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An attempt to adapt the concept of seismic intensity to structural engineering needs

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Abstract: The interest for the topic dealt with was raised by the occurrence of the destructive Vrancea earthquake of 1977.03.04, when the first strong motion record of Romania was obtained at the Building Research Institute (INCERC) Bucharest. The attempt to assess the ground motion intensity on the basis of instrumental criteria of the MSK intensity scale failed, due to strongly divergent results obtained by means of alternatively using the peak ground acceleration (*PGA)* and peak ground velocity (*PGV)* criteria. This failure was due to the fact that the (inflexible) MSK criteria relied on the implicit, non-realistic, assumption that all ground motions are characterized by a velocity / acceleration corner period of 0.5 s. A flexible *Spectral Intensity Assessment System* (*SIAS*, relying on accelerographic information, was developed by the author. This makes it possible to estimate, according to needs, global intensity, frequency related intensity, intensity averaged upon a spectral band etc. Alternative basic kinematic ground motion characteristics for global intensities and for frequency related intensities were introduced. Correlation analysis was performed. Characteristic parameters were calibrated and alternative calibrations of them are discussed. Some illustrative cases and some comments and recommendations are finally presented.

Keywords: seismic intensity, global intensity, response spectrum, frequency related intensity, average intensity, intensity spectrum.

1. Introduction

Seismic intensity (related as a rule to seismic ground motion) means the potential of ground motion to affect, more or less severely, *exposed elements* (named also *elements at risk*). Several intensity scales were successively developed. The scales endorsed most recently by the ESC (European Seismological Commission) are the MSK scale [12] and the EMS scale [9]. Both scales rely basically on the post-event interpretation of the "macroseismic" effects of earthquakes. Three basic types of

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entities are taken here into account: <*vulnerability of elements at risk*>, <*observed effects of event*>, <*intensity of event*>. In symbolic terms, the basic equation in which the entities referred to intervene is

<*OBSERVED EFFECTS*> =
= <*VULNERABILITY*> × <*INTENSITY*> (1.a)

The intensity of an event is estimated on the basis of the symbolic solution

<*INTENSITY*> =
= [<*VULNERABILITY*>]$^{(-1)}$ × <*OBSERVED EFFECTS*> × (1.b)

A need to relate intensity to kinematic characteristics of ground motion was felt already long ago, at a time when neither instrumental data on strong motion, nor appropriate instruments were available. Mercalli came up at that time with some estimates of ground acceleration that were rather close to conventional, reduced, design values. The accumulation of data and estimates on ground motion parameters led to an attempt at more complete estimates, at the level of the MSK scale. According to the most recent version of the instrumental criteria of that scale, [12], the average values for *PGA* (peak ground acceleration), *PGV* (peak ground velocity) and $PS_{M}D$ (peak displacement of Medvedev's seismoscope, having a natural period of 0.25 s and a logarithmic decrement of 0.5? [10], for the intensity degrees VI to IX, were as in Table 1.

Besides the macroseismic criteria of intensity estimate, the MSK scale presents also instrumental criteria (as secondary criteria of intensity estimate, Table 1), while the EMS scale does not offer instrumental criteria, in spite of the recognition, in the comments attached to the scale, that correct instrumental data recorded on ground motion provide complete information on the features of the event.

Table 1. Average values of kinematic parameters according to the MSK 1976 scale

MSK intensity	*PGA* (cm/s^2)	*PGV* (m/s)	$PS_{M}D$ (mm)
VI	50	4	2
VII	100	8	4
VIII	200	16	8
IX	400	32	16

Note: $PS_{M}D$ means peak displacement of Medvedev's seismoscope, where the seismoscope is a pendulum having the natural period of 0.5 s and a logarithmic decrement of 0.5?

The examination of this table indicates that:
- the values adopted build geometric progressions (ratio: 2.0);
- the values adopted correspond to a standard response spectrum shape (more precisely, a velocity / acceleration corner period of 0.5 s, as adopted in [10], on the basis of examination of response spectra for Californian strong motion records).

