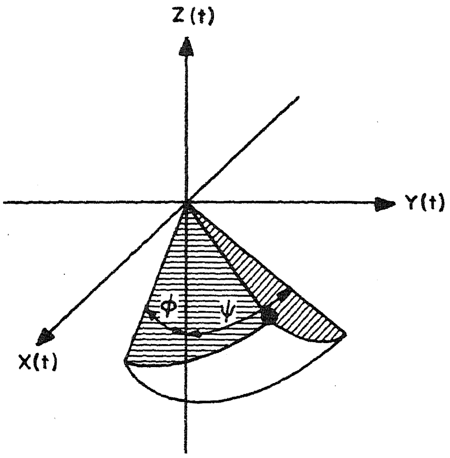

Figure 1

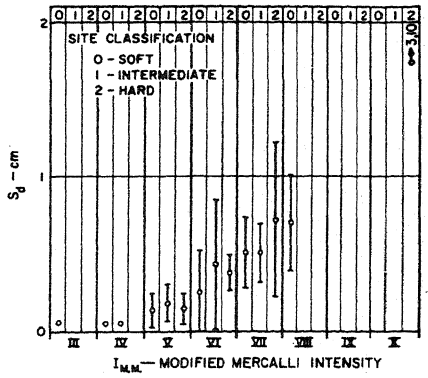

Figure 3

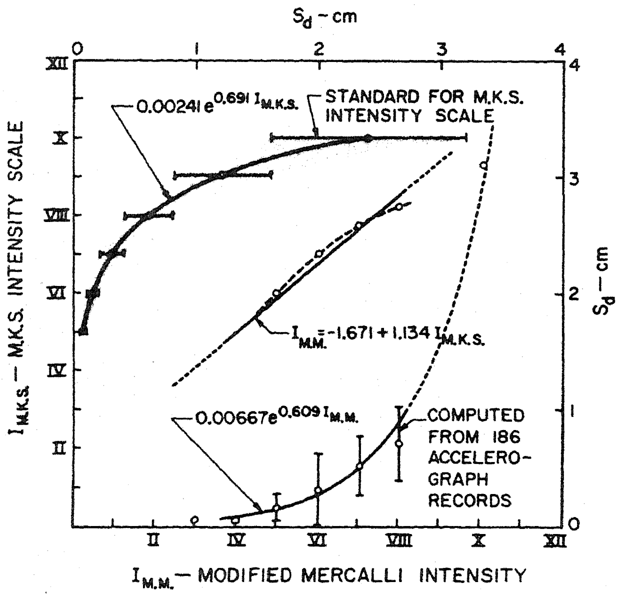

Figure 2

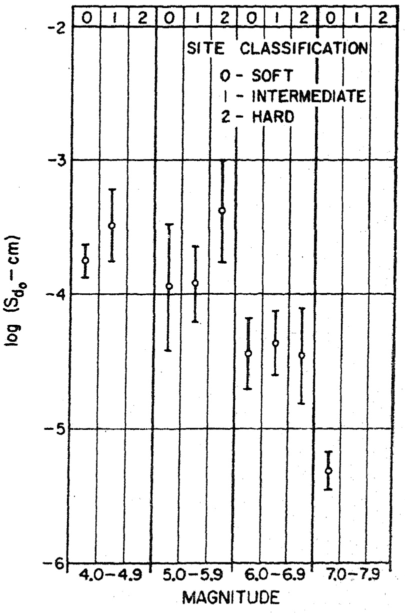

Figure 4

a) An Instrumental Comparison of the Modified Mercalli (M. M. I.) and Medvedev-Karnik-Sponheuer (M. K. S.) Intensity Scales

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