LOCAL MAGNITUDE SCALE $M_L$ EVALUATION
FOR THE MAIN CRUSTAL SEISMIC ZONES OF ROMANIA

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Received June 3, 2014

Abstract. The seismic activity on the Romanian territory consists of both crustal and intermediate-depth earthquakes. The crustal seismicity is moderate and more scattered compared to the intermediate-depth one. In this paper we study the problem of homogeneous determination of local magnitude for earthquakes from the main seismic zones of Romania (Vrancea, Fagaras Mountains, Banat, Transylvania, Dobrogea and Romanian Plain). A waveforms database of digitally recorded data is used to derive new magnitude relations for different seismic areas of Romania. Wood-Anderson amplitudes are computed from the available data and the maximum peak-to-peak amplitudes are measured on the horizontal components of the broad-band sensors to define the local magnitude scale. The duration magnitude ($M_D$) is used as reference to calibrate the new magnitude scale based on amplitudes. The new coefficients are estimated through a multiple regression method. Our tests show that the new magnitude scale significantly improves the earthquake size evaluation and stability compared to the solution computed by present-day procedures at the National Institute for Earth Physics.

Key words: magnitude, Wood-Anderson, amplitudes, earthquakes.

1. INTRODUCTION

The crustal seismicity of Romania is distributed in several epicentral areas: Vrancea, Fagaras-Campulung, Sinaia, Banat, Romanian plain and Dobrogea. To these seismic areas we can add some epicentral areas with local importance in Jibou and Tarnavele region in Transylvania, the northern and western part of the Oltenia region and northern part of Moldavia (Fig. 1).

In this paper we studied the most significant epicentral areas of Romania, such as: Vrancea, Sinaia, Romanian Plain, Banat, Transylvania and Dobrogea.

The magnitude was essentially introduced as a simple and efficient way to define empirically the earthquake size, and not as a direct representation of a physical parameter.
To characterize the size of seismic events, one relative to the other, both empirical scales (such as magnitude scale) and physical model-based scales (such as seismic moment scale) are used. The choice of using one or another methodology depends especially on the comparison purpose and on the data availability.

Fig. 1 – Location of crustal earthquakes recorded in Romania in 2008–2010.

The magnitude problem becomes inevitably complex taking into account the dependence on type of waves (surface and body waves, coda waves etc.), focal depth (crustal, intermediate-depth or deep earthquakes), changes in seismic equipment and frequency content. It is very important to emphasize that each magnitude scale has a particular domain of validity and different magnitude scales will give, in general, different values for the same event. These differences are an endless source of confusion for mass-media, who generally considers all magnitude scales together as the “Richter’s scale”.

The purpose of this paper is to revise the local magnitude formula for the crustal earthquakes. The magnitude is a basic parameter to characterize the seismotectonic of Romania, the seismic cycle evolution and early warning system [1, 2, 3].

In order to calibrate and compare the magnitude scales used in the present work with previous estimations, we have to adopt a reference scale. For our study we have chosen the local magnitude scale defined by [4] and revised by [5].
Similar researches were made for Italian events [6] and Turkish earthquakes [7].

The methodology used in this study to obtain the coefficients for local magnitude relation (for crustal events) is similar with the method used to obtain the intermediate-depth earthquakes for Vrancea seismic zone [8].

2. METHOD

Starting with 2002, National Institute for Earth Physics (NIEP) implemented at the national seismic network the Antelope software package, a real time acquisition and data processing system. In its initial configuration the real time system used only one relation for computing local magnitude. The relation used for both crustal events and intermediate-depth earthquakes (independent towards the focal depth) [4]:

\[ M_{L\text{ant}} = C_0 + \log_{10}A + C_1 \log_{10}\Delta + C_2 \log_{10}(\Delta C_3 + C_4) + C_5, \]

where: \( A \) represents the Wood-Anderson maximum amplitude; \( \Delta \) is the epicentral distance; \( C_0, C_1, C_2, C_3, C_4 \), and \( C_5 \) are coefficients derived from a linear regression.

