A note on instrumental comparison of the Modified Mercalli Intensity (*MMI*) in the western United States and the Mercalli-Cancani-Sieberg (*MCS*) intensity in Yugoslavia

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ABSTRACT – In contrast to their essentially equivalent definitions and published descriptions of MCS *in Yugoslavia and* MMI *in the western United States, it is shown that the recorded strong motion peak velocities imply significant differences between these two intensity scales. For* IV ≤ MMI ≤ VIII *we found that* I_{MCS}' $3.25+0.70 I_{MMI}$, *where* I_{MCS} *and* I_{MMI} *designate levels of* MCS *and* MMI *scales.*

Introduction

Seismic risk analyses, leading to distribution of the amplitudes of the inertial forces for earthquake resistant design, require estimation of the size, location and frequency of occurrence of future earthquakes. To carry out this work, it is necessary to gather data on past earthquake activity in the region for sufficiently long period of time, so that one can extrapolate the occurrence rates for the future 30 to 50 years. In most regions of the world this constitutes a difficult task, because reliable, uniform and complete catalogues of earthquake activities rarely exist any place for a period longer than 200 to 300 years (Trifunac, 1990). Often, the only alternative is to use the geologic and tectonic studies in the region (Lee and Trifunac, 1987b; Anderson, 1979; Trifunac and Todorovska, 1989a) and to convert the estimates of the time-rates of change of seismic moment to the locally applicable magnitude or intensity occurrence rates. The results can be verified partly by comparison with recent data on measured magnitudes or reported intensities. An important step in employing such inferences is to define accurately the relationship between various intensity and magnitude scales in the different regions from which the data and the regional functional relationships on these scales have been extracted.

At present, sufficient data for development of empirical scaling laws of ground motion, involving peak amplitudes and spectral characteristics, is available only for the western United States and Japan. To «transfer» these empirical relationships for use in central and eastern United States and to other countries, it is necessary to «transfer» or to «correct» for the differences in the scaling parameters (magnitudes, intensities) and to develop functional corrections for amplitude attenuation with distance. For example, recently we compared the intensity attenuation equations in the western United States with the related attenuation in Yugoslavia (Trifunac and Todorovska, 1989b) and found that their functional forms are similar. In this paper we will compare the intensity scales used in these two regions.

The field observations and the published results on intensities following damaging earthquake shaking depend not only on the definition of the scale used, and on the team gathering, interpreting and presenting the results, but also on the type and distribution of structures, their construction materials, and the geologic setting of the shaken area. Earthquakes of similar magnitudes can be disastrous in one region or can lead to only minor damage in another. Perusal of the damage reports for the western United States during the last 50 years typically indicates only «little or moderate» damage, so far. One consequence of this is that for this region we do not have a data base to construct distribution functions describing the fragility of various structural systems. In contrast, for example, Chinese engineers have presented detailed and useful distribution functions, following their investigations of the destructive effects of the Tangshan earthquake in 1976 (Yang et al., 1981). Yugoslav investigators have

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Received and revised february 1991.

likewise presented comprehensive description of the damage following the Monte Negro earthquake in 1979 (Petrovski et al., 1984). Many metropolitan areas in the United States have thousands of old unreinforced brick masonry structures, and estimation of future damage by earthquake shaking there would benefit from the possibility to «use» the Chinese and Yugoslav data, for example, in an effort to describe the fragility of these buildings. The first step in «transferring» this experience consists of identifying the «correct» level of shaking as sampled by the descriptive intensity scales. In these examples, specifically, this requires knowledge of what Modified Mercalli Intensity in the Western United States corresponds to the «same» amplitude and duration of shaking in Yugoslavia and in China.

For use of many empirical scaling laws, which have been developed with data in California, in the tectonic and geologic environment of different countries it is essential to know how to convert the *MMI* to the local intensity scale. We presented several examples of such relative calibration of intensities for India, Japan and the Soviet Union, with respect to the *MMI* as it is used in the Western United States. In this paper we extend these ideas to the *MCS* intensity scale as it is used at present in Yugoslavia. Formal description of this scale is very similar to the *MMI* and to the Medvedev-Sponheuer-Karnik (MKS) scales used in many eastern European Countries (Fig. 1; Shebalin, 1969). Though an attempt was made in the 1960's to convert all intensity reports in Yugoslavia to *MKS* scale, and the catalog on reported intensities using *MKS* scale was published in 1974, *MCS* intensity scales is still used there.

