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# $M_L^{SM}$ COMPUTED FROM STRONG MOTION ACCELEROGRAMS RECORDED IN YUGOSLAVIA

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## SUMMARY

It is shown that the new definition[1] of strong motion local magnitude $M_L^{SM}$ leads to stable estimates of magnitudes for earthquakes in Yugoslavia, with epicentral distances $R < 100$ km and for $2{\cdot}5 < M_L^{SM} < 6{\cdot}5$. Tables with magnitudes computed using this new procedure are presented for all earthquakes contributing to the strong motion accelerogram files in EQINFOS for Yugoslavia.[2] The similarity of our findings with the analogous analyses for California suggests new possibilities for relative calibration between various local magnitude scales, which are used in southeastern Europe, and $M_L$ in California.

## INTRODUCTION

In 1935 Richter[3] proposed the use of the magnitude scale $M_L$, which is determined from the peak response of a Wood–Anderson seismometer ($T_n = 0{\cdot}8$ sec, fraction of critical damping $\zeta = 0{\cdot}8$ and static magnification $V_S = 2800$). At first this scale was used for epicentral distances greater than 25 km and less than 600 km. Later Gutenberg and Richter[4] extended its use to small epicentral distances ($< 25$ km) by using torsional seismometers with static magnification equal to 4. Since it is based only on the peak response, this magnitude cannot characterize any detailed features of the earthquake source. Yet, because it samples amplitudes with frequencies centred near 1 Hz, which is in the centre of the period range of interest to earthquake engineering and strong motion seismology, this scale continues to be useful for many studies of the near source ground motion. With a gradual increase in the number of the recorded accelerograms[5,6] in California, the associated source mechanism studies[7,8] and the empirical investigations of the dependence of spectral amplitudes on magnitude,[9,10] it became possible to investigate the properties of this magnitude scale also at small epicentral distances,[11–14] and to show how it can be extended to the estimation of the local magnitude, $M_L^{SM}$, computed from the recorded strong motion accelerograms.[1]

For the estimation of engineering seismic risk the very first step of analysis requires description of the earthquake occurrence in terms of earthquake magnitudes and distances from the site, and then description of the attenuation of strong motion amplitudes with distance. Procedures for detailed computation and mapping of seismic risk are now available for scaling earthquakes both in terms of magnitude and site intensity,[15–17] these having been developed using empirical results on attenuation,[18] local site effects, magnitude and intensity, all in California.[10,19] For successful transfer of such models elsewhere and for

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Table I. Distribution of the available strong motion records versus published magnitude, $M_p$, and distance $\Delta = (R^2 + H^2)^{1/2}$

| $M_p$ | $\log_{10} \Delta$ (km) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0·7* | 0·9 | 1·1 | 1·3 | 1·5 | 1·7 | 1·9 | 2·1 | 2·3 |
| 6·76–7·25 | | | 2 | 2 | 1 | 2 | 1 | 9 | 6 |
| 6·26–6·75 | | | | | | | | | |
| 5.76–6.25 | | | | 3 | 11 | 5 | 3 | 1 | |
| 5·26–5·75 | | 1 | 3 | | 3 | 2 | 3 | 5 | 1 |
| 4·76–5·25 | | 1 | 3 | 9 | 11 | 5 | | 1 | 2 |
| 4·26–4·75 | 4 | 4 | 13 | 28 | 19 | 4 | | | 1 |
| 3·76–4·25 | 1 | 3 | 15 | 25 | 12 | 6 | 1 | | |
| 3·26–3·75 | 1 | 1 | 34 | 10 | 4 | 3 | | | |
| 2·76–3·25 | 2 | 3 | 21 | 6 | 6 | 2 | | | |

*Intervals 0·2 units wide and centred at 0·7, 0·9, 1·1, . . .

independent development of similar results in other seismically active regions, it is essential first to describe the local magnitude scales and the local attenuation equations in various respective regions.

In the immediate vicinity of the source, the attenuation of the wave amplitudes should be least affected by the quality factor $Q$, and by other local features of geologic structure, so that $M_L^{SM}$ estimates should be less sensitive to regional geologic and tectonic setting, in contrast to other magnitude estimates using more distant ( > 100 km) stations. Therefore $M_L^{SM}$ should also be useful for relative calibration of different magnitude estimates in Europe, for better understanding of the differences caused by various instruments, regional variations of $Q$ and different procedures and magnitude definitions.[20–24]

In 1987 a programme on digitization of 449 accelerograms recorded in Yugoslavia was completed,[2] contributing digitized data on more than 200 earthquakes between 1975 and 1983. From these data 183 contributing earthquakes have been identified and cross-referenced with various regional catalogues and can be used to compare the regional estimates of magnitude with $M_L^{SM}$ for 325 recorded accelerograms (Tables I and II). The aim of this paper is to present our estimates of $M_L^{SM}$ in Yugoslavia using Trifunac's definition[1] of $M_L^{SM}$ and thus facilitate relative calibration of different more distant estimates of magnitudes in eastern Europe. With those results it will be possible to improve the accuracy of the seismic risk estimates in Yugoslavia and to some extent in the neighbouring Balkan countries.

For small epicentral distances the new definition of $M_L^{SM}$ will take into account the mean effects of the source size, the local geologic conditions and the changes of the shape of the spectral amplitudes of the strong ground motion with magnitude. Since for small epicentral distances most seismological instruments go off scale, the use of $M_L^{SM}$ will provide additional data for estimation of $M_L$, when this is not available or possible from other sources.

Figure 1 illustrates the data available for this study. It shows that all recordings were obtained between 1975 and 1983, for magnitudes between 2·5 and 7, for mostly shallow focal depths ( < 25 km) and for small epicentral distances, typically less than 50 km (Table I). Much of these data came from the Monte Negro earthquake of 1979 and its many aftershocks. The total number of digitized and processed accelerograms is 449. Of those, 325 records could be identified to have occurred during 183 earthquakes.

## DEFINITION OF $M_L^{SM}$

The definition of $M_L^{SM}$ is[1]

$$M_L^{SM} = \bar{M}_L^{SM} - D(\bar{M}_L^{SM}) \tag{1}$$

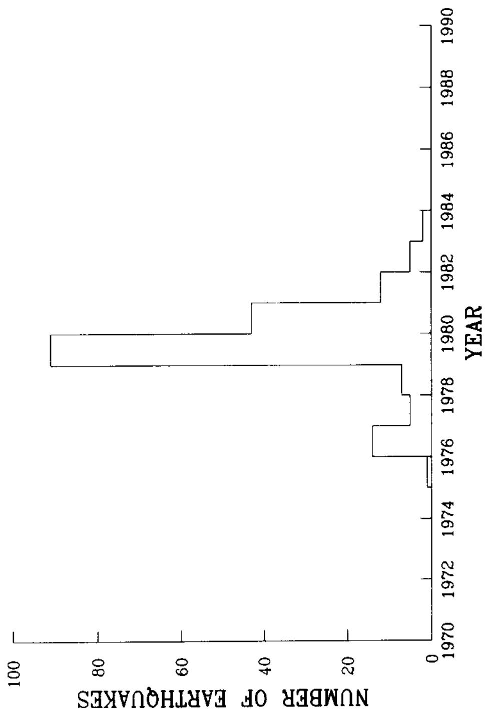


Figure 1(a). Number of earthquakes in the Yugoslav strong motion data base for period from 1975 to 1983

