AN ATTEMPT TO RECALIBRATE INSTRUMENTAL CRITERIA FOR INTENSITY ASSESSMENT

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ABSTRACT

The authors contributed during a quite long period of time to the development of comprehensive and flexible system of estimating seismic intensity on the basis of instrumental (accelerographic) data on earthquake ground motion. The system makes it possible to determine for a record, according to needs, global intensities, intensities corresponding to definite frequencies, intensities averaged upon a spectral band, continuous or discrete intensity spectra. Moreover, the intensity measures developed may rely, according to choice, on different outcomes of processing of primary instrumental data. A problem to which the paper is devoted is represented by the calibration of an important parameter, namely the logarithm base adopted in view of conversing instrumental information to intensity measures. After the attempts of the past, new sources are used this time to solve the problem. Alternative solutions are examined and discussed in this view.

Keywords: Instrumental seismic intensity; seismic intensity spectra; seismic intensity recalibration

REZUMAT

Autorii au contribuit pe parcursul unei perioade destul de lungi de timp la dezvoltarea unui sistem global şi flexibil de estimare a intensităţii seismice bazat pe datele instrumentale (accelerografice) privind mişcarea seismică a terenului. Sistemul permite să se determine pentru o înregistrare, în funcţie de nevoi, intensităţi globale, intensităţi corespunzătoare unor frecvenţe anumite, intensităţi mediate pe o bandă spectrală, spectre continue sau discrete de intensităţi. În plus, măsurile de intensitate dezvoltate se pot baza, la alegere, pe diferite rezultate ale prelucrării datelor instrumentale primare. O problemă căreia îi este dedicat articolul este reprezentată de calibrarea unui parametru important, şi anume baza logaritmului adoptat în vederea conversiei informaţiei instrumentale în măsuri de intensitate. După încercările din trecut, sunt folosite de această dată noi surse pentru a rezolva problema. Sunt examinate şi discutate soluţii alternative din acest punct de vedere.

Cuvinte cheie: Intensitate seismică instrumentală; spectre de intensitate seismică; recalibrarea intensităţii seismice

1. INTRODUCTION

The paper is devoted to the analysis of a suitable revision of the calibration of instrumental criteria for the assessment of seismic ground motion intensity.

The system of intensity estimate based on instrumental data, referred to as *IES*, presented in (Sandi and Floricel, 1998) and (Sandi and Borcia, 2011), is briefly reminded in Section 2.

The initial calibration of some parameters of *IES* (Sandi and Floricel, 1998) was subject to discussion in (Sandi and Borcia, 2011). Meanwhile, some new data of technical literature (Aptikaev, 2005), (Borcia et al., 2010), (ШИЗ, 2013) provide information that appears to be appropriate for a possible recalibration of parameters referred to (Section 3 of the paper).

The main goal of the new developments presented was to reach a best possible compatibility between the intensity estimates *relying on instrumental information and on macroseismic information respectively.*

2. A BRIEF PRESENTATION OF THE MOTIVATION AND FEATURES OF IES

2.1. General

The main reasons for developing *IES* were as follows:

1. The traditional concept of intensity of seismic ground motion provides little information that is relevant for a more in depth analysis of ground motion features (as required for engineering analyses). This is due mainly to the disregard of spectral (maybe also of directional) features of ground motion.

2. The EMS-98 macroseismic scale (Grünthal, 1998), which was endorsed by the European Seismological Commission, provides no instrumental criteria for intensity assessment. Nevertheless, in the commentary attached to the main text of the document it is explicitly recognized that a good instrumental record obtained during a seismic event fully characterizes seismic motion during that event.

3. While about half a century ago little instrumental information on actual ground motion was available, by now the information worldwide at hand is extremely rich and is bound to additionally increase at an even accelerated pace.

4. The concepts and techniques developed in the frame of *IES* make it possible to revise the assessment of intensity of "historical" intensities and, on this basis, to contribute to a revision of estimates of seismic conditions for some significant sites / regions.

The initial intention in developing *IES* was to deal with global intensities (irrespective of spectral or directional features) of ground motion.

Two main data sources on ground motion were considered:

- a log-log envelope spectrum (as routinely used in the specification of design conditions for important equipment) of the actual ground motion response spectrum (Sandi, 1986) (this made it possible to define the spectrum based intensity I_S);
- the integral of the square of ground motion acceleration proposed by (Arias, 1970) (this made it possible to define the intensity) (an equivalent source was provided by the consideration of Fourier spectra of ground motion acceleration; this made it possible to define the intensity I_F, where $I_F \equiv I_A$, due to analytical reasons).

The consideration of the importance of spectral (and also of directional) features of ground motion led to the need of exploring the possibilities to characterize in more detail ground motion severity. This led at its turn to define intensities related to a certain frequency φ (Hz) and rules of averaging intensity upon a frequency interval (φ', φ''), as well as averaging intensities for two orthogonal horizontal directions. New definitions were added to those concerning global intensity:

- a product of values of response spectra of absolute acceleration, $s_{aa}(\varphi, 0.05)$, and of absolute velocity, $s_{va}(\varphi, 0.05)$, was used in order to define the frequency related intensity homologous to I_S, $i_s(\varphi)$, and also the homologous averaged intensity $i_{\tilde{s}}(\varphi', \varphi'')$;
- an integral of the square of acceleration of the mass of a pendulum driven into motion by the ground, having an undamped natural frequency φ and 0.05 critical damping was used in order to define the frequency related intensity homologous to I_A, $i_d(\varphi)$, and also the homologous averaged intensity $i_{\tilde{d}}(\varphi', \varphi'')$, (the subscript *d* means destructiveness spectrum);
- an integral of the square of the modulus of the square of the Fourier transform of acceleration of the mass of a similar pendulum was used to define the frequency related intensity homologous to I_F, $i_f(\varphi)$, and also the homologous averaged intensity $i_{\tilde{f}}(\varphi', \varphi'')$, where the subscript f means Fourier spectrum.