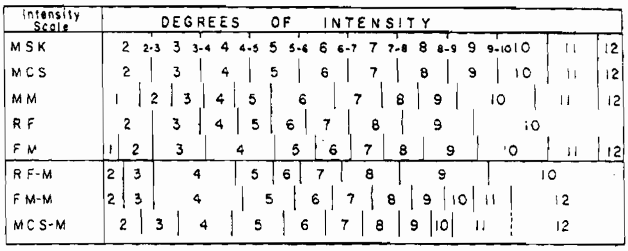

Fig. 1 – Correlation of seismic intensity scales used in the Balkan region (after Shebalin, 1969).

Table 1 – Number of records used in this study to compare MMI in Western United States and MCS in Yugoslavia.

Intensity	Number of accelerograms used at sites with *MMI* intensity of U.S. (Trifunac and Brady, 1975)	Number of accelerograms recorded at sites with *MCS* intensity in Yugoslavia (this study)
III	2	—
IV	3	1-2*
V	33	25-36
VI	67	60-63
VII	75	21-22
VIII	6	4-12
IX	—	4
X	1	—

* For site intensities reported by a ranger of values (e.g. $I_{MCS} = VII - VIII$) using upper or lower levels of a range results in different groupings of reported intensities

Relative scaling of *MCS* in Yugoslavia and *MMI* in the western United States

We begin by developing a relationship between the peak recorded ground velocity and a reported *MCS* intensity at a recording site in Yugoslavia. We choose to work with peak velocity rather than with peak acceleration or peak displacement for the following reasons. The noise characteristics of typical optically recording analog accelerographs (Amini et al, 1982; 1987) are such that the highest signal to noise ratio is in the frequency range near 1 Hz (near 1.5 Hz for M = 3.5, to 0.5 Hz for M = 7.5). Assuming that not only the amplitudes but also the shapes of the recorded spectra can change in going from one geologic environment to another, and using only one scaling parameter (peak velocity) which samples the central frequencies of the useful frequency band should provide the most stable single parameter scaling. Using peak acceleration would be less representative because (1) the scaling would be biased towards the high frequency portion of the useful frequency band and (2) if the shapes of the Fourier spectra were different in the two regions (e.g. different Q's) the result would be more biased again (Lee et al., 1990). Using computed peak displacements would be even more difficult. The uniformly processed strong motion data in Yugoslavia (Jordanovski et al., 1987) is band-pass filtered to the variable long periods where the signal to noise ratio is about one. This results in variable low-pass filtering of the displacement spectra and thus reduces the estimates of the peak displacements in a way which is dependent not only on the regional attenuation, but also on the differences in the signal to noise ratio of the Yugoslav data set relative to the data recorded in California.

Table 1 presents the distribution of the data which is available for this study (third column is for *MCS* intensities in Yugoslavia). It corresponds to 127 sites in Yugoslavia for which all information is available at present. In the same table the second column shows the distribution of the similar data in the study of Trifunac and Brady (1975) for accelerograms recorded in the western United States. Since 1975 numerous new earthquakes have been recorded and their recordings, correlated with amplitude and frequency characteristics of strong motion (Lee and Trifunac, 1985; Trifunac and Lee, 1989; Trifunac, 1989). However, in this work we choose to work with the original data base of Trifunac and Brady (1975) since it was used for other related comparisons of intensity scales in Japan (JMA Scale, Wong and Trifunac, 1979), U.S.S.R. (MKS scale, Trifunac, 1977a) and India (SRR, Trifunac, 1977b). It is seen from Table 1 that the range of intensities covered by the two data sets has similar distributions and comparable number of observations for intensity levels V, VI and VII. Both data sets lack data for low and for high intensities.

Table 2 – Mean Values and Standard Deviations of Peak, Velocity for Different Mercalli-Cancani-Sieberg Intensities in Yugoslavia.

M.C.S. Intensity		Component	Number of Data	velocity $\bar{v}$	(cm/s) σ
IV	IV^-	vert.	2	0.60	0.22
	IV^+		1	0.91	–
	IV^-	horiz.	4	1.38	0.48
	IV^+		2	2.05	0.12
V	V^-	vert.	36	0.60	0.46
	V^+		25	0.59	0.55
	V^-	horiz	72	1.21	1.01
	V^+		50	1.32	1.21
VI	VI^-	vert.	60	0.91	0.67
	VI^+		63	0.83	0.74
	VI^-	horiz.	120	2.15	2.10
	VI^+		126	1.83	2.16
VII	VII^-	vert.	21	2.69	1.57
	VII^+		22	1.74	1.67
	VII^-	horiz.	42	6.90	4.26
	VII^+		44	4.01	4.26
VIII	$VIII^-$	vert.	4	7.40	3.42
	$VIII^+$		12	4.79	3.29
	$VIII^-$	horiz.	8	14.55	7.78
	$VIII^+$		24	11.46	7.77
IX	IX^-	vert.	4	16.41	2.69
	IX^+		4	16.41	2.69
	IX^-	horiz.	8	37.95	12.94
	IX^+		8	37.95	12.94