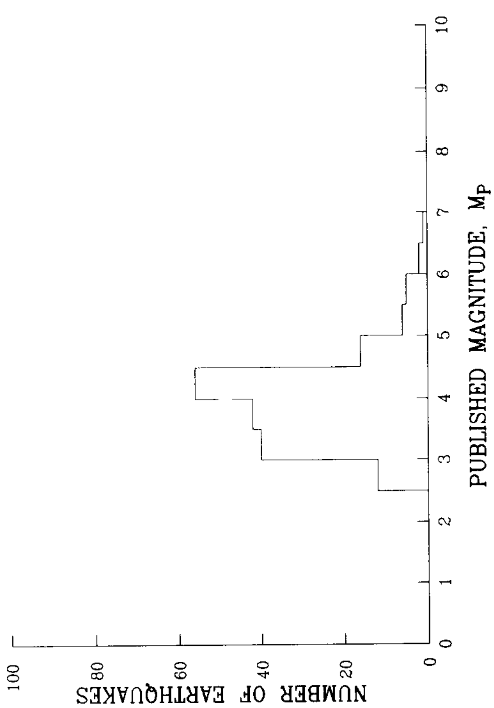


Figure 1(b). Distribution of magnitudes in the Yugoslav strong motion data base

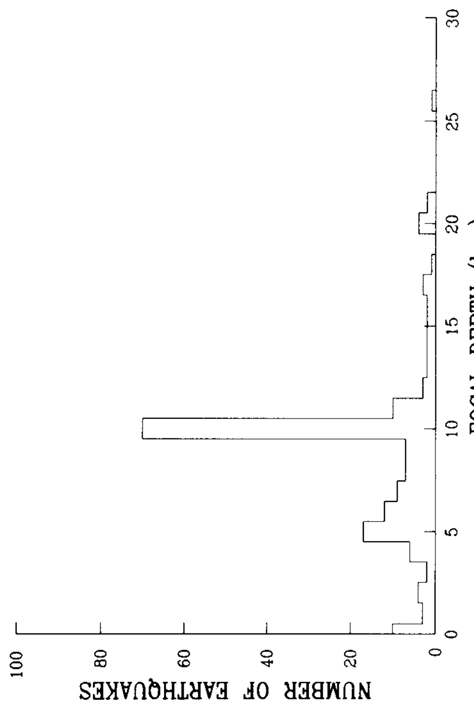


Figure 1(c). Distribution of focal depths

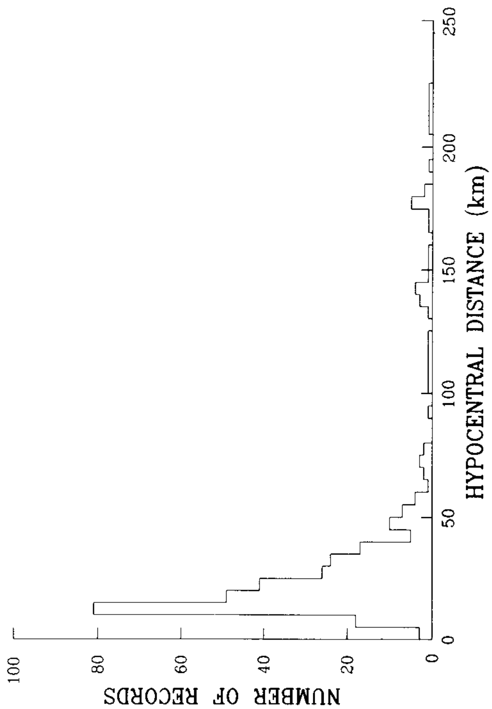


Figure 1(d). Distribution of hypocentral distances for the Yugoslav strong motion data base

Table II.

| EQ# | EQ.REF# | | DATE MO/DA/YR | TIME GMT | SEC. | LAT. (N) | LONG. (E) | H KM | MAGNITUDES 1 | 2 | 3 | 4 | 5 | S.M. 1 | 2 | # OF REC | INT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | 9/ 7/75 | 1623 | | 45.84 | 15.74 | 0 | 4.50 | | | | | 4.40 | 4.14 | | 5.5MCS |
| 2 | 2 | | 5/11/76 | 0532 | | 46.20 | 13.11 | 10 | 4.10 | | | | | 4.41 | 4.55 | 2 | 5MCS |
| 3 | 3 | 2 | 7/14/76 | 0539 | 33.2 | 46.35 | 13.31 | 6 | 4.40 | | | | 4.30 | 3.96 | 3.47 | | |
| 4 | 4 | | 9/ 7/76 | 1108 | | 46.21 | 13.02 | 5 | 4.10 | | | | 4.20 | 3.95 | 3.68 | | 5.5MCS |
| 5 | 5 | 3 | 9/11/76 | 1631 | 11.0 | 46.30 | 13.22 | 7 | 5.10 | 4.93 | | 4.93 | 5.50 | 4.71 | 4.13 | 2 | 7.5MM |
| 6 | 6 | 4 | 9/11/76 | 1635 | 2.8 | 46.24 | 13.17 | 11 | 5.60 | | | | 5.70 | 5.51 | 5.18 | 2 | 9.0MM |
| 7 | 7 | 5 | 9/11/76 | 1648 | 54.6 | 46.29 | 13.17 | 1 | 4.30 | 3.95 | | 3.95 | | 4.24 | 4.02 | | |
| 8 | 8 | 6 | 9/12/76 | 1953 | 27.8 | 46.29 | 13.24 | 6 | 4.50 | 4.16 | | 4.16 | 4.50 | 4.14 | 3.67 | | 7.0MM |
| 9 | 9 | 7 | 9/13/76 | 1854 | 45.9 | 46.33 | 13.21 | 4 | 4.40 | 4.33 | | 4.33 | 4.40 | 4.45 | 4.33 | 2 | 6.0MM |
| 10 | 10 | 8 | 9/15/76 | 0315 | 19.4 | 46.28 | 13.18 | 9 | 5.80 | | | | 6.00 | 5.94 | 5.82 | 2 | 9.0MM |
| 11 | 11 | 9 | 9/15/76 | 0438 | 52.7 | 46.31 | 13.17 | 7 | 4.80 | 4.57 | | 4.57 | 4.70 | 4.55 | 4.13 | 2 | 7.0MM |
| 12 | 12 | 10 | 9/15/76 | 0458 | 41.8 | 46.33 | 13.21 | 5 | 4.60 | 4.46 | | 4.46 | 4.40 | 4.25 | 3.77 | | 6.0MM |
| 13 | 13 | 11 | 9/15/76 | 0921 | 17.8 | 46.33 | 13.15 | 2 | 6.10 | | | | 6.10 | 6.04 | 5.69 | 2 | 9.5MM |
| 14 | 14 | | 9/15/76 | 0945 | | 46.30 | 13.14 | 5 | 4.20 | | | | 4.30 | 4.24 | 4.11 | | |
| 15 | 15 | 12 | 9/15/76 | 1111 | 10.8 | 46.33 | 13.24 | 8 | 5.00 | 4.67 | | 4.67 | 4.90 | 4.65 | 4.11 | 2 | 7.5 |
| 16 | 17 | 14 | 9/16/77 | 2348 | 7.5 | 46.28 | 12.97 | 11 | 5.30 | 4.77 | | 4.77 | 5.30 | 4.80 | 4.09 | | 8.0MM |
| 17 | 18 | 15 | 9/28/77 | 0143 | 14.7 | 46.29 | 13.05 | 17 | 4.20 | 3.79 | | 3.79 | | 4.32 | 4.27 | | |
| 18 | 19 | | 9/23/77 | 0258 | | 41.49 | 20.08 | 37 | 4.70 | | | | | 4.75 | 4.63 | | 7.0MM |
| 19 | 20 | | 11/ 3/77 | 0223 | | 42.12 | 24.03 | 11 | 5.50 | | | | | 5.53 | 5.33 | | 7.MCS |
| 20 | 21 | | 12/ 7/77 | 1921 | | 46.26 | 13.13 | 10 | 3.40 | | | | | 3.38 | 3.34 | | |
| 21 | 22 | 16 | 1/ 1/78 | 0423 | 46.3 | 43.30 | 17.60 | 20 | 3.80 | 4.00 | | 4.00 | | 3.52 | 3.27 | | 5.5MCS |
| 22 | 23 | 17 | 2/20/78 | 1213 | 33.5 | 46.48 | 13.25 | 0 | 4.00 | 3.62 | | 3.62 | | 4.62 | 5.08 | | 6.0MCS |
| 23 | 24 | 18 | 3/16/78 | 0608 | 39.0 | 43.10 | 18.03 | 20 | 4.00 | 3.76 | 3.98 | 3.87 | | 3.94 | 3.76 | | 6.0MCS |