A summary look at *IES* is provided in Table 2.1.

Table 2.1. System of instrumental criteria for intensity assessment

Name	Symbols used for intensities: * global ** related to a frequency φ *** averaged upon a frequency interval (φ', φ'')			Source of definition / comments
	*	**	***	
Spectrum based intensities	I_S	$i_s(\varphi)$	$i_s^{\sim}(\varphi', \varphi'')$	Linear response spectra for absolute accelerations and velocities / use of EPA, EPV, redefined as EPAS, EPVS respectively (see relations (2.2)); averaging rules specified
Intensities based on Arias' type integral	I_A	$i_d(\varphi)$	$i_d^{\sim}(\varphi', \varphi'')$	Quadratic integrals of acceleration of ground (for I_A), or of pendulum of natural frequency φ (for $i_d(\varphi)$) / extensible to tensorial definition; averaging rules specified
Intensities based on quadratic integrals of Fourier images	$I_F (\equiv I_A)$	$i_f(\varphi)$	$i_f^{\sim}(\varphi', \varphi'')$	Quadratic integrals of Fourier image of acceleration (for I_F), or quadratic functions of Fourier images (for $i_d(\varphi)$) / extensible to tensorial definition; averaging rules specified.

Note that:

- all definitions adopted make it possible to perform averaging upon orthogonal horizontal directions;
- all definitions of $i_x(\varphi)$ category make it possible to determine also intensities averaged upon a certain frequency band, denoted generically $i_x^{\sim}(\varphi', \varphi'')$;
- the definitions $i_x(\varphi)$ make it possible to consider continuous intensity spectra, while the definitions $i_x^{\sim}(\varphi', \varphi'')$ make it possible to consider discrete intensity spectra, with stepwise variation.

2.2. Basic relations

2.2.1. Alternative definitions dealt with

A system of alternative definitions, relying on the developments of (Sandi, 1979), (Sandi, 1986) and (Sandi and Floricel, 1998), with slight updating, is briefly presented. The system consists of:

a) alternative definitions of global intensities, denoted generically I_X:
   - spectrum based intensity I_S, defined on the basis of linear response spectra (Sandi, 1986);
   - intensity based on an integral used in Arias' definition (Arias, 1970), I_A;
   - intensity based on Fourier spectra, I_F;

b) alternative definitions of intensities depending on oscillation frequency, $\varphi(\mathrm{Hz})$, or period, $T(s)$, (Sandi and Floricel, 1998), denoted generically $i_x(\varphi)$:
   - spectrum based intensity $i_s(\varphi)$;
   - intensity based on destructiveness spectra, $i_d(\varphi)$, which generalizes I_A;
   - intensity based on Fourier spectra, $i_f(\varphi)$.

2.2.2. Basic definitions

The subsequent presentation relies (with some updating) on the developments of (Sandi and Floricel, 1998). The definitions were thus developed as follows:

a) adoption of a system of alternative parameters of ground motion, having a kinematic sense, denoted generically Q_X (in case of global measures) or $q_x(\varphi)$ (in case of measures related to an oscillation frequency φ - Hz); all parameters of these categories have a physical dimension m^2s^{-3};

b) definition on this basis of alternative global intensities, denoted generically I_X (in case of global intensities) or $i_x(\varphi)$ (in case of intensities related to an oscillation frequency φ - Hz), by means of expressions:

$$I_X = \log_b Q_X + I_{X0} = I_{XQ} + I_{X0} \quad (2.1\text{ a})$$

$$i_x(\varphi) = \log_b q_x(\varphi) + i_{x0} = i_{xq} + i_{x0} \quad (2.1\text{ b})$$

where the logarithm basis b was calibrated initially as $b = 4$, in order to provide compatibility with the fixed geometric ratio 2 corresponding to a difference of one intensity unit in the frame of the MSK scale (Medvedev, 1962, 1977), where a fixed velocity / acceleration corner period of 0.5 s was postulated; the structure of these relations was kept since the drafting of (Sandi, 1979, 1986); a generalization potential is dealt with in subsection 2.2.4, in connection with a possible recalibration of the initial option $b = 4$ of the logarithm basis used;

c) introduction of a rule of averaging of parameters upon a frequency band, to obtain values $q_x^{\sim}(\varphi', \varphi'')$,

$$q_x^{\sim}(\varphi', \varphi'') = [1./\ln(\varphi''/\varphi')] \times \int_{\varphi'}^{\varphi''} q_x(\varphi)\, d\varphi/\varphi \quad (2.2)$$

while the corresponding averaged intensities $i_x^{\sim}(\varphi', \varphi'')$ will be obtained on this basis using again the relation (2.1.b), with the same calibration of the free term i_{x0}, as well as introduction of a rule for averaging upon two orthogonal horizontal directions,