This relation is not appropriate for intermediate-depth earthquakes since it does not take into account the focal depth. Therefore we chose a new relation for local magnitude estimation in order to have for each seismic region of Romania a magnitude relation (each seismic zone has different characteristics) [5].

\[ M_L = C_1 \log_{10}A + C_2 \log_{10}R + C_3 R - C_4, \]

where: \( A \) is the Wood-Anderson maximum amplitude; \( R \) – hypocentral distance (km); \( \Delta \) – epicentral distance; \( h \) – focal depth; \( C_1, C_2, C_3 \), and \( C_4 \) are a set of coefficients determined after a linear regression.

The set of coefficients presented above were determined after a multiple regression using as reference magnitude the duration magnitude (\( M_D \)) computed with HYPOPLUS program developed by [9],

\[ M_D = -C_1 + C_2 \log \tau + C_3 \Delta + C_4 h, \]

where: \( \tau \) – recording duration (seconds), \( \Delta \) – epicentral distance (km), \( h \) – focal depth (km).

For our study we used a set of 2717 crustal earthquakes from Romania, events that were recorded between 2008 and 2010.

3. RESULTS

In this analysis we included a very large amount of data, which we divided into several areas as following.
3.1. VRANCEA SEISMOGENIC ZONE ($H \leq 60$ km)

The superficial seismicity associated with the subduction process in Vrancea propagates diffusely towards East relative to the Carpathian Arch, within a stripe marked by Peceneaga-Camena fault to the North and Intra-Moesian fault to the South (so called the sub-plate of the Black Sea). Seismicity consists of moderate earthquakes with magnitudes not larger than 5.6, and seems to be decoupled of the seismic activity in the subducted lithosphere. This seismicity shows time (main shocks of the sequences that are associated with aftershocks and often pre-shocks or earthquake swarms) and space clustering. Seismic sequences are common for the eastern part of the zone (Ramnicu Sarat region), and swarms predominate in the northern part of the zone (Vrâncioaia region).

For Vrancea ($h \geq 60$ km) were used 397 seismic events with depth ranging between 3 and 59 km, with $1.7 \leq M_D \geq 4.3$ (Fig. 2).

![Fig. 2 – Distribution of Vrancea ($h \leq 60$ km) epicenters.](image)

For the events recorded in the above mentioned seismic area we used a set of 2515 maximum amplitudes measured on the horizontal component of the broadband sensors (for each seismic event we used 3 up to 14 stations). After linear regression using as reference magnitude $M_D$, we derived the new local magnitude relation for Vrancea crustal events as following:

$$M_L = 0.56941 \cdot \log A + 1.319 \cdot \log R − 9.5515 \cdot 10^{-4} \cdot R + 0.69822.$$  \hspace{1cm} (4)

Comparing the new local magnitude relation with the duration magnitude $M_D$ (Fig. 3) one can observe systematic differences measured by significant deviation by the slope of the first bisector slope (0.93 towards 1). These differences shows
smaller magnitudes values obtained with the new local magnitude relation than the reference magnitude values, except the earthquakes with duration magnitudes smaller than 2 which in this case gives higher values than the reference magnitudes.

Fig. 3 – Linear approximation between the new value of local magnitude $M_L = 4.6$ and the duration magnitude $M_D$ [6], for Vrancea ($H \leq 60$ Km).

The dependence of $M_L$ magnitude as a function of amplitude is represented in Fig. 4 for the 397 selected events. As can be seen, the errors are larger at small magnitudes, as expected. We can conclude that the dispersion caused by the variation of hypocenter distance ($R$) is less important than dispersion caused by amplitude errors.

Fig. 4 – Dependence of local magnitude $M_L$ as function of amplitude for Vrancea ($H \leq 60$ km).
3.2. BANAT SEISMOGENIC ZONE

Seismicity of Banat zone is characterized by several earthquakes with magnitudes greater than 5, but less than 5.6. Historical information suggests for Crisana area maximum possible earthquakes with magnitudes greater than 6, but in the last century only one earthquake with magnitude closer to 5 was recorded.

For Banat seismogenic zone we have identified 151 seismic events with depths between 3 and 28.5 km, with $1.8 \leq M_D \leq 3.4$ magnitudes (Fig. 5).

![Fig. 5 – Epicenters distribution for Banat seismogenic zone.](image)

We have selected 697 maximum amplitudes recorded on the horizontal component of the broad-band sensors (for each seismic events were used for location 3 up to 11 seismic stations).