| 24 | 25 | 160 | 6/20/78 | 2003 | 25.1 | 40.75 | 23.26 | 20 | 6.00 | | | | 6.00 | 5.95 | 5.39 | | |
| 25 | 26 | | 11/16/78 | 2023 | | 41.97 | 21.50 | 0 | 3.50 | | | | | 3.59 | 3.59 | | 5.5MCS |
| 26 | 28 | 21 | 12/17/78 | 0216 | 49.3 | 43.44 | 17.38 | 16 | 4.50 | | | | | 4.22 | 3.80 | 2 | |
| 27 | 27 | | 12/31/78 | 1556 | | 41.99 | 23.22 | 21 | 4.60 | | | | | 5.07 | 5.37 | 2 | |
| 28 | 29 | 22 | 2/17/79 | 2206 | 3.0 | 44.69 | 17.25 | 5 | 3.40 | 3.60 | 3.19 | 3.40 | | 3.35 | 3.30 | | 5.5MCS |
| 29 | 112 | 23 | 3/31/79 | 1555 | 24.0 | 41.88 | 19.07 | 6 | 4.00 | 4.03 | 4.08 | 4.06 | | 4.09 | 4.03 | 2 | |
| 30 | 113 | 24 | 4/ 9/79 | 0210 | 19.8 | 41.90 | 19.05 | 0 | 5.20 | 5.04 | | 5.04 | 5.10 | 5.33 | 5.26 | 3 | 7.5 |
| 31 | 114 | | 4/10/79 | 1054 | | 41.90 | 19.19 | 10 | 3.60 | | | | | 3.54 | 3.43 | | |
| 32 | 31 | 26 | 4/15/79 | 0619 | 45.8 | 42.02 | 19.07 | 13 | 7.00 | | | | 6.80 | 7.09 | 6.74 | 23 | 9.0MCS |
| 33 | 116 | 27 | 4/15/79 | 0631 | 9.4 | 42.16 | 18.74 | 10 | 4.90 | 4.47 | | 4.47 | | 4.87 | 4.66 | 3 | |
| 34 | 117 | | 4/15/79 | 0701 | | 42.00 | 19.30 | 10 | 3.60 | | | | | 3.46 | 3.32 | | |
| 35 | 118 | 28 | 4/15/79 | 0711 | 27.9 | 41.98 | 19.18 | 11 | 4.20 | 3.90 | 3.74 | 3.82 | | 4.18 | 4.00 | | |
| 36 | 119 | 29 | 4/15/79 | 0725 | 31.6 | 41.94 | 19.47 | 10 | 4.10 | 4.01 | 3.66 | 3.83 | | 4.20 | 4.14 | | |
| 37 | 120 | | 4/15/79 | 0748 | | 41.80 | 19.14 | 10 | 3.80 | | | | | 3.88 | 3.82 | | |
| 38 | 121 | 31 | 4/15/79 | 0808 | 41.9 | 42.24 | 18.65 | 10 | 4.40 | 4.48 | 4.32 | 4.40 | | 4.07 | 3.64 | | |
| 39 | 122 | 32 | 4/15/79 | 0813 | 17.1 | 41.92 | 19.24 | 26 | 4.30 | 4.45 | 4.35 | 4.40 | | 4.35 | 4.23 | | |
| 40 | 123 | | 4/15/79 | 0910 | | 41.92 | 19.33 | 10 | 4.40 | | | | | 4.06 | 3.62 | 2 | |
| 41 | 124 | 37 | 4/15/79 | 1025 | 25.3 | 1.91 | 19.40 | 15 | 4.90 | 4.86 | | 4.86 | | 4.85 | 4.62 | 3 | |
| 42 | 125 | 38 | 4/15/79 | 1107 | 30.2 | 42.08 | 19.06 | 6 | 4.20 | 3.96 | 4.10 | 4.03 | | 4.37 | 4.37 | 2 | |
| 43 | 126 | 39 | 4/15/79 | 1142 | 16.5 | 41.93 | 19.41 | 10 | 3.70 | 3.87 | 3.70 | 3.79 | | 3.58 | 3.42 | | |
| 44 | 127 | 40 | 4/15/79 | 1243 | 46.2 | 42.08 | 19.19 | 12 | 4.40 | 3.99 | 4.13 | 4.06 | | 4.09 | 3.67 | 2 | |
| 45 | 128 | 41 | 4/15/79 | 1324 | 33.6 | 42.41 | 18.74 | 10 | 4.30 | | 3.97 | 3.97 | | 3.66 | 3.13 | | |
| 46 | 32 | 42 | 4/15/79 | 1443 | 5.9 | 42.26 | 18.71 | 9 | 5.80 | | | | | 5.58 | 5.11 | 6 | |
| 47 | 130 | | 4/15/79 | 1524 | | 42.39 | 18.87 | 10 | 4.50 | | | | | 4.15 | 3.69 | | |
| 48 | 131 | 43 | 4/15/79 | 1752 | 56.2 | 42.55 | 18.55 | 9 | 4.10 | 4.18 | 3.82 | 4.00 | | 3.64 | 3.23 | | |
| 49 | 132 | 46 | 4/15/79 | 2049 | 46.8 | 42.00 | 19.21 | 14 | 4.30 | 4.43 | 4.47 | 4.45 | | 4.01 | 3.62 | | |
| 50 | 133 | 49 | 4/16/79 | 0756 | 1.7 | 41.79 | 19.56 | 17 | 4.20 | 4.10 | 4.26 | 4.18 | | 4.26 | 4.16 | | |
| 51 | 134 | 51 | 4/16/79 | 1004 | 39.1 | 41.92 | 19.24 | 10 | 4.90 | 5.03 | | 5.03 | | 5.17 | 5.25 | 2 | |
| 52 | 135 | 53 | 4/16/79 | 1430 | 51.9 | 42.00 | 19.03 | 15 | 4.10 | 4.32 | 4.09 | 4.20 | | 4.21 | 4.17 | 2 | |