$$Q_X = (Q_{X1} + Q_{X2})/2 \quad (2.3.\text{a})$$

$$q_x(\varphi) = [q_{x1}(\varphi) + q_{x2}(\varphi)]/2 \quad (2.3.\text{b})$$

$$q_x^{\sim}(\varphi', \varphi'') = [q_{x1}^{\sim}(\varphi', \varphi'') + q_{x2}^{\sim}(\varphi', \varphi'')]/2 \quad (2.3.\text{c})$$

d) the interval (φ', φ'') adopted as a reference in order to compare I or Q parameters with $i^{\sim}$ or $q^{\sim}$ parameters was adopted as (0.25 Hz, 16.0 Hz); in a logarithmic scale, this is consistent with considering $\varphi = 2$ Hz as a central frequency (an alternative interval (0.125 Hz, 32.0 Hz) appeared to be less appropriate, due to the processing problems raised for very low or very high frequencies);

e) the alternative definitions of parameters Q_X are:

- spectrum based parameter (starting from the ideas of Newmark and Hall (ATC, 1986), Q_S,
- parameter based on Arias' definition (Arias, 1970), Q_A, and
- Fourier spectrum based parameter, Q_F;
- using the notations:

$$EPAS = \max_{\varphi}[s_{aa}(\varphi, 0.05)/2.5] \quad \text{(units: m/s2)} \quad (2.4.\text{a})$$

$$EPVS = \max_{\varphi}[s_{va}(\varphi, 0.05)/2.5] \quad \text{(units: m/s)} \quad (2.4.\text{b})$$

($s_{aa}(\varphi, n)$: response spectrum of absolute accelerations; $s_{va}(\varphi, 0.05)$: response spectrum of absolute velocities), one introduces

$$Q_S = EPAS \times EPVS \quad (2.5.\text{a})$$

then,

$$Q_A = \int [w_g(t)]^2\, dt \quad (2.5.\text{b})$$

($w_g^{(\varphi)}(\varphi)$: ground motion acceleration), and

$$Q_F = \int \left|w_g^{(\varphi)}(\varphi)\right|^2 d\varphi \quad (2.5.\text{c})$$

($w_g^{(\varphi)}(\varphi)$: Fourier transform of ground motion acceleration); note here that the definitions Q_A and Q_F can be directly extended to tensorial definitions related to the components of ground motion along an orthogonal system of axes, making it possible to account for ground motion directionality and that, due to analytical reasons, one has $Q_A \equiv 2Q_F$;

f) the alternative definitions of parameters $q_x(\varphi)$ are:

- spectrum based parameter, $q_s(\varphi)$,
- parameter based on destructiveness characteristic, $q_d(\varphi)$, and

- Fourier spectrum based parameter, $q_f(\varphi)$,

$$q_s(\varphi) = s_{aa}(\varphi, 0.05) \times s_{va}(\varphi, 0.05) \tag{2.6.a}$$

$$q_d(\varphi) = \int [w_a(t, \varphi, 0.05)]^2 \, \mathrm{d}t \tag{2.6.b}$$

($w_a(t, \varphi, n)$: absolute acceleration of an SDOF pendulum having an undamped natural frequency φ and a fraction of critical damping n).

$$q_f(\varphi) = \varphi \left| w_a^{(\varphi)}(\varphi) \right|^2 \tag{2.6.c}$$

($w_a^{(\varphi)}(\varphi, n)$: Fourier transform of absolute acceleration of an SDOF pendulum having an undamped natural frequency φ and a fraction of critical damping n).

Note: The definitions (2.4) were adopted instead of the definitions of EPA and EPV, developed by Newmark and Hall (ATC, 1986). The reasons for this decision were as follows: the definitions proposed by Newmark and Hall include averaging upon a short oscillation period band. This implies uneven reductions, which are proportionally much more significant for shorter period peaks than for longer period peaks. In case one would adopt, conversely, averaging upon a short oscillation frequency band, the unevenness would occur in the opposite sense. To provide a reasonable evenness, one should pass to averaging upon relatively short log period or, what is equivalent, relatively short log frequency, bands, but this may become more complicated from the computational point of view. It seemed therefore more reasonable to adopt the parameters $EPAS$ and $EPVS$, as shown in relations (2.4).

2.2.3. Correlation analysis and calibrations adopted

The free terms I_{X0} and i_{x0} of expressions (2.1.a) and (2.1.b) were calibrated in (Sandi and Floricel, 1998) in a way to provide a best correlation between the alternative definitions adopted, after having postulated

- a logarithm basis $b = 4$ and
- a free term value $I_{S0} = 8.0$,

on the basis of comparison of values I_S with macroseismic estimates for several cases of intensity assessment. Computations were performed accepting at that time the logarithm basis *b* = 4, in order to provide compatibility with the ratios adopted for the instrumental criteria in the frame of the MSK scale.

The sample accelerograms used were ground level records, obtained in Romania during the events of 1977.03.04, 1986.08.30, 1990.05.30 and 1990.05.31.

The *primary* processing concerned determination of:

- the global quantities Q_S, Q_A;
- the frequency dependent quantities $q_x(\varphi)$, $q_d(\varphi)$, $q_f(\varphi)$ determined for 121 φ values each (the values φ represented practically a geometric progression in the frequency interval (0.25 Hz, 16.0 Hz));
- the averaged values $q_{\tilde{s}}(\varphi', \varphi'')$, $q_{\tilde{d}}(\varphi', \varphi'')$, $q_{\tilde{f}}(\varphi', \varphi'')$, determined alternatively for the following intervals: (0.25, 16), (0.5, 8), (1, 4), (0.25, 0.5), (0.5, 1.0), (1.0, 2.0), (2.0, 4.0), (4.0, 8.0), (8.0, 16.0), where the numerical values are expressed in Hz.