The new local magnitude relation for seismic events recorded in Banat area after a linear regression is:

$$M_L = 0.23342 \cdot \log A + 0.4085 \cdot \log R - 6.67306 \cdot 5 \cdot R + 1.89483. \quad (5)$$

By comparing the new local magnitude relation with duration magnitude $M_D$ (Eq. 3) are observed systematic differences measured by significant deviation by the slope of the first bisector slope (0.73 towards 1). New local magnitudes values are very close with the $M_D$ reference magnitude values in the 2.0–2.5 interval, and at higher magnitudes values the differences are larger (Fig. 6). The magnitude errors are growing a lot under 2.0 value, mainly because noise/signal ratio is becoming smaller.
The dependence of $M_L$ magnitude as a function of amplitude is represented in Fig. 7 for the 151 selected events. As can be seen, the errors are larger at small magnitudes, as expected. We can conclude that the dispersion caused by the variation of hypocenter distance ($R$) is less important than dispersion caused by amplitude errors.

Fig. 7 – Dependence of local magnitude $M_L$ as function of amplitude for Banat seismogenic zone.

3.3. SINAIA – CAMPULUNG SEISMOGENIC ZONE

The Fagaras-Campulung zone is located at the contact between Moesian Platform and the Southern Carpathian orogen. It is characterized by strong shocks...
with magnitudes $M_W$ up to 6.5. These are the strongest crustal earthquakes that occur on Romania’s territory. The last major event occurred on 26th of January 1916 ($M_W$=6.4) and was followed by a significant activity of aftershocks.

For Sinaia – Campulung seismogenic zone were identified 206 seismic events with focal depths between 2.3 and 58.4 km, and magnitudes $1.4 \leq M_D \geq 3.5$ (Fig. 8).

![Fig. 8 – Epicenters distribution for Sinaia – Campulung seismogenic zone.](image)

We have selected 846 maximum amplitudes recorded on the horizontal component of broad-band sensors (each seismic event recorded at 3–12 seismic stations).

The new local magnitude relation obtained for Sinaia–Campulung seismogenic area after a linear regression is as following:

$$M_L = 0.35186 \cdot \log A + 0.37433 \cdot \log R + 2.9574E-4 \cdot R + 2.00172. \quad (6)$$

From the graphic below (Fig. 9) it can be observed that there are no significant differences between magnitudes derived from the relations used in this study. This two magnitude relations can be approximated to be linear, but there are some differences between the values (over magnitude 3.0 the reference magnitude $M_D$ gives higher values than the $M_L$ magnitude).
The dependence of $M_L$ magnitude as a function of amplitude is represented in Fig. 10 for the 206 selected events. As can be seen, the errors are larger at small magnitudes, as expected. We can conclude that the dispersion caused by the variation of hypocenter distance ($R$) is less important than dispersion caused by amplitude errors.

3.4. ROMANIAN PLAIN SEISMOGENIC ZONE

The Intramoesian Fault crosses the Moesian platform on SE-NW direction, delimiting two sectors with different composition and basement.
For the Romanian plain seismic zone we have identified 90 seismic events with focal depths between 1.7 and 50 km, with $M_D$ magnitudes $1.8 \leq M_D \leq 3.9$ (Fig. 11). 633 maximum amplitudes were recorded on the horizontal component of a broad-band sensor (each event being recorded at 3–12 seismic stations).

![Epicenters distribution for Romanian Plain seismogenic area.](image)

The new local magnitude relation obtained for Romanian Plain seismogenic area after a linear regression is the following:

$$M_L = 0.45284 \cdot \log A + 0.90093 \cdot \log R - 4.9066 \times 10^{-4} \cdot R + 1.44797. \quad (7)$$

For the Romanian plain seismic area, we can observe from the linear fit between the two magnitude relations $M_L$ and $M_D$ that, for the small magnitudes, the new $M_L$ values are a little bit higher than the reference magnitude $M_D$; this situation is reversed as we go higher on the magnitude scale (Fig. 12).