Table II. (*cont.*)

| EQ# | EQ.REF# | | DATE MO/DA/YR | TIME GMT | SEC. | LAT. (N) | LONG. (E) | H KM | MAGNITUDES 1 | 2 | 3 | 4 | 5 | S.M. 1 | 2 | # OF REC | INT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 53 | 228 | | 4/16/79 | 1535 | | 41.82 | 19.21 | 14 | 3.30 | | | | | 4.17 | 4.85 | 1 | |
| 54 | 136 | 55 | 4/16/79 | 1551 | 7.3 | 41.81 | 19.37 | 10 | 3.80 | 3.57 | 3.59 | 3.58 | | 3.68 | 3.50 | 2 | |
| 55 | 137 | 56 | 4/16/79 | 2300 | 27.0 | 41.86 | 19.38 | 11 | 4.20 | 4.30 | 4.10 | 4.20 | | 4.48 | 4.59 | 3 | |
| 56 | 138 | 58 | 4/17/79 | 0353 | 32.4 | 41.80 | 19.48 | 10 | 4.20 | 3.86 | 3.95 | 3.91 | | 4.14 | 3.93 | | |
| 57 | 33 | 59 | 4/17/79 | 0539 | 57.9 | 42.45 | 18.62 | 0 | 4.90 | 5.10 | | 5.10 | | 4.61 | 4.15 | 2 | |
| 58 | 140 | 61 | 4/17/79 | 1806 | 16.0 | 42.04 | 19.05 | 1 | 4.00 | 3.92 | 4.17 | 4.05 | | 4.22 | 4.28 | | |
| 59 | 141 | 64 | 4/18/79 | 0245 | 12.1 | 41.89 | 19.10 | 8 | 3.70 | 3.96 | 4.03 | 3.99 | | 3.63 | 3.48 | | |
| 60 | 142 | 65 | 4/18/79 | 0350 | 4.9 | 41.91 | 19.14 | 7 | 4.10 | 4.17 | 4.07 | 4.12 | | 3.95 | 3.69 | 3 | |
| 61 | 30 | 67 | 4/18/79 | 1519 | 20.4 | 46.34 | 13.29 | 21 | 4.80 | 4.92 | | 4.92 | | 4.78 | 4.59 | 2 | 7.0MM |
| 62 | 143 | 68 | 4/18/79 | 1951 | 13.4 | 42.01 | 19.06 | 5 | 4.60 | 4.43 | | 4.43 | | 4.56 | 4.36 | 4 | |
| 63 | 144 | 69 | 4/19/79 | 0017 | 35.3 | 41.90 | 19.18 | 10 | 4.50 | 4.42 | | 4.42 | | 4.71 | 4.75 | 3 | |
| 64 | 145 | 70 | 4/19/79 | 0542 | 49.8 | 42.04 | 19.03 | 2 | 4.60 | 4.36 | | 4.36 | | 4.63 | 4.50 | 4 | |
| 65 | 146 | 71 | 4/19/79 | 0707 | 5.4 | 42.01 | 19.02 | 3 | 4.00 | 4.29 | 4.15 | 4.22 | | 3.78 | 3.51 | | |
| 66 | 147 | | 4/20/79 | 2341 | | 41.88 | 19.16 | 10 | 3.60 | | | | | 3.08 | 2.81 | | |
| 67 | 148 | | 4/21/79 | 0136 | | 41.80 | 19.10 | 5 | 3.50 | | | | | 3.44 | 3.36 | | |
| 68 | 149 | | 4/21/79 | 0149 | | 41.85 | 19.10 | 5 | 3.20 | | | | | 3.51 | 3.67 | | |
| 69 | 150 | 72 | 4/21/79 | 0238 | 5.7 | 41.98 | 19.20 | 20 | 4.30 | 4.66 | | 4.66 | | 4.90 | 5.34 | 2 | |
| 70 | 151 | | 4/21/79 | 0404 | | 41.83 | 19.37 | 10 | 3.80 | | | | | 3.73 | 3.58 | | |
| 71 | 152 | 73 | 4/21/79 | 0433 | 1.2 | 41.80 | 19.18 | 5 | 4.30 | 4.19 | 4.30 | 4.24 | | 4.17 | 3.90 | 2 | |
| 72 | 153 | 74 | 4/21/79 | 0454 | 26.9 | 41.83 | 19.16 | 5 | 3.90 | 3.87 | 4.27 | 4.07 | | 3.78 | 3.57 | | |
| 73 | 154 | | 4/22/79 | 0444 | | 41.95 | 19.27 | 10 | 3.50 | | | | | 2.96 | 2.72 | | |
| 74 | 155 | 78 | 4/22/79 | 0632 | 12.0 | 41.92 | 19.24 | 5 | 4.50 | 4.43 | 4.45 | 4.44 | | 4.52 | 4.39 | 3 | |
| 75 | 156 | 79 | 4/22/79 | 0732 | 7.4 | 41.78 | 19.32 | 16 | 4.00 | 3.91 | 3.71 | 3.81 | | 3.52 | 3.13 | | |
| 76 | 157 | 80 | 4/23/79 | 1252 | 46.3 | 41.92 | 19.26 | 8 | 3.20 | 3.19 | | 3.19 | | 2.81 | 2.71 | | |
| 77 | 158 | | 4/24/79 | 0023 | | 41.81 | 19.29 | 10 | 3.60 | | | | | 3.53 | 3.42 | | |
| 78 | 159 | | 4/24/79 | 1645 | | 41.81 | 19.10 | 10 | 3.60 | | | | | 4.10 | 4.44 | | |
| 79 | 160 | 81 | 4/24/79 | 2226 | 24.9 | 41.94 | 19.28 | 10 | 3.60 | 3.54 | 3.67 | 3.60 | | 3.37 | 3.20 | 2 | |
| 80 | 161 | 82 | 4/25/79 | 0636 | 46.3 | 41.92 | 19.25 | 6 | 3.80 | 3.92 | 4.08 | 4.00 | | 3.96 | 3.96 | | |
| 81 | 162 | 83 | 4/25/79 | 1514 | 32.0 | 41.83 | 19.19 | 11 | 3.80 | 3.93 | 4.07 | 4.00 | | 3.85 | 3.77 | | |
| 82 | 164 | | 4/25/79 | 1812 | | 41.94 | 19.13 | 5 | 3.30 | | | | | 3.81 | 4.13 | | |
| 83 | 163 | 84 | 4/25/79 | 1912 | 17.6 | 41.85 | 19.26 | 11 | 3.60 | 3.78 | 3.92 | 3.85 | | 3.59 | 3.51 | | |
| 84 | 165 | 85 | 4/28/79 | 0338 | 2.6 | 42.19 | 18.81 | 2 | 4.50 | 4.56 | | 4.56 | 4.50 | 4.21 | 3.79 | 2 | 7.0 |
| 85 | 166 | 86 | 4/29/79 | 1024 | 17.7 | 42.00 | 19.23 | 10 | 3.90 | 4.00 | 4.08 | 4.04 | | 3.52 | 3.19 | | |
| 86 | 167 | 87 | 4/30/79 | 1700 | 5.7 | 42.27 | 18.82 | 4 | 4.50 | 4.33 | | 4.33 | | 3.72 | 3.07 | | |
| 87 | 168 | 88 | 5/ 1/79 | 0639 | 6.4 | 41.93 | 19.26 | 4 | 3.20 | 3.40 | 3.41 | 3.41 | | 3.32 | 3.38 | | |
| 88 | 169 | 90 | 5/ 3/79 | 1639 | 45.7 | 41.85 | 19.13 | 5 | 3.50 | 3.66 | 3.71 | 3.68 | | 3.61 | 3.62 | | |
| 89 | 170 | | 5/ 6/79 | 2252 | | 41.89 | 19.36 | 10 | 3.50 | | | | | 3.23 | 3.07 | | |
| 90 | 34 | 92 | 5/12/79 | 0330 | 34.2 | 42.26 | 18.91 | 9 | 5.20 | 5.08 | | 5.08 | 5.00 | 5.25 | 5.11 | 6 | |
| 91 | 172 | 93 | 5/14/79 | 0953 | 7.6 | 41.93 | 19.19 | 10 | 4.60 | 4.60 | | 4.60 | | 4.85 | 4.93 | 2 | |
| 92 | 173 | 94 | 5/20/79 | 0845 | 28.5 | 42.19 | 18.82 | 5 | 4.30 | 4.59 | | 4.59 | | 4.42 | 4.38 | 2 | |
| 93 | 35 | 95 | 5/24/79 | 1723 | 18.2 | 42.15 | 18.76 | 5 | 6.20 | | | | 6.10 | 6.25 | 5.99 | 12 | 7.5MM |
| 94 | 175 | | 5/24/79 | 1942 | | 42.16 | 18.71* | 56 | 3.80 | | | | | 4.15 | 4.32 | | |
| 95 | 176 | | 5/24/79 | 2228 | | 42.21 | 18.65 | 10 | 4.10 | | | | | 4.00 | 3.77 | | |
| 96 | 177 | | 5/25/79 | 0332 | | 42.29 | 18.76 | 10 | 3.70 | | | | | 3.93 | 4.00 | | |
| 97 | 178 | | 5/25/79 | 0722 | | 42.20 | 18.73 | 10 | 4.10 | | | | | 3.65 | 3.24 | | |
| 98 | 179 | | 5/25/79 | 1145 | | 42.14 | 18.76 | 10 | 4.30 | | | | | 4.23 | 4.00 | 2 | |
| 99 | 180 | | 5/27/79 | 1447 | | 42.15 | 18.78 | 10 | 4.40 | | | | | 4.59 | 4.59 | | |
| 100 | 181 | | 5/28/79 | 1327 | | 42.12 | 18.68 | 10 | 4.20 | | | | | 4.38 | 4.39 | | |
| 101 | 182 | | 5/30/79 | 0538 | | 41.85 | 19.06 | 10 | 4.10 | | | | | 4.01 | 3.79 | | |
| 102 | 183 | | 5/30/79 | 2347 | | 42.30 | 18.76 | 10 | 4.40 | | | | | 3.86 | 3.33 | 2 | |
| 103 | 184 | | 6/ 1/79 | 0929 | | 42.37 | 18.60 | 10 | 3.80 | | | | | 3.68 | 3.49 | | |
| 104 | 185 | | 6/ 4/79 | 0251 | | 42.13 | 18.78 | 8 | 4.40 | | | | | 4.40 | 4.24 | | |

Table II. (*cont.*)