The distribution of the recorded strong motion data with respect to the hypocentral distance is also very similar for U.S. strong motion data (Lee and Trifunac, 1987a) and for Yugoslav data (Jordanovski et al., 1987). In both data sets records are available for distances between about 5 and 60 km. Neither data set has a significant number of recordings for distances greater than 70 to 80 km. Both data sets are available for earthquake magnitudes between 3.5 and 6.5. Since the spectral shapes and amplitudes of the recorded motions depend on hypocentral distance and earthquake magnitude, uniformity and similarity of coverage in the two data sets suggests that no significant biases in the relative comparison of the corresponding ground motions and the associated intensity of shaking would be expected.

At 30 of 127 sites the *MCS* intensities in Yugoslavia have been reported by the range of values (e.g. VII-VIII). Rather than to use half interval values we performed two separate studies by assigning all estimates either to their lower reported bound (designated by «$-$» in the text and in the tables) or to the higher reported bound (denoted by «+»). Thus for example V^- in Table 2 means that those site intensities which were reported as V to VI have been assigned to $MCS = V$, while V^+ means that the intensities assigned as IV to V have been considered as V. Table 2 then presents the averages and standard deviations of the peak velocity recorded at sites with *MCS* intensities between IV and IX. It is seen that for intensities IV, VIII and IX the number of data points is-not adequate for reliable estimates.

Table 3 presents the regression coefficients a_0 and b_0 in

Table 3 – Regression coefficients in $\log_{10} v_{H,V} = a_0 + b_0 I^{\mp}_{MCS} \pm \sigma$.

		a_0	b_0	σ
v_H	-	-1.88	0.38	0.10
	+	-1.87	0.37	0.05
v_V	-	-2.20	0.38	0.07
	+	-2.19	0.37	0.11

I^-_{MCS} = VII when reported I_{MCS} = VII - VIII
I^+_{MCS} = VIII when reported I_{MCS} = VII - VIII

Table 4 – Coefficients A and B in equation $I^{\mp}_{MCS} = A + BI_{MM}$.

where I_{MM} represents numerical values assigned to correspond to the Modified Mercalli Intensity levels at a site

		A	*B*
I^-_{MCS}	V*:	2.89	0.74
	H:	3.29	0.66
I^+_{MCS}	V:	2.95	0.76
	H:	3.35	0.68

* *V* and *H* indicate that these coefficients have been derived from the corresponding correlations for vertical (*V*) and horizontal (*H*) peak velocities

$$\log_{10} v_{H,V} = a_0 + b_0\, I^{\mp}_{MCS} \pm \sigma, \tag{1}$$

where σ is the standard deviation with respect to the regression model using a_0 and b_0, v_H (horizontal) and v_V (vertical) are peak velocities at a site with *MCS* intensity level equal to I_{MCS}. This equation can be compared with (Trifunac and Brady, 1975)

$$\log_{10} v_H = -0.63 + 0.25 I_{MM} \tag{2a}$$

$$\log_{10} v_V = -1.10 + 0.28 I_{MM} \tag{2b}$$

obtained from analogous regressions of peak velocities recorded in the Western United States at sites with Modified Mercalli Intensity levels $IV \le I_{MM} \le X$. Combining equation (1) with equations (2) gives

$$I^{\mp}_{MCS} = A + BI_{MM} \tag{3}$$

where A and B are given in table 4. These results suggest that for $IV \le I_{MCS} \le VIII$

$$I_{MCS} \approx 3.25 + 0.70 I_{MM} \tag{4}$$

It is seen that equation (4) indicates that for example, $MMI = IV$ corresponds to $MCS = VI$ and MMI

= *VIII* to *MCS* = *IX*, a surprising result when one considers Figure 1. For $V \leq I_{MM} \leq X$ this figure implies $I_{MCS} \sim I_{MM} - 0.5$, which is not only different, but also of opposite trend relative to equation (4). In a related comparison of *MKS* and *MMI* (Trifunac, 1977a) we found that *MMI* = *III* corresponds to *MKS* = *IV* and *MMI* = *VIII* to *MKS* = *VIII* − *IX*.