The quantities I_{XQ}, $i_{xq}(\varphi)$ and $i_{\tilde{xq}}(\varphi', \varphi'')$, (2.1.a), (2.1 b), were determined thereafter (for $b = 4$). They served as a basis for graphic representations as well as for correlation and regression analysis.

The *secondary processing* was related to correlation and regression analysis. Following combinations were considered:

a) $I_S \leftrightarrow I_A$, $I_S \leftrightarrow i_{\tilde{s}}(\varphi', \varphi'')$, $I_S \leftrightarrow i_{\tilde{d}}(\varphi', \varphi'')$, $I_S \leftrightarrow i_{\tilde{f}}(\varphi', \varphi'')$,

where (φ', φ'') was (0.25 Hz, 16. Hz);

b) $I_A \leftrightarrow i_{\tilde{s}}(\varphi', \varphi'')$, $I_A \leftrightarrow i_{\tilde{d}}(\varphi', \varphi'')$, $I_A \leftrightarrow i_{\tilde{f}}(\varphi', \varphi'')$,

where (φ', φ'') was the same;

c) $i_{\tilde{s}}(\varphi', \varphi'') \leftrightarrow i_{\tilde{d}}(\varphi', \varphi'')$,
$i_{\tilde{s}}(\varphi', \varphi'') \leftrightarrow i_{\tilde{f}}(\varphi', \varphi'')$,
$i_{\tilde{d}}(\varphi', \varphi'') \leftrightarrow i_{\tilde{f}}(\varphi', \varphi'')$,

where (φ‘, φ“) was the same.

d) the same as (c), where (φ', φ'') was alternatively:
(0.5 Hz, 8 Hz), (1 Hz, 4 Hz),
(0.25 Hz, 0.5 Hz), (0.5 Hz, 1 Hz),
(1 Hz, 2 Hz), (2 Hz, 4 Hz),
(4 Hz, 8 Hz), (8 Hz, 1 Hz).

The variants (a), (b), (c) were intended to explore the quantities considered for a global characterization of ground motion, while the variant (d) was intended to go into details for relatively narrow (one-octave) frequency intervals.

The outcome of correlation and regression analysis is presented in Tables 2.2 and 2.3.

Table 2.2. Correlation coefficients (upper triangle) and r.m.s. deviations (lower triangle) for motions as a whole

φ' = 0.25Hz φ'' = 16 Hz	I_{SQ}	I_{AQ}	i^*_{sq} (φ',φ")	i^*_{dq} (φ',φ")	i^*_{fq} (φ',φ")
I_{SQ}	*	0.94 ...0.98	0.96 ...0.98	0.94 ...0.97	0.93 ...0.97
I_{AQ}	0.14 ...0.18	*	0.93 ...0.98	1.00	0.99 ...1.00
i^*_{sq} (φ', φ")	0.12 ...0.14	0.15 ...0.23	*	0.93 ...0.98	0.92 ...0.97
i^*_{dq} (φ', φ")	0.14 ...0.17	0.02 ...0.03	0.15 ...0.23	*	0.99 ...1.00
i^*_{fq} (φ', φ")	0.15 ...0.17	0.04 ...0.05	0.16 ...0.23	0.04 ...0.05	*

Table 2.3. Correlation coefficients for various frequency intervals

(φ', φ''), **Hz**	$i^*_{sq} \leftrightarrow i^*_{dq}$	$i^*_{sq} \leftrightarrow i^*_{fq}$	$i^*_{dq} \leftrightarrow i^*_{fq}$
(0.25, 0.5)	0.96...0.98	0.95...0.98	0.98...1.00
(0.5, 1.0)	0.96...0.98	0.94...0.99	0.99...1.00
(1.0, 2.0)	0.94...0.98	0.92...0.98	0.99...1.00
(2.0, 4.0)	0.92...0.98	0.86...0.96	0.98...0.99
(4.0, 8.0)	0.91...0.96	0.82...0.86	0.95...0.97
(8.0, 16.0)	0.84...0.95	0.52...0.78	0.78...0.88

The results obtained were at the basis of data of Table 2.4. The calibration of Table 2.4 results, in case one accepts, as postulated in Sandi (1986), $I_{S0} = 8$.

Table 2.4. Calibrations proposed for constants I_{X0} and i_{x0}

Parameter	I_{S0}	I_{A0}	i_{s0}	i_{d0}	i_{f0}
Calibration	8.00	6.75	7.70	5.75	6.95

Note: in order to shorten the text, the symbols $i_x^{\sim}(\varphi', \varphi'')$ were replaced, when possible, by i_x^*.

The experience available to date has shown that the calibrations derived on the basis of data of Tables 2.2 to 2.4 appear to be convenient. On the other hand, an aspect to be revised is represented by the calibration of the parameter b of relations (2.1), which is discussed in next subsection. The deviations between the estimates based on the alternative instrumental criteria proposed reach seldom 0.5 intensity degrees and are, usually, lower than 0.25 degrees. So, the definitions adopted lead to a degree of accuracy that exceeds considerably the accuracy that may be provided by the use of macroseismic criteria. Some illustrative examples in this sense are offered by the intensity spectra presented in (Sandi and Borcia, 2006).