| EQ# | EQ.REF# | | DATE MO/DA/YR | TIME GMT | SEC. | LAT. (N) | LONG. (E) | H KM | MAGNITUDES 1 | 2 | 3 | 4 | 5 | S.M. 1 | 2 | # OF REC | INT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 105 | 186 | | 6/18/79 | 0956 | | 42.19 | 18.65 | 10 | 4.30 | | | | | 4.25 | 4.05 | | |
| 106 | 187 | | 6/20/79 | 2118 | | 42.17 | 18.69* | 49 | 4.80 | | | | | 4.68 | 4.38 | 2 | |
| 107 | 188 | | 7/14/79 | 1407 | | 42.26 | 18.76 | 10 | 3.90 | | | | | 4.27 | 4.47 | 2 | |
| 108 | 189 | 96 | 7/20/79 | 0256 | 2.9 | 41.86 | 19.21 | 5 | 3.60 | 3.60 | 3.53 | 3.57 | | 4.10 | 4.43 | | |
| 109 | 190 | | 8/ 2/79 | 1414 | | 42.06 | 19.04 | 10 | 4.20 | | | | | 4.73 | 5.09 | | |
| 110 | 191 | | 8/ 6/79 | 0748 | | 42.31 | 18.58 | 10 | 4.10 | | | | | 4.12 | 3.98 | | |
| 111 | 192 | | 8/17/79 | 0530 | | 41.89 | 19.31 | 3 | 4.40 | | | | | 4.30 | 4.03 | | |
| 112 | 193 | | 8/24/79 | 1016 | | 42.16 | 18.79* | 38 | 3.90 | | | | | 4.04 | 4.03 | | |
| 113 | 36 | 149 | 9/ 7/79 | 1257 | 56.9 | 44.84 | 17.38 | 0 | 3.20 | 3.54 | 3.15 | 3.35 | | 2.92 | 2.85 | | 5.0MCS |
| 114 | 194 | 100 | 9/21/79 | 1202 | 41.7 | 41.95 | 19.36 | 4 | 4.20 | 3.90 | 4.17 | 4.04 | | 4.11 | 3.86 | | |
| 115 | 195 | | 11/ 5/79 | 1824 | | 42.00 | 19.31 | 11 | 3.20 | | | | | 3.46 | 3.59 | | |
| 116 | 196 | 101 | 11/ 6/79 | 0805 | 25.6 | 41.90 | 19.26 | 6 | 3.10 | | 3.65 | 3.65 | | 3.58 | 3.87 | | |
| 117 | 198 | 102 | 11/ 9/79 | 0148 | 49.7 | 41.88 | 19.30 | 17 | 4.10 | 3.84 | 4.17 | 4.00 | | 4.32 | 4.38 | | |
| 118 | 199 | | 11/ 9/79 | 0238 | | 41.82 | 19.19 | 7 | 3.10 | | | | | 3.49 | 3.71 | | |
| 119 | 200 | 103 | 11/ 9/79 | 0420 | 2.2 | 41.87 | 19.24 | 4 | 3.70 | 3.61 | 3.57 | 3.59 | | 3.35 | 3.10 | | |
| 120 | 201 | 104 | 11/10/79 | 0419 | 34.7 | 41.90 | 19.37 | 6 | 4.20 | | 4.38 | 4.38 | | 5.11 | 5.85 | | |
| 121 | 202 | 105 | 11/20/79 | 1831 | 59.3 | 42.01 | 18.96 | 8 | 4.50 | 3.90 | 3.78 | 3.84 | | 4.77 | 4.87 | 2 | |
| 122 | 37 | 157 | 5/18/80 | 2002 | 57.9 | 43.21 | 20.97 | 6 | 5.70 | | | | | 5.87 | 5.81 | 8 | 8.0MCS |
| 123 | 38 | 159 | 5/18/80 | 2026 | 42.7 | 43.24 | 20.96 | 11 | 5.00 | | | | | 5.07 | 4.96 | 2 | |
| 124 | 39 | | 5/18/80 | 2019 | | 43.26 | 20.90 | 10 | 4.30 | | | | | 4.56 | 4.66 | | |
| 125 | 40 | | 5/18/80 | 2041 | | 43.29 | 20.89 | 1 | 4.90 | | | | | 4.81 | 4.53 | | |
| 126 | 42 | 106 | 5/21/80 | 0922 | 41.0 | 43.33 | 21.00 | 7 | 3.80 | 3.90 | 3.79 | 3.85 | | 3.52 | 3.26 | | 6.0MM |
| 127 | 43 | 107 | 5/23/80 | 1226 | 23.9 | 43.28 | 21.04 | 0 | 4.50 | 4.58 | | 4.58 | | 4.81 | 4.96 | | |
| 128 | 44 | 108 | 5/23/80 | 1237 | 35.5 | 43.19 | 21.02 | 5 | 3.20 | 3.28 | | 3.28 | | 3.48 | 3.62 | | |
| 129 | 45 | | 5/23/80 | 1340 | | 43.12 | 21.30 | 10 | 3.00 | | | | | 3.44 | 3.71 | | |
| 130 | 46 | 109 | 5/25/80 | 0603 | 36.2 | 43.26 | 21.06 | 13 | 3.60 | 3.72 | 3.79 | 3.76 | | 4.14 | 4.51 | | |
| 131 | 47 | 110 | 5/25/80 | 0708 | 49.4 | 43.27 | 20.95 | 9 | 3.60 | 3.58 | 3.22 | 3.40 | | 3.53 | 3.41 | | |
| 132 | 48 | 111 | 5/26/80 | 0025 | 37.1 | 42.87 | 20.98 | 10 | 3.40 | 3.07 | | 3.07 | | 3.32 | 3.26 | | |
| 133 | 50 | | 5/31/80 | 1642 | | 43.30 | 20.80 | 10 | 2.80 | | | | | 2.98 | 3.17 | | |
| 134 | 51 | 113 | 6/ 1/80 | 2124 | 44.6 | 43.28 | 21.01 | 8 | 3.40 | 3.53 | 3.50 | 3.51 | | 3.93 | 4.27 | | |
| 135 | 52 | 114 | 6/ 3/80 | 1908 | 5.7 | 43.25 | 21.00 | 10 | 3.50 | 3.50 | 3.34 | 3.42 | | 3.58 | 3.57 | | |
| 136 | 53 | 115 | 6/ 4/80 | 0321 | 43.3 | 43.27 | 20.99 | 4 | 3.10 | 2.94 | | 2.94 | | 3.30 | 3.43 | | |
| 137 | 54 | | 6/ 4/80 | 2129 | | 43.31 | 20.80 | 10 | 3.20 | | | | | 3.21 | 3.23 | | |
| 138 | 55 | | 6/ 5/80 | 0603 | | 43.27 | 21.00 | 10 | 3.00 | | | | | 3.13 | 3.26 | | |
| 139 | 56 | 116 | 6/ 9/80 | 0811 | 22.7 | 43.07 | 20.73 | 10 | 2.90 | | | | | 3.21 | 3.43 | | |
| 140 | 57 | 117 | 6/10/80 | 2125 | 1.8 | 43.34 | 21.05 | 10 | 4.10 | 4.02 | 3.95 | 3.99 | | 4.07 | 3.89 | 2 | |
| 141 | 58 | 118 | 6/12/80 | 2346 | 26.7 | 43.05 | 20.98 | 12 | 3.50 | 3.49 | 3.05 | 3.27 | | 4.11 | 4.54 | | |
| 142 | 59 | | 6/14/80 | 0642 | | 43.01 | 20.61 | 10 | 3.30 | | | | | 3.97 | 4.43 | | |
| 143 | 60 | 119 | 6/14/80 | 0220 | 21.6 | 43.05 | 20.97 | 18 | 3.30 | 3.07 | | 3.07 | | 3.53 | 3.62 | | |
| 144 | 61 | 120 | 6/17/80 | 0952 | 6.0 | 43.25 | 20.95 | 10 | 3.70 | 3.80 | 3.57 | 3.68 | | 3.96 | 4.04 | 2 | |
| 145 | 62 | 121 | 6/17/80 | 2214 | 39.5 | 43.23 | 20.95 | 10 | 3.70 | 3.84 | 3.50 | 3.67 | | 3.81 | 3.80 | 2 | |
| 146 | 63 | 122 | 6/19/80 | 0147 | 2.3 | 43.19 | 20.92 | 10 | 3.60 | 3.57 | 3.55 | 3.56 | | 3.95 | 4.13 | | |
| 147 | 64 | 123 | 6/19/80 | 0442 | 16.1 | 43.27 | 21.07 | 10 | 3.50 | 3.31 | 3.47 | 3.39 | | 3.28 | 3.14 | | |
| 148 | 65 | 124 | 6/28/80 | 0610 | 12.0 | 43.22 | 20.94 | 6 | 3.40 | 3.27 | 3.16 | 3.21 | | 3.59 | 3.66 | | |
| 149 | 66 | 125 | 6/29/80 | 0552 | 11.7 | 43.21 | 20.88 | 9 | 3.70 | 3.84 | 3.49 | 3.66 | | 3.49 | 3.30 | | |
| 150 | 68 | 126 | 7/ 1/80 | 0643 | 11.4 | 43.26 | 20.96 | 9 | 3.10 | | 2.99 | 2.99 | | 3.03 | 3.05 | | |
| 151 | 69 | 127 | 7/ 2/80 | 1423 | 52.1 | 43.27 | 20.97 | 8 | 3.10 | | | | | 2.91 | 3.02 | | |
| 152 | 70 | | 7/13/80 | 2054 | | 43.29 | 20.63 | 10 | 3.10 | | | | | 3.82 | 4.33 | | |
| 153 | 71 | 128 | 7/13/80 | 2207 | 53.3 | 44.73 | 17.31 | 7 | 3.40 | | 2.96 | 2.96 | | 2.95 | 2.77 | 4 | |
| 154 | 41 | 129 | 7/19/80 | 0037 | 57.9 | 41.45 | 20.38 | 12 | 4.50 | 4.80 | | 4.80 | | 4.72 | 4.86 | | ?6.5MCS |
| 155 | 72 | 130 | 7/31/80 | 2152 | 39.3 | 43.31 | 20.95 | 10 | 3.20 | 3.44 | 3.42 | 3.43 | | 3.61 | 3.84 | | |

Table II. (*cont.*)