For *MMI* in the range between V and VIII, equation (4) is similar in overall amplitudes to

$$I_{MM} = -0.013\, I_{MCS}^2 + 1.068\, I_{MCS} - 0.902, \qquad (5)$$

which was proposed by Console, Peronaci, Sist and Sonaglia in 1972 (Abraseys, 1975). For increasing intensities equation (4) implies diminishing differences between *MMI* and *MCS*, while equation (5) suggests the opposite.

In many engineering analyses of earthquake design criteria for important structures, lack of locally available strong motion data has resulted in use of scaling equations developed in California and in terms of MMI scale. Since peak accelerations of strong ground motion approximately double for every increase in the level of the intensity of shaking, it is seen that the differences implied by this analysis are not small.

In this (I_{MCS}) and in the work of Trifunac and Brady (1975) (I_{MM}) we use the reported site intensities, where the strong motion data has been recorded. Since a given level of shaking can occur from a nearby small earthquake or from a large distant earthquake, it is seen that the effects of spectral changes caused by attenuation are «mixed» in the data base as used in our regression analyses. To avoid region specific attenuation equations and thus to allow transfer of data and of the associated empirical results from one region to another, we have decided not to use distance parameters in any of the scaling equations involving site intensity. This is clearly done at the expense of increasing the standard deviation of the estimates. However, series of analyses which have been performed on strong motion data so far (Trifunac, 1989; Trifunac and Todorovska, 1989a) suggest that it is useful to continue with that approach. For completeness of this analysis and to test the stability of our inferences, the data was divided into subsets with epicentral distances up to 10, 20, 50, 100 and beyond 100 km (all data). For each of these subsets, coefficients a_0 and b_0 were calculated independently. Coefficients a_0 were −2.4, −2.5, −2.5, −2.5 and −2.2, while b_0 were .41, .42, .42, .42 and .38 respectively. It is seen that the results of peak velocities are indeed sufficiently stable with respect to the epicentral distance.

Discussion and conclusions

By correlating the peaks of recorded velocity of strong ground motion with reported site intensities, we have developed empirical relationship between *MCS* intensity, as it is used in Yugoslavia, and *MMI* in the Western United States. For small levels of shaking we found *MCS* to be about two intensity levels above *MMI*. This difference diminishes to only one level of intensity for higher levels of shaking. Our results are expected to represent the average trends for $V \leq MMI \leq VII$, but the overall consistency of the available data suggests that our results may be valid even for $III \leq MMI \leq IX$.

Most residential structures affected by strong shaking in Yugoslavia could be classified as unreinforced brick masonry. On the other hand most residential structures in the Western United States are light wooden structures. Consequently, those field observations which employ the effects of shaking on such structures could be further studied as one of the most likely contributors to the observed differences. There is some evidence that the overall average *Q* in Yugoslavia might be higher than in the Western United States (Lee et al., 1990). If true, this would suggest higher content of high frequency motion in Yugoslavia relative to the motions in the Western United States. This would affect the differences in high frequency amplitudes of Fourier spectra of strong motion, making comparison of peak accelerations less reliable for relating *MCS* and *MMI* scales than the peak velocities.

Of course, many other factors may be responsible for contributing to the systematic differences in the shape of Fourier spectrum amplitudes of strong shaking in Yugoslavia relative to the shaking in the Western United States. Differences in the average stress drop, source dimensions (Trifunac, 1973) and frequency dependent attenuation (Trifunac and Lee 1990) are the most obvious candidates. Systematic testing and investigation of such possible differences will not only contribute to the better understanding of strong earthquake ground motion in Yugoslavia, but, more important, it will teach us how to transfer the experience on characterization of strong ground motion from one tectonic region to another.

Acknowledgements

We are indebted to Professor Grandori for bringing to our attention the results of Console, Peronaci, Sist and Sonaglia in 1972, and for other valuable suggestions, which lead to the improvements of the original manuscript.

References

Ambraseys, N.N. (1975) Advancements in Engineering Seismology in Europe, Bull. of European Committee on Earthquake Eng., No. 4, 7-18, Bulgarian Academy of Sciences, Sofia.

Amini, A., V.W. Lee and M.D. Trifunac (1982) Noise in Earthquake Accelerograms, ASCE, EMD Vol. 108, 1121-1129.

Amini, A., M.D. Trifunac and R.L. Nigbor (1987) A Note on the Noise Amplitudes of Some Strong Motion Accelerographs, Int. J. Soil Dynamics and Earthquake Eng. Vol. 6, No. 3, 180-185.

Anderson, J.G. (1979) Estimating the Seismicity from Geological Structure for Seismic Risk Studies, Bull. Seism. Soc. Amer., *69*, 135-158.