2.2.4. Addenda. Possible recalibrations of logarithm basis.

The outcome of recent statistical studies, presented in subsection 3.2, shows that the logarithm basis b = 4, used to date in relations (2.1.a), (2.1.b), appears to be not the most appropriate one and that using a logarithm basis around $b = 7.5$ appears to be more appropriate. This raises the problem of conversion between intensity estimates corresponding to the use of different logarithm bases. Further relations in this connection are applied starting from the relation (2.1.a), but they are usable also for the relation (2.1.b) and for averaged intensities $i_x^{\sim}(\varphi', \varphi'')$ as well. Given the positive experience acquired to date, the structure of relations (2.1.a), (2.1.b), will be kept further on.

Two logarithm bases, b' and b'', and two corresponding free terms, $I_{X0'}$ and $I_{X0''}$ respectively, are considered for relation

(2.1.a). Their use would lead to different estimated intensities, $I_{X'}$ and $I_{X''}$ respectively. In case one wants the two estimates to coincide for a reference intensity I_{Xc}, the conditions

$$I_{Xc} = \log_{b'} Q_{Xc} + I_{X0'} = I_{XQ'} + I_{X0'} = $$
$$= \log_{b''} Q_{Xc} + I_{X0''} = I_{XQ''} + I_{X0''} \quad (2.7)$$

are to be fulfilled. This leads to the result

$$I_{X0''} = I_{Xc} - \left(I_{Xc} - I_{X0'}\right) \times \lg b' / \lg b'' \quad (2.8)$$

(lg: decimal logarithm)

To end this section, some concluding remarks may be presented as follows:

- a comprehensive system of analytical relations, on which in depth intensity estimates can be conducted, was presented;
- the statistical analysis presented reveals the strong correlation between the alternative criteria proposed;
- the developments presented make it possible to determine discrete (averaged) intensity spectra, which may represent an attractive tool for case studies (Sandi and Borcia, 2011);
- basic relations, (3.7) and (3.8), to be used in case of eventual rescaling of the logarithm basis *b* intervening in the analytical relations presented were developed.

3. RECALIBRATION ATTEMPTS. PROCEDURES AND BASIC DATA USED

3.1. General

The various alternative definitions of intensity based on relations (2.1) appeared to be quite satisfactory. The strong correlations between them and also the compatibility with macroseismic estimates at hand (Borcia et al. 2010) were encouraging. Nevertheless, some data, at hand in (Aptikaev, 2005) (with some updating in (Aptikaev, 2006), (Borcia et al., 2010) and (ШИЗ, 2013)) provided arguments for a calibration revision.

The calibrations to be revised referred to the logarithm base *b* and to the free terms I_{S0}, I_{A0}, i_{s0}, i_{d0} and i_{f0}. The sources used in this sense are provided by the papers referred to before.

The techniques and results obtained in the frame of the successive attempts developed to date are briefly presented.

3.2. Data and results provided in (Aptikaev, 2005, 2006)

The data, summarized in (Aptikaev et al., 2008), relied on a statistical examination of a set of macroseismic and instrumental data concerning a set of events are presented in Table 3.1.

Table 3.1 Number of events considered

Intensity	9	8	7	6	5	4	3	2
Number	84	178	212	353	391	172	75	75

The outcome of statistical analysis carried out on the basis of these data shows that logarithmic relationships between intensity and some kinematic parameters are generally appropriate. The empirical relations determined on a statistical basis are:

$$\lg A(\equiv PGA),\ \mathrm{cm/s^2} = -0.755 + 0.4I \pm 0.39\,(0.25)$$
(correlation coefficient: 0.82) (3.1)

$$\lg V(\equiv PGV),\ \mathrm{cm/s} = -2.23 + 0.47I \pm 0.33\,(0.20)$$
(correlation coefficient: 0.84) (3.2)

$$\lg D(\equiv PGD),\ \mathrm{cm} = -4.26 + 0.68I \pm 0.65\,(0.33)$$
(correlation coefficient: 0.81) (3.3)

$$\lg P,\ \mathrm{cm^2/s^3} = -2.22 + 0.87I \pm 0.49\,(0.41)$$
(correlation coefficient: 0.89) (3.4)

where P represents the peak wave kinematic power.

Quantities under "±" mean standard deviations, related both to intensity and ground motion parameters estimations. In parentheses are given values for intensities $I > 6$.

It turns out, on the basis of these relations, that the average values obtained for a jump of one intensity unit are:

- for peak ground accelerations, (PGA) $10^{0.40} \approx 2.51$;
- for peak ground velocities, (PGV) $10^{0.47} \approx 2.95$;
- for peak ground displacements, (PGD) $10^{0.68} \approx 4.79$;
- for peak wave kinematic power, (P) $10^{0.87} \approx 7.41$

(as also for the product of peak ground acceleration and peak ground velocity).

The facts that the above factor 0.47 is higher than the homologous factor 0.40, while the above factor 0.68 is higher than the homologous factor 0.47, correspond to a rather well known trend of increase of dominant oscillation periods of ground motion with increasing intensity (this trend was quite systematically observed, on the basis of instrumental data obtained at a same location during different earthquakes, in Romania too). These results, which correspond to reality, are in direct contradiction with the features of the MSK scale criteria, which relied on the assumption of fixed corner periods, $T_c = 0.5\text{s}$, irrespective of intensity.