| EQ# | EQ.REF# | | DATE MO/DA/YR | TIME GMT | SEC. | LAT. (N) | LONG. (E) | H KM | MAGNITUDES 1 | 2 | 3 | 4 | 5 | S.M. 1 | 2 | # OF REC | INT. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 156 | 74 | 132 | 9/ 3/80 | 1159 | 40.9 | 43.26 | 20.93 | 10 | 3.20 | 3.51 | 3.26 | 3.39 | | 3.29 | 3.34 | | |
| 157 | 75 | 134 | 10/10/80 | 0103 | 46.7 | 43.23 | 20.91 | 10 | 2.80 | | | | | 2.85 | 3.00 | | |
| 158 | 76 | 135 | 10/11/80 | 1055 | 12.0 | 43.28 | 20.95 | 10 | 3.00 | | | | | 2.80 | 2.81 | | |
| 159 | 77 | | 10/11/80 | 2339 | | 43.20 | 20.30 | 0 | 2.90 | | | | | 3.28 | 3.52 | | |
| 160 | 78 | 136 | 10/21/80 | 1943 | 11.1 | 43.23 | 20.88 | 10 | 3.90 | | | | | 3.93 | 3.82 | 2 | |
| 161 | 79 | 151 | 11/ 3/80 | 1911 | 45.7 | 43.22 | 20.85 | 10 | 3.80 | | 3.68 | 3.68 | | 3.68 | 3.49 | 2 | |
| 162 | 81 | 152 | 12/ 8/80 | 0632 | 0.9 | 43.31 | 21.03 | 10 | 3.30 | 3.51 | | 3.51 | | 3.41 | 3.45 | | |
| 163 | 82 | 153 | 12/14/80 | 0254 | 48.6 | 43.27 | 21.07 | 10 | 3.90 | 4.10 | 4.28 | 4.19 | | 4.22 | 4.38 | 2 | |
| 164 | 83 | 154 | 12/22/80 | 1909 | 39.9 | 43.22 | 20.99 | 10 | 3.70 | 3.88 | 3.49 | 3.68 | | 3.93 | 4.00 | 2 | |
| 165 | 87 | | 2/28/81 | 2253 | | 42.95 | 20.56 | 0 | 3.90 | | | | | 4.00 | 3.96 | 2 | |
| 166 | 91 | 156 | 3/ 7/81 | 0653 | 16.0 | 42.95 | 20.78 | 0 | 3.80 | 3.74 | 3.82 | 3.78 | | 3.70 | 3.52 | | |
| 167 | 92 | | 3/ 8/81 | 1310 | | 42.84 | 20.68 | 10 | 3.40 | | | | | 3.54 | 3.56 | | |
| 168 | 98 | | 5/11/81 | 1325 | | 43.27 | 18.53 | 10 | 3.40 | | | | | 3.53 | 3.55 | | 5.5MCS |
| 169 | 99 | 137 | 7/24/81 | 0253 | 43.1 | 44.71 | 17.27 | 5 | 3.00 | 3.15 | 3.14 | 3.14 | | 2.70 | 2.67 | 3 | |
| 170 | 100 | 138 | 7/24/81 | 0255 | 51.6 | 44.67 | 17.24 | 10 | 2.90 | 2.90 | 2.79 | 2.84 | | 2.67 | 2.71 | 2 | |
| 171 | 101 | 139 | 8/13/81 | 0258 | 13.5 | 44.70 | 17.22 | 7 | 5.40 | | | | | 5.89 | 6.16 | 4 | 8.0MCS |
| 172 | 102 | 140 | 8/13/81 | 0437 | 12.4 | 44.69 | 17.19 | 7 | 3.50 | 3.56 | | 3.56 | | 2.97 | 2.73 | 2 | |
| 173 | 103 | 142 | 8/14/81 | 0444 | 54.4 | 44.73 | 17.22 | 10 | 3.20 | 3.32 | 3.19 | 3.29 | | 2.95 | 2.89 | 2 | |
| 174 | 204 | | 8/19/81 | 2043 | | 42.17 | 18.95 | 10 | 4.50 | | | | | 4.39 | 4.13 | | |
| 175 | 104 | | 8/21/81 | 0330 | | 44.89 | 17.37 | 11 | 3.20 | | | | | 3.30 | 3.36 | 3 | |
| 176 | 105 | | 8/30/81 | 0311 | | 44.98 | 17.40 | 10 | 2.80 | | | | | 2.82 | 2.97 | 2 | |
| 177 | 110 | | 6/ 2/82 | 0542 | | 43.35 | 20.94 | 2 | 4.6 | | | | | 5.04 | 5.30 | | 7.5MCS |
| 178 | 106 | 144 | 7/ 3/82 | 0341 | 32.5 | 44.68 | 17.19 | 6 | 2.80 | | 3.18 | 3.18 | | 2.66 | 2.75 | 3 | 5.0MCS |
| 179 | 109 | 158 | 7/14/82 | 1614 | 53.8 | 42.13 | 21.43 | 7 | 4.40 | | 4.42 | 4.42 | | 3.97 | 3.48 | 3 | 6.0MCS |
| 180 | 107 | 146 | 10/12/82 | 0133 | 59.3 | 44.69 | 17.14 | 6 | 3.30 | | | | | 3.20 | 3.16 | 4 | 5.0?MM |
| 181 | 108 | | 11/22/82 | 1857 | | 44.58 | 16.80 | 10 | 2.9 | | | | | 3.49 | 3.88 | 3 | |
| 182 | 203 | 147 | 1/ 5/83 | 0403 | 30.5 | 41.96 | 19.19 | 10 | 3.80 | | 3.98 | 3.98 | | 4.38 | 4.78 | | |
| 183 | 111 | 148 | 2/25/83 | 1822 | 13.6 | 41.95 | 21.66 | 6 | 4.50 | | 4.17 | 4.17 | | 4.29 | 3.93 | 9 | 6.5MCS |

* REPORTED FOCAL DEPTHS ARE NOT RELIABLE

where

$$\bar{M}_L^{SM} = M_L^* - b_2(M_L^*)(2 - s) \tag{2}$$

and

$$M_L^* = \log_{10} A_{\text{synthetic}} - \text{Att}(\Delta_0) \tag{3}$$

$A_{\text{synthetic}}$ is the peak amplitude (in mm) of the computed response of a Wood–Anderson seismometer, the attenuation function Att $(\Delta_0)$ is given[1] in Table III for $\Delta_0 = (R^2 + H^2)^{1/2}$, and $R$ and $H$ are the epicentral distance and the source depth respectively. $D(\bar{M}_L^{SM})$ is given in Tables IV(a) and IV(b) and represents the mean deviation of $\bar{M}_L^{SM}$ from $M_L$ or $M_p$ (median of local magnitudes published in various seismological catalogues) computed from distant stations, but for earthquakes recorded by strong motion accelerographs in Yugoslavia (Table II). When $M_p$ or $M_L$ is available one should use $D(\bar{M}_L^{SM})$ defined versus $M_p$ as in Table IV(a). When $M_L$ or $M_p$ is not available $D(\bar{M}_L^{SM})$ is evaluated from Table IV(b) where it is given in terms of $\bar{M}_L^{SM}$. $b_2(M_L^*)$ represents a correction function for average local site amplification effects. $s = 0$ corresponds to a site on sediments, while $s = 2$ is for sites on geological basement rocks.[16] The amplitudes of $b_2(M_L^*)$ are given in Table IV(c). The above computation of $M_L^{SM}$ is carried out for each recorded horizontal acceleration component. All such estimates are then averaged to give $M_L^{SM}$ for the earthquake.

Table III. Att ($\Delta_0$) for $\Delta_0 = \sqrt{R^2 + H^2}$*

| $\Delta_0$ (km) | Att ($\Delta_0$) | $\Delta_0$ (km) | Att ($\Delta_0$) | $\Delta_0$ (km) | Att ($\Delta_0$) |
|---|---|---|---|---|---|
| 1·0 | − 1·62 | 100·0 | − 3·08 | 340·0 | − 4·21 |
| 5·0 | − 2·08 | 120·0 | − 3·13 | 360·0 | − 4·30 |
| 10·0 | − 2.30 | 130·0 | − 3·18 | 380·0 | − 4·38 |
| 15·0 | − 2.42 | 140·0 | − 3·23 | 400·0 | − 4.45 |
| 20·0 | − 2·51 | 150·0 | − 3·28 | 420·0 | − 4·52 |
| 25·0 | − 2·58 | 160·0 | − 3·33 | 440·0 | − 4·58 |
| 30·0 | − 2·63 | 170·0 | − 3·38 | 460·0 | − 4·63 |
| 35·0 | − 2·68 | 180·0 | − 3·43 | 480·0 | − 4·69 |
| 40·0 | − 2·71 | 190·0 | − 3·48 | 500·0 | − 4·73 |
| 45·0 | − 2·75 | 200·0 | − 3.53 | 520·0 | − 4·78 |
| 50·0 | − 2·78 | 220·0 | − 3·63 | 540·0 | − 4·82 |
| 60·0 | − 2·83 | 240·0 | − 3·73 | 560·0 | − 4·85 |
| 70·0 | − 2·88 | 260·0 | − 3·83 | 580·0 | − 4·88 |
| 80·0 | − 2·93 | 280·0 | − 3·93 | 600·0 | − 4·90 |
| 90·0 | − 2·98 | 300·0 | − 4·02 | | |
| 100·0 | − 3·03 | 320·0 | − 4·12 | | |

*This attenuation law has been proposed on the basis of recordings made mostly in California.[1]

Table IV(a). $D(\bar{M}_L^{SM})$ in equation (1) versus $M_P$, for data in Yugoslavia

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $M_P$ | 2·5 | 3·0 | 3·5 | 4·0 | 4·5 | 5·0 | 5·5 | 6·0 | 6·5 | 7·0 |
| $D(\bar{M}_L^{SM})$ | 1·91 | 1·69 | 1·45 | 1·21 | 0·96 | 0·70 | 0·43 | 0·15 | − 0·14 | − 0·43 |

Table IV(b). $D(\bar{M}_L^{SM})$ in equation (1) versus $\bar{M}_L^{SM}$, for data in Yugoslavia

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $\bar{M}_L^{SM}$ | 4·0 | 4·5 | 5·0 | 5·5 | 6·0 | 6·25 | 6·50 | 6·75 | 7·00 | 7·25 |
| $D(\bar{M}_L^{SM})$ | 1·84 | 1·67 | 1·48 | 1·08 | 0·58 | 0·33 | 0·08 | − 0·17 | − 0·42 | − 0·67 |

Table IV(c). $b_2(M_L^*)$ in equation (2), for data in California

| | | | | | |
|---|---|---|---|---|---|
| $M_L^*$ | 3·5 | 4·5 | 5·5 | 6·5 | 7·5 |
| $b_2(M_L^*)$ | 0·10 | 0·10 | 0·11 | 0·12 | 0·13 |

It is seen that equation (3) is analogous to

$$M_L = \log_{10} A - \log_{10} A_0(R) \tag{4}$$

which corresponds to the original definition of the local magnitude scale,[3,25] with $A$ (in mm) representing the peak response of a Wood–Anderson seismometer, and $\log_{10} A_0(R)$ representing Richter's empirical attenuation law.