Jordanovski, L.R., V.W. Lee, T. Olumčeva, C. Sinadinovski, M.I. Todorovska and M.D. Trifunac (1987) Strong Earthquake Ground Motion Data in EQINFOS: Yugoslavia, Part I, Rep. No. 87-05, Dept. of Civil Eng., Univ. Southern California, Los Angeles, California.

Lee, V.W. and M.D. Trifunac (1985) Attenuation of Modified Mercalli Intensity for Small Epicentral Distance in California, Rep. No. 85-02, Dept. of Civil Eng., Univ. of Southern California, Los Angeles, California.

Lee, V.W. and M.D. Trifunac (1987a) Strong Earthquake Ground Motion Data in EQINFOS: Part I, Rep. No. 87-01, Dept. of Civil Eng., Univ. of Southern California, Los Angeles, California

Lee, V.W. and M.D. Trifunac (1987b) Microzonation of a Metropolitan Area, Rep. No. 87-02, Dept. of Civil Eng., Univ. Southern California, Los Angeles, California.

Lee, V.W. M.D. Trifunac, M. Herak, M. Živčić and D. Herak (1990) M_L^{SM} Computed from Strong Motion Accelerograms Recorded in Yugoslavia, Int. J. Earthquake Eng. and Structural Dyn., Vol. 19, No. 8,1167-1179.

Petrovski, J., Z. Milutinović, D. Ristić, and N. Nocevski (1984) Earthquake Damage Prediction Modeling for Needs of Physical and Urban Planning, Report IZIIS 84084, Skopje Yugoslavia.

Shebalin, N.V. (1969) Makroseismicheskoye pole i ochag silnogo zemletreseniya, Dissertation, Institute of the Physics of the Earth, Moscow.

Trifunac, M.D. (1973) Analysis of Strong Earthquake Ground Motion for Prediction of Response Spectra, Int., J. Earthquake Eng. and Struct. Dynamics. Vol. 2, No. 1, 59-69.

Trifunac, M.D. (1977a) An Instrumental Comparison of the Modified Mercalli (*MMI*) and Medredev-Karnik-Sponheuer (MKS) Intensity Scales, Sixth World Conf. Earthquake Eng., N. Delhi, India, 2-359.

Trifunac, M.D. (1977b) Statistical Analysis of the Computed Response of Structural Response Recorders (SRR) for Accelerograms Recorded in the United States of America, Sixth World Conf. Earthquake Eng., N. Delhi, India 10-25.

Trifunac, M.D. (1989) Scaling Strong Motion Fourier Spectra by Modified Mercalli Intensity, Local Soil and Geologic Site Conditions, Structural Eng./ Earthquake Eng., JSCE, Vol. 6, No. 2.

Trifunac, M.D. (1990) A Microzonation Method Based on Uniform Risk Spectra, Int. J. Soil Dynamics and Earthquake Eng., Vol. 9, No. 1, 34-43.

Trifunac, M.D. and A.G. Brady (1975) On the Correlation of Seismic Intensity Scales with the Peaks of Recorded Strong Ground Motion, Bull. Seism. Soc. Amer. *65*, 139-162.

Trifunac, M.D. and V.W. Lee (1989) Empirical Models for Scaling Fourier Amplitude Spectra of Strong Ground Acceleration in Terms of Earthquake Magnitude, Source to Station Distance, Site Intensity and Recording Site Conditions, Int. J. Soil Dynamics and Earthquake Eng. Vol. 8, No. 3, 110-125.

Trifunac, M.D. and V.W. Lee (1990) Frequency Dependent Attenuation of Strong Earthquake Ground Motion, Int. J. Soil Dynamics and Earthquake Eng., Vol. 9, No. 1, 3-15.

Trifunac, M.D. and M.I. Todorovska (editors) (1989a) Methodology for Selection of Earthquake Design Motions for Important Éngineermg Structures, Rep. No. 89-01 Dept. of Civil Eng., Univ. of Southern California, Los Angeles, California.

Trifunac, M.D. and M.I. Todorovska (1989b) Attenuation of Seismic Intensity in Albania and Yugoslavia, Int. J. Earthquake Eng. and Structural Dynamics, Vol. 10, No. 5 617-631.

Wong, H.L. and M.D. Trifunac (1979) A Comparison of Modified Mercalli (*MMI*) and Japanese Meteorological Agency (JMA) Intensity Scales, Int. J. Earthquake Eng. and Structural Dynamics, Vol. 7, 75-83.

Yang, Y.S., L. Yang and Y.S. Ko (1981) On Seismic Destruction and Seismic Design of Multi-Story Masonry Buildings, Institute of Engineering Mechanics, Harbin, China.