The dependence of $M_L$ magnitude as a function of amplitude is represented in Fig. 13 for the 90 selected events. As can be seen, the errors are larger at small magnitudes, as expected. We can conclude that the dispersion caused by the variation of hypocenter distance ($R$) is less important than dispersion caused by amplitude errors.
Local magnitude scale $M_L$ evaluation for seismic zones of Romania

3.5. DOBROGEA SEISMOGENIC ZONE

This seismogenic zone belongs to the southern edge of the Predobrogean Depression marked by the Sfantu Gheorghe fault.
For Dobrogea seismic zone we have identified 155 seismic events with focal depths between 3 and 28.9 km, and $M_D$ magnitudes $1.4 \leq M_D \leq 2.9$ (Fig. 14).

We have selected 443 maximum amplitudes recorded on the horizontal component of a broad-band sensor (each event being recorded at 1–6 seismic stations).

The new local magnitude relation obtained for Dobrogea seismogenic area after a linear regression is the following:

$$M_L = 0.0426 \cdot \log A + 0.1122 \cdot \log R + 3.2245E^{-4} \cdot R + 1.85186.$$  \hspace{1cm} (8)

For Dobrogea seismogenic zone, the magnitude problem is very similar with Romanian Plain, meaning at lower magnitude values the new $M_L$ presents higher magnitude values than the reference magnitude $M_D$, and as we go at higher levels of magnitude scale the reference magnitude $M_D$ gives higher values than the new magnitude $M_L$ (Fig. 15).
3.6. TRANSYLVANIA SEISMOGENIC ZONE

A seismic zone is located between Tarnava Mare and Tarnava Mica, in the central part of the Transylvanian Depression, where several historical earthquakes with magnitude between 5 and 6 were recorded.

For Transylvania seismogenic zone we have identified 190 seismic events with depths between 1.3 and 37.9 km, and magnitudes values situated in $1.8 \leq M_D \leq 2.9$. (Fig. 16). 1116 maximum amplitudes were recorded on the horizontal component of a broadband sensor (each event being recorded at 3–9 seismic stations).

The new local magnitude relation obtained for Transylvania seismogenic area after a linear regression is as following:

$$M_L = 0.09295 \cdot \log A + 0.22292 \cdot \log R - 9.90702E-5 \cdot R + 2.13471.$$  \hspace{1cm} (9)

For this seismogenic area we can observe that the duration magnitude gives higher values than the new $M_L$ magnitude (Fig. 17). In this case, we have small seismic events and the ambiental noise at the stations is higher than the seismic signal. Very likely, this affects the estimation of earthquake duration and explains the large variation for $M_D$ values. From this point of view we can’t take into account a linear approximation relation for this area.
Fig. 16 – Epicenters distribution for Transylvania seismogenic area.

Fig. 17 – Linear fit between the new magnitude $M_L$ and the reference magnitude $M_D$, for Transylvania seismogenic zone.
4. CONCLUSIONS

The seismic events used in this study recorded between 2008–2010 were located with HYPOPLUS software developed by [9].

In this study we have determined new coefficients for $M_L$ magnitude relation, for all seismic zones of Romania. We also obtained new magnitude relations for all seismic zones of Romania using Wood-Anderson amplitudes measured on a horizontal component of broadband sensors. These new magnitude relations were calibrated with the duration magnitude $M_D$ and are taking into account the focal depth.

This study was done on different data sets gives a good accuracy and stability of magnitude values up to 4.5.

Data base will be continuously updated with new records obtained with National Seismic Network of digital and analogic stations installed on Romania’s territory. The direct result of this activity is to identify the earthquakes recorded on Romanian territory or at the borders, precise location of these events, magnitude and local intensity determination.

For crustal events, the new magnitude relations were tested only in “off-line mode”, in the future time they will be implemented into the real-time acquisition and data processing system ANTELOPE, for a rapid real-time magnitude evaluation.

The differences between $M_D$ and $M_L$ for different seismic zones of Romania show a good correlation excluding the Transylvania seismic zone, where the amplitude values are very close. For all studied crustal zones, in all cases, the reference magnitude $M_D$ presents higher values than the new local magnitude $M_L$. This could be caused by stations with considerable epicentral distances for which the recorded duration is greater than for close stations.

Acknowledgments. This work was supported by a grant of the Romanian National Authority for Scientific Research, CNCS – UEFISCDI, project number PN-III-RU-TE-2012-3-0215.

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