## $M_L^{SM}$ FOR DATA IN EQINFOS FILES

By using the new definition of the local magnitude scale $M_L$, as described above, we have computed $M_L^{SM}$ for all earthquakes which contributed to the uniformly processed strong motion data base in EQINFOS files for Yugoslavia.[2] Table II presents the list of the contributing earthquakes.

Using equations (2) and (3) we evaluated $\bar{M}_L^{SM}$ for each record associated with an earthquake in Table II. Empirical relations showing the frequency dependent attenuation on sediments and on basement rock[10,18] are not available for Yugoslavia. In this analysis we assume that $b_2(M_L^*)$ in equation (2), as determined for California data,[1] can be applied here as well. Site characterization for Yugoslav data is also not available. Since most recordings there have been obtained on sediments, in this analysis we will adopt an approximate working assumption that $s = 0$ for all data.[16] Then by comparing the estimates of $\bar{M}_L^{SM}$ with the published magnitudes for these events we derived $D(\bar{M}_L^{SM})$, which is shown in Figure 2. $D(\bar{M}_L^{SM})$ was evaluated by using the Richter[3,25] attenuation law given by '$\log_{10} A_0(R)$' and also by using the new attenuation function in the near field 'Att $(\Delta_0)$' proposed by Trifunac,[1] 'without constraints' and 'with constraints' (that the source dimension $S$ and the source coherence length $S_0$ must be less than the hypocentral distance $\Delta$). The data on $D(\bar{M}_L^{SM})$ were smoothed by averaging over 0·5 magnitude intervals and plotted as points in Figure 2. Tables IV(a) and IV(b) represent the curve 'with constraints' for data in Yugoslavia (Figure 2) and show results versus $M_p$ and versus $\bar{M}_L^{SM}$. $M_L^{SM}$ can be evaluated either using $D(\bar{M}_L^{SM})$ versus $M_p$ or versus $\bar{M}_L^{SM}$, but the estimates using $M_p$ are more stable because of saturation of $M_L^{SM}$ for large events. Figure 3(a) shows $M_L^{SM}$ versus $M_p$ using $D(\bar{M}_L^{SM})$ in terms of $M_p$ and for all 183 available events, containing many one point estimates. The resulting standard deviation of the estimates is equal to 0·30 magnitude units. Considering only those estimates for which 2 and more than 2 strong motion records are available, the number of $M_L^{SM}$ estimates reduces to 67, but the standard deviation also reduces to 0.26 magnitude units. Figure 3(b) shows $M_L^{SM}$ versus $M_p$ estimates using $D(\bar{M}_L^{SM})$ in terms of $\bar{M}_L^{SM}$. The standard deviation of these estimates is 0·55 for 183 data points. Again, ignoring those $M_L^{SM}$ estimates that are based on only one strong motion recording would again reduce the number of data points to 67 and the standard deviation of the estimates to 0·50. It is seen that the estimates in Figure 3(a) are better.

Column 1 in Table II shows the earthquake number (1–183) of the 183 earthquakes used in the analysis. Column 2 is the cross-reference with the earthquake number listed in Table I of EQINFOS files.[2] Column 3 gives the corresponding cross-reference earthquake number listed in Table A2 of the Yugoslav EQINFOS data.[2] Column 4 shows the date of the earthquake given in the order MONTH/DAY/YEAR. Column 5 presents the time of the earthquake in GMT to the nearest minute. Columns 6 and 7 show the latitude and

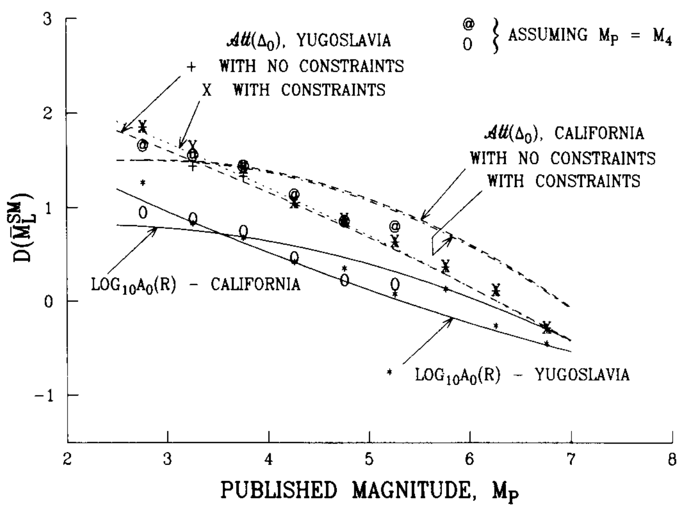


Figure 2. Comparison of $D(\bar{M}_L^{SM})$ for strong motion data in Yugoslavia and California, versus published magnitude, $M_p$

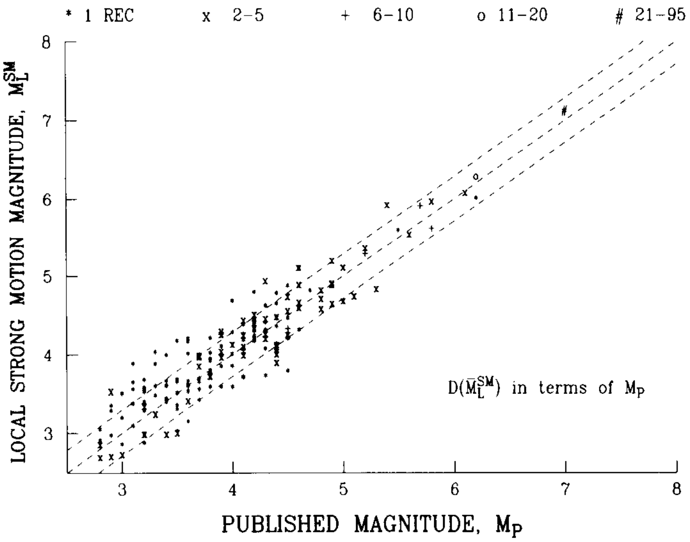


Figure 3(a). $M_L^{SM}$ versus $M_p$, using $D(\bar{M}_L^{SM})$ in terms of $M_p$

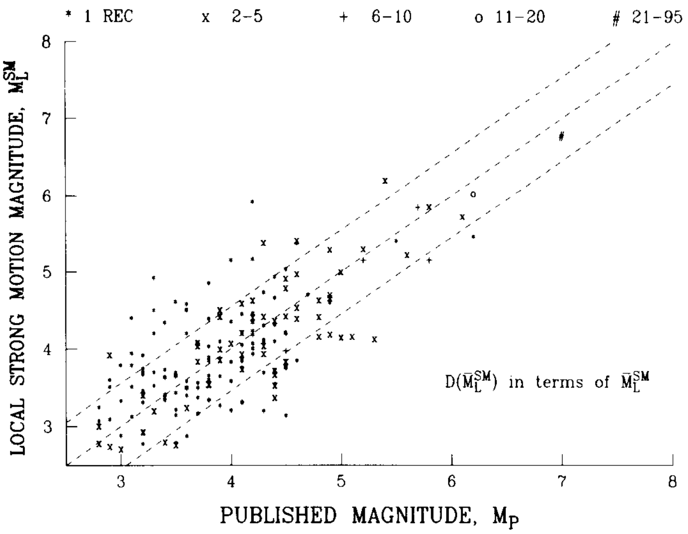


Figure 3(b). $M_L^{SM}$ versus $M_p$, using $D(\bar{M}_L^{SM})$ in terms of $\bar{M}_L^{SM}$

the longitude of the epicentre. Column 8 gives the focal depth in km. All events with entries in column 3 of Table II were located using all the available data including the local networks (see Appendix A in Jordanovski *et al.*[2]). The coordinates of the hypocentres for the rest of the events were taken from ISC and CSEM bulletins. Column 9 lists the published (1) magnitude $M_p$. Columns 10 to 13 present different magnitude estimates (2,3,4 and 5) as discussed in the following text. Columns 14 and 15 give the strong motion magnitudes $M_L^{SM}$ calculated using equations (1) to (3) (with $D(\bar{M}_L^{SM})$ versus $M_p(1)$ and $M_L^{SM}(2)$, respectively). Column 16 shows the number of strong motion stations used in the computation of $M_L^{SM}$ (only for those events with two or more stations recording the strong motion). Column 17 gives the epicentral intensity.