Looking at the values of kinematic parameters derived on the basis of previous relations, it turns out that one obtains quite reasonable values even for lowest intensities, for which the assumption of a fixed value of 2.0 for a jump of one intensity unit did no longer work. So, at first sight it appears to be reasonable to adopt such values, perhaps with a minor rounding up (e.g.: 2.5 for accelerations, 3.0 for velocities, 4.8 for displacements, 7.5 for peak kinematic power). These results should be combined with the need of revising the logarithm basis *b* = 4, adopted initially (Sandi, 1986), (Sandi and Floricel, 1998), referred to further on. In case the rounded up values suggested are accepted, the result would be a value *b* = 7.5, which would make it possible to cover in a more satisfactory manner an extensive interval of intensities, going e.g. downwards up to intensity 2.

3.3. Use of specifications of (ШИЗ, 2013)

The Russian draft standard (ШИЗ, 2013) presents an in depth, comprehensive discussion on macroseismic and instrumental criteria, that would certainly deserve an in depth debate for comparison with the developments of the EMS-98 scale (the object of this paper confines a discussion just to the calibration of instrumental criteria). The ground motion parameters adopted as criteria used for intensity estimate are: $PGA(\text{cm/s}^2)$, $PGV(\text{cm/s})$, $PGD(\text{cm})$, $PGA \times d^{0.5}(\text{cm/s}^{1.5})$ and $\lg(PGA \times PGV)(\text{cm}^2/\text{s}^3)$. The parameter *d* represents a reference motion duration, from the first to the last moment when the oscillation envelope exceeds half of the maximum oscillation amplitude. The table specifying the values of these parameters for intensities ranging from $I = 5.5$ to $I = 9.5$ presents the r.m.s. intensity deviation $\sigma(I)$ for the five parameters referred to, which takes the values 0.60, 0.55, 0.70, 0.35 and 0.26 respectively for them. One can state on this basis that the parameter $\lg(PGA \times PGV)$, for which the value $\sigma(I)$ is minimum, may be considered to be the most appropriate among the instrumental criteria considered for intensity estimate. Note here the similarity of the parameter $\lg(PGA \times PGV)$ with the intensity measure

$$I_{SQ} = \log_b(EPAS \times EPVS) \qquad (3.5)$$

introduced by the relations (2.1a), 2.4a,b) and (2.5a). It turns out that a comparison between the outcomes provided by the two approaches deserves to be made.

The values of $\lg(PGA \times PGV)$ specified for the sequence of intensities 5.5, 6.0, 6.5 … 9.5 are reproduced in Table 3.2.

Table 3.2. Values of $\lg(PGA \times PGV)$ specified in (ШИЗ, 2013) for intensities 5.5 to 9.5

Intensity	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
Value*	2.0	2.4	2.8	3.2	3.5	3.9	4.3	4.7	5.0

Value* of $\lg(PGA \times PGV)$

Since there is no kind of pure progression of this sequence, it becomes clear that some rounding up must have occurred. Assuming that an arithmetic progression is appropriate for this sequence (in the absence of rounding up), it turns out that the value of $\lg(PGA \times PGV)$ should increase with an arithmetic rate of $3.0/4 = 0.75$ for one intensity unit and $3.0/8 = 0.375$ for half intensity unit. This is equivalent with postulating a logarithm base $b = 10^{0.75} \approx 5.6234$. There is a clear difference with respect to the outcome $b \approx 7.5$ obtained on the basis of the statistical processing referred to in (Aptikaev, 2005, 2006). A new attempt of estimate of the logarithm base *b* becomes thus justified.

3.4. Sensitivity of calibration with respect to the variation of some input data

A first attempt to contribute to the estimate of the most appropriate value *b* is now presented, using this time the database of (Aptikaev et al., 2008) and (Borcia et al., 2010). The analysis of a new set of data was initiated, in order to acquire additional experience and to explore the possibilities of corresponding recalibration of relations (2.1 a, b). A set of instrumental and macroseismic data related to some earthquakes of the American continent and of the Vrancea seismogenic zone (Romania), was used. The data from Moldova, where general investigations of the features and effects of the earthquakes of 1986 and 1990 were presented in (***, 1990), (Drumea & al., 1990), were determined recently, with a look at the spectral interval for which damage survey data were relevant. The macroseismic estimates for Romania were taken from the isoseismal maps of the standards developed by INCDFP (National Institute for Research and Development of Earth Physics, Romania). The macroseismic intensities estimated belonged to the interval (5.0, 9.0). Alternative instrumental intensity estimates, considering:

- on one hand the initial calibration $b' = 4.0$ of relations (2.1 a, b) and the corresponding free term values of Table 2.4, and
- on the other hand two recalibrations for ($b'' = 8.0$ and for $b'' = 6.0$) and, alternatively, $I_{Xc} = 7.0$ or $I_{Xc} = 8.0$, were conducted. The analysis was carried out alternatively for the intensities I_S and I_A. The results are presented in graphic terms, in Figure 3.1 … 3.3 for I_S and for I_A, respectively. The abscissae used represent respectively:

$$x_S = \lg(EPAS \times EPVS) \qquad (3.6a)$$

$$x_A = \lg\left(\int [w_g(t)]^2 \mathrm{d}t\right) \qquad (3.6b)$$

The alternative straight lines of Figures 3.1, 3.2 and 3.3 correspond to different calibrations of the relations of passage from kinematic criteria to intensities (Aptikaev et al., 2008). The initial calibration (as for $yX4$) was $b = 4$, $I_{S0} = 8{,}0$, $I_{A0} = 6.75$, as introduced in (Sandi and Floricel, 1998). The two newly introduced calibrations (as for $yX8$ and for $yX8'$ respectively), related to the two parallel lines, corresponded to $b = 8$, with $I_{Xc} = 7{,}0$ and $I_{Xc} = 8{,}0$ respectively. The ordinates are macroseismic intensities. Note also that the empty circles or triangles of figures referred to represent revised estimates, lying on the same vertical lines (the same abscissae) as the initial estimates, which were plotted too.

The alternative straight lines of Figures 3.2 and 3.3 correspond to new calibrations of the relations of passage from kinematic criteria to intensities (ШИЗ, 2013). The initial calibration (as for $yX4$) was $b = 4$, $I_{S0} = 8{,}0$, $I_{A0} = 6.75$, as introduced in (Sandi and Floricel, 1998). The two newly introduced calibrations (as for $yX6$ and for $yX6'$ respectively), related to the two parallel lines, corresponded to $b = 6$, with $I_{Xc} = 7.0$ and $I_{Xc} = 8.0$ respectively. In Figure 3.3, the coincidence values assumed for I_{Xc} were, alternatively, 7, 8, 9.

3.5. Use of regression analysis

An additional approach aimed at helping to a most appropriate calibration of relations concerning estimating intensity on the basis of instrumental data was regression analysis. Using the relations concerning linear regression, it turned out that the regression functions are:

- for I_S, $y = 1.2121x + 7.7672$

$$R^2 = 0.9467 \quad (3.7)$$

- for I_A, $y = 1.265x + 6.8486$

$$R^2 = 0.9373 \quad (3.8)$$

Since the factor multiplying x in previous two expressions is equal to 1 / log b, it turned out that the logarithm base should be 6.68 for I_S and 6.17 for I_A respectively.

3.6. Some comments on the results obtained

Looking at the plots, and thinking of the source of macroseismic data, it turns out that:

- the Figures 3.1…3.4 provide a comprehensive view on the relationship between the alternative, macroseismic and instrumental, intensity estimates;
- a general, clear, trend of correlation between the instrumental criteria adopted, on one hand, and the macroseismic estimates, on the other hand, exists;
- the structure of relation (2.1a) is fairly confirmed;
- the scatter appears to be lower for the measure x_A (which is related to I_A) than for the measure x_S (which is related to I_S);
- the way of estimating macroseismic intensity in Moldova, where this was done recently, paying attention to the spectral interval for which survey data are relevant, led to a lowest scatter;
- an attempt of revising to a more credible picture the macroseismic data of the isoseismal maps of Romania improved the appearance of plots too;
- macroseismic intensity appears again as a quite rough measure of ground motion severity (e.g.: in the maps on isoseismals or of zonation for Romania, the jumps for just integer intensity degrees lead to a quite rough partition of the territory);
- the rather high scatter of data of Figures 3.1 and 3.2 (which is related to the scatter put to evidence by relations (3.1) etc.) makes a firm option between the calibrations tested hard at this very moment; this should be postponed up to a time when such an exercise can rely on much more similar data.

4. FINAL CONSIDERATIONS

Looking at the data and results presented in Subsections 3.3, 3.4 and 3.5, it turns out that a calibration b = 6 might be recommendable. The rounding up to this value may seem quite brutal, but it is necessary to keep in view following facts:

- the macroseismic estimates are expressed usually in terms of integer values (sometimes, in practice, also in terms of halves of integers);
- the results referred to in the paper favour the assumption that a common logarithm base should be used for the alternative definitions of intensity.

One could, thus, recommend the use of this calibration as a start point of further research.

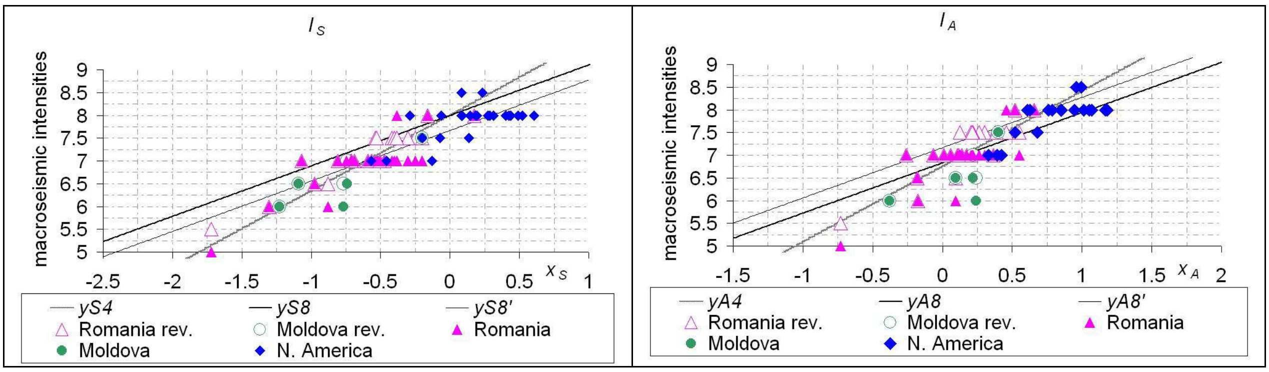

Fig. 3.1. Macroseismic intensities versus global instrumental estimates for b = 8 (based on I_S (left) and on I_A (right))