The magnitudes in column 9 of Table II represent median values of local magnitudes published by ISC and CSEM. To test how homogeneous that data may be we carried out the following study. The data recorded at two Yugoslav stations VIR (on the island Vir near Zadar) and LJU (Ljubljana) between 1975 and 1983 were analysed. VIR was in operation from 1975 to 1982 and recorded most events from Table II. Both VIR and LJU were equipped with short period seismographs ($T_0 = 0{\cdot}5$ to $1{\cdot}0$ sec) with record amplitudes proportional to the ground velocity. Since our analysis showed that the period of the peak response did not vary much, the records at these two stations were scaled with respect to the reference set of events given in Jordanovski *et al.*[2] (Table II), using

$$M = \log_{10} A_{\max} + p \log_{10} R + q$$

where $M$ is local magnitude, $A_{\max}$ is maximum record amplitude in mm, and $R$ is epicentral distance in km. At VIR half peak to peak amplitudes of $P_g$ and $S_g$ waves, $A(P_g)$ and $A(S_g)$, were read together with their corresponding periods $T(P_g)$ and $T(S_g)$. Using the above equation, different magnitude estimates $M_{i^*}$ were then determined after replacing $A_{\max}$ by: $A(S_g)$ for $i^* = 1$, $A(P_g)$ for $i^* = 2$, $[A(S_g)A(P_g)]^{1/2}$ for $i^* = 3$, $A(S_g)/T(S_g)$ for $i^* = 4$ and $A(P_g)/T(P_g)$ for $i^* = 5$, and regressing for $p$ and $q$. At LJU the peak amplitude $A_{\max}$ and its period $T_{\max}$ were read and two magnitudes $M_{j^*}$ were determined, using $A_{\max}$ for $j^* = 1$ and $A_{\max}/T_{\max}$ for $j^* = 2$.

For completeness of this presentation, Table II also shows all data of Table A2 in Jordanovski *et al.*[2] The third column of this table presents the earthquake number used in Table A2. The tenth and eleventh columns give $M_2$ (averages of $M_{i^*}$, $i^* = 1, \ldots, 5$) and $M_3$ (average of $M_{j^*}$, $j^* = 1, 2$) respectively. The twelfth column gives $M_4$ which is the average of $M_2$ and $M_3$, when both are available, or equals $M_2$ or $M_3$ when either of the two is available. Thus, by comparing $M_1$ and $M_4$, one can study the consistency of almost all the magnitude estimates in our data base. Out of 160 events present in Table A2 of Jordanovski *et al.*[2] 137 can be compared in this way.

The thirteenth column in Table II presents $M_5$, which corresponds to the estimates of $M_L$ contained in Table I of Ambraseys.[22] It is seen that his data base contains 19 events in Friuli, Greece and Yugoslavia, for the period considered by our study. Those are typically events with $M_L \geqslant 4{\cdot}2$, and their magnitudes agree favourably with our estimates designated by $M_1$, in the ninth column of Table II. Typical differences are about 0·1 magnitude units.

To test the stability of the $M_L^{SM}$ estimates we computed $D(\bar{M}_L^{SM})$ again for all the data associated with these 137 events, now assuming that $M_4$ is equal to $M_p$. The results are shown as points in Figure 2. It is seen that the estimates based on $M_4$ lead to essentially the same results as the large data set in Table II, using $M_p$ as median of $M_L$ from different European stations. We conclude that $D(\bar{M}_L^{SM})$ as shown in Figure 2 is sufficiently stable and can be used for computation of $M_L^{SM}$ in Yugoslavia.

## DISCUSSION AND CONCLUSIONS

By computing $\bar{M}_L^{SM}$ from equation (2) and evaluating $D(\bar{M}_L^{SM})$ for strong motion accelerations recorded in Yugoslavia we found that the final estimates of $\bar{M}_L^{SM}$ in this region are as stable as the corresponding estimates in California (the standard deviation of the estimates of $\bar{M}_L^{SM}$ in Figure 3(a) is 0·3 magnitude units for all the 183 earthquakes in Table II). Estimates using $D(\bar{M}_L^{SM})$ determined from Table IV(a), in terms of $M_p$ give more stable results on $M_L^{SM}$ than estimates using Table IV(b), with $D(\bar{M}_L^{SM})$ in terms of $\bar{M}_L^{SM}$.

We employed standard and published algorithms for epicentral and focal determinations and in most cases with an adequate number of stations and data points. Typical error of such locations (for events identified in column 3 of Table II and originally listed in Table A2 of Jordanovski *et al.*[2]) is about 5 km. Then, the dependence of $M_L^{SM}$ on hypocentral distance is contained in the attenuation function (Table III), indicating that, for distances greater than $\sim 10$ km, uncertainties in focal locations do not contribute much to the uncertainties in the computed magnitudes (less than 0·1 magnitude units).

We studied $M_L^{SM} - M_p$ versus distances $R$ and $\Delta = (R^2 + H^2)^{1/2}$ (where $R$ is the epicentral distance and $H$ is the focal depth) and found no systematic departures from zero (see also Luco,[13] Trifunac[1]). This implies that the new attenuation function Att $(\Delta_0)$ can be used for Yugoslav earthquakes without any modification

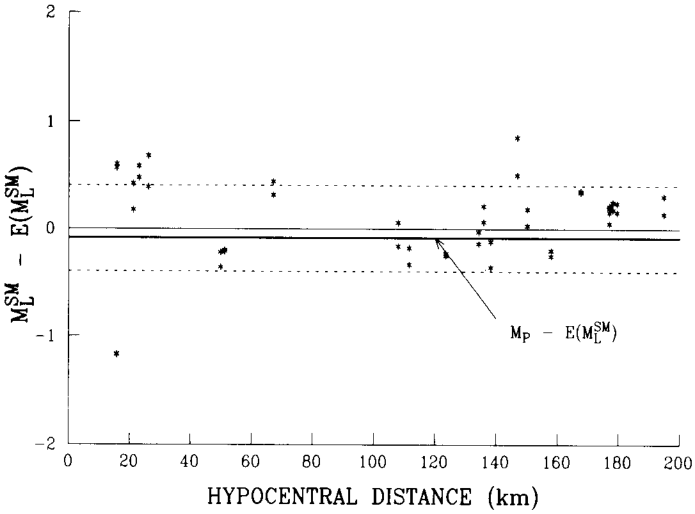


Figure 4. $M_L^{SM} - E(M_L^{SM})$ versus hypocentral distance

being indicated by the currently available data for $\Delta < 100$ km. For the Monte Negro earthquake of April 15, 1979 ($M_p = 7$ and $M_L^{SM} = 7{\cdot}1$) $M_L^{SM} - E(M_L^{SM})$ estimates for the individual stations ($E$ designates expected value) were symmetrically scattered about zero for $\Delta$ up to about 200 km, suggesting that our extension[1] of Att $(\Delta_0)$ beyond 100 km, using the shape[3,25] of $\log_{10} A_0(R)$, is also in agreement with the recorded data (Figure 4).

Trifunac[1] considered several causes and possible explanations for the amplitudes and the shape of $D(\bar{M}_L^{SM})$ versus $M_p$. At present it appears that for $M_p$ less than about 5.5 to 6, the amplitudes of $D(\bar{M}_L^{SM})$ are governed by the $Q$ structure in the region, as sampled by the strong motion data and by more distant records which are used to estimate $M_p$. The similarity of the shape of $D(\bar{M}_L^{SM})$ in California[1] and in Yugoslavia and no obvious dependence of $M_L^{SM} - M_p$ versus $\Delta$ for data in Yugoslavia suggest that the nature of the attenuation of the strong motion amplitudes in these two different regions of the world is similar. Trifunac and Todorovska[26] arrived at similar conclusions using independent comparisons of the intensity data. This means that it will be possible to use California data in seismic risk studies in Yugoslavia (or vice versa) more directly and without major corrections for magnitude scaling and near field attenuation. Att $(\Delta_0)$ represents attenuation in a narrow frequency band centred around periods equal to 1 sec. Therefore, for example, for use of frequency dependent scaling relationships on spectral amplitudes[10] developed for California data, still further analyses and verification will be required before those can be used in Yugoslavia.

Figure 2 also shows the amplitudes of $D(\bar{M}_L^{SM})$ for California data. It is seen that for small magnitudes, near 3·5, $D(\bar{M}_L^{SM})$ for California data is nearly the same as $D(\bar{M}_L^{SM})$ estimated for Yugoslavia. However, between magnitudes 4·5 and 6·5 California data give $D(\bar{M}_L^{SM})$ larger than $D(\bar{M}_L^{SM})$ for Yugoslavia by 0·4 to 0·5 magnitude units. This suggests a somewhat larger overall average value of $Q$ for Yugoslavia (say $Q \sim 150$–200) than for California ($Q \sim 100$–150) assuming that (i) the average distances between strong motion and distant recordings are comparable and also (ii) that the distant recordings can be assumed to lead to the same estimates as the corresponding stations would in California. Detailed analysis and interpretation of such trends is beyond the scope of this paper, as this requires large scale analysis of many recordings in Europe. In this work, as in other studies for California,[1] we want to determine only the relative scaling of the recorded strong motion amplitudes and of magnitudes determined by the regional seismological networks. This will enable correct relative scaling of recorded strong motion amplitudes, and then the data in various catalogues, which are used in seismic risk studies and mapping, can be used with greater confidence and with more accuracy.

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