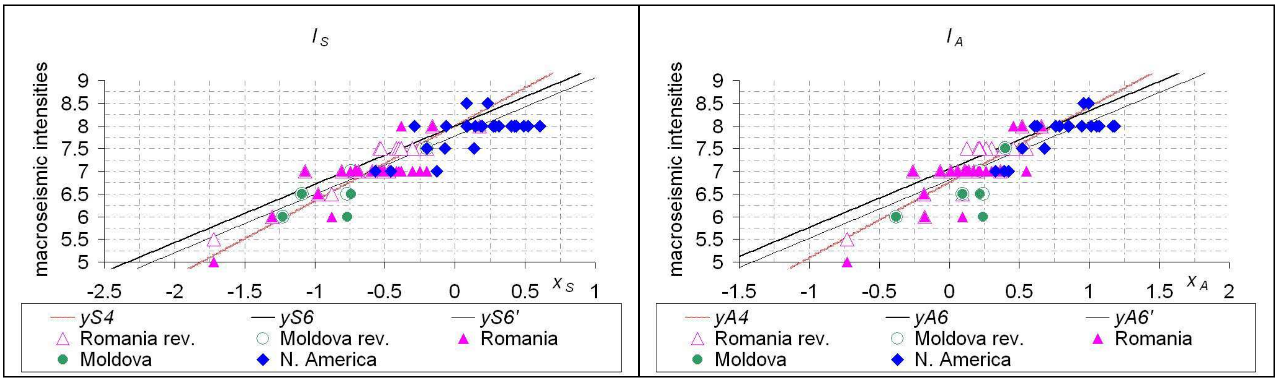

Fig. 3.2. Macroseismic intensities versus global instrumental estimates for *b* = 6 (based on I_S (left) and on I_A (right))

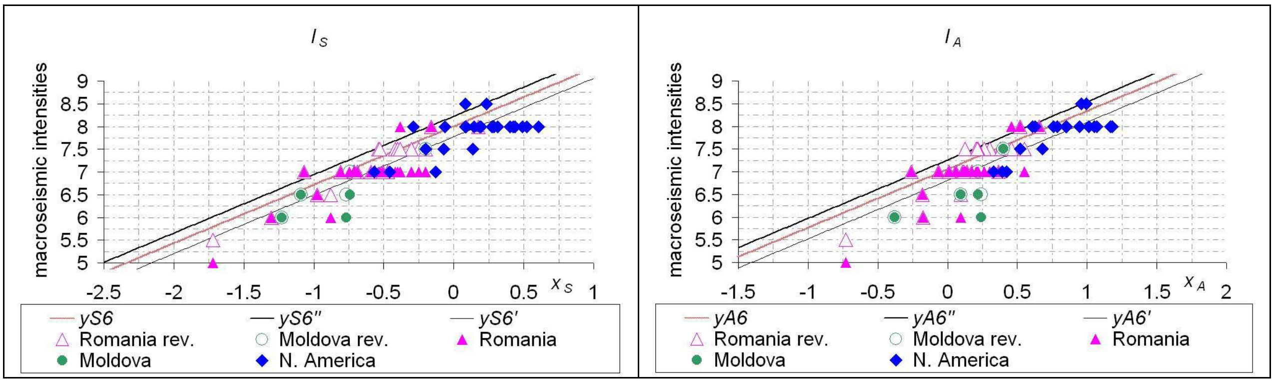

Fig. 3.3 Macroseismic intensities versus global instrumental estimates (based on I_S (left) and on I_A (right)) for *b* = 6 (alternative calibration assumptions of parameter I_{xc} of Subsection 2.2.4)

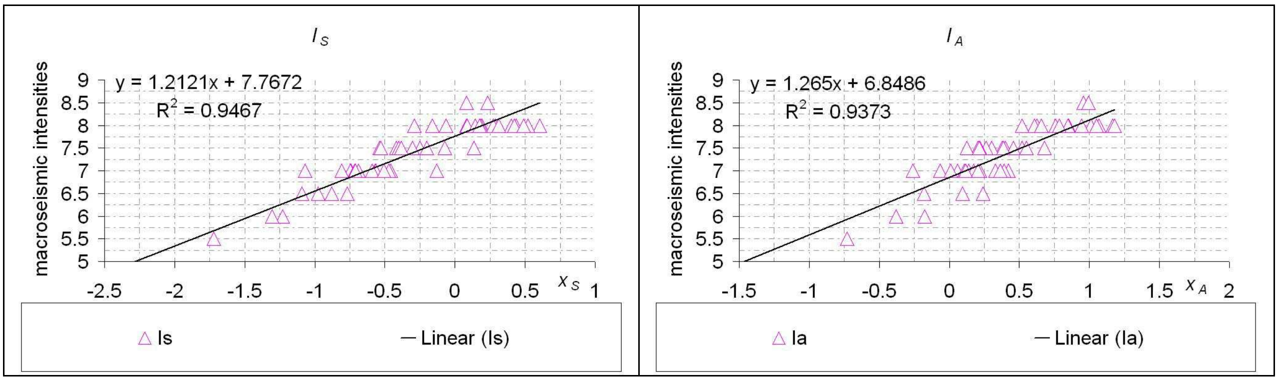

Fig. 3.4. Regression functions for I_S (left) and I_A (right)

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