The first strong ground motion accelerogram of Romania was obtained at INCERC Bucharest on 1977.03.04. In the aftermath of the event, the author was asked by a highly placed government official to urgently assess the ground motion intensity in agreement with the instrumental criteria of the MSK scale [27]. The attempt to fulfil this request failed, because a huge gap, of two intensity degrees, occurred between the outcomes of using alternatively the *PGA* and the *PGV* criteria prescribed in the standard.

A critical examination of the cause of the failure referred to showed that this was due to the assumption on which the standard implicitly relied, namely that the "dynamic" factor of the motion should always correspond to the function $S(T)$,

$$S(T) = S_0 \qquad (T \leq 0.5 \text{ s}) \qquad (2.a)$$

$$S(T) = S_0 \times 0.5 / T \qquad (T > 0.5 \text{ s}) \qquad (2.b)$$

On the contrary, experience shows that response spectra of actual motions reveal a wide manifold of kinds of response spectra to be taken into account. For instance, the system of response spectra of absolute acceleration of the event of 1977.03.04, show maximum spectral values in the neighbourhood of a period $T \approx 1.5$ s.

It turned out that in order to develop a consistent tool, it is necessary to critically reconsider the concept of ground motion intensity, in connection with instrumental data recorded during earthquakes. The main object of this paper is to present an attempt to develop appropriate criteria of intensity estimate relying on instrumental (seismological) records obtained during seismic events. Following developments are intended to offer a solution to the task of assessing ground motion intensity on the basis of instrumental information, by bridging a gap between:

- the traditional seismological approach (as revealed by the two intensity scales most recently endorsed by the European Seismological Commission, [12] and [9] respectively), which is blind towards the consideration of spectral characteristics, and
- the use of philosophy and knowhow of structural dynamics, that makes it possible to adopt a much stronger approach, oriented towards an in depth analysis of the spectral (and, also, if necessary, directional) features of ground motion.

It is known that ground motions with low dominant frequencies tend to have severe effects especially on relatively flexible structures, while ground motions with high dominant frequencies tend to have severe effects especially on relatively rigid structures. This fact may be expressed in terms of dependence of intensity upon oscillation frequency. In the simple reference case of a structural model as a single degree of freedom dynamic system, the dependence of intensity on oscillation frequency φ (Hz) may be expressed as a function, $j(\varphi)$.

The intensity (corresponding to various scales, as e.g. the MSK or the EMS scales) has no physical dimension. On the other hand, according to various definitions used, as e.g. [6], [14], the intensity, J or $j(\varphi)$, depends on some entity having a kinematic sense (related to the ground motion in a horizontal direction, or in the horizontal plane), denoted Q or $q(\varphi)$ respectively, which have, all of them, the physical dimension $\langle L^2T^{-3}\rangle$. Studies of the relationship between kinematic entities and macroseismic intensity ([10], [4]), indicated that the sequence of intensity degrees is related to amplitudes of kinematic entities along geometric progressions. In the case of the MSK scale, (see Table 1), the geometric ratio adopted was $\rho_a = \rho_v = \rho_s = 2.0$, for parameters *PGA* (peak ground acceleration), *PGV* (peak ground velocity), PS_MD (peak displacement of Medvedev seismoscope).

Following developments are using several alternative definitions of intensity:

- global intensity, J_X;
- frequency related intensity, $j_x(\varphi)$,

- intensity averaged upon a spectral interval, (φ', φ"), $j_x^{\sim}$ (φ', φ");
- intensity averaged upon horizontal, orthogonal, directions, J_{X12}, j_{x12} (φ).

2. Analytical background

2.1. General

In order to assess intensity on the basis of instrumental data, the first step is to make available an analytical way to convert some of the kinematic ground motion characteristics into a kind of intensity measure. Several alternative ways to do this are presented subsequently. According to the needs of the performed ground motion analysis, it is appropriate to consider *global intensity*, J_X, or *frequency related intensity*, j_x (φ), or *intensity averaged upon a frequency band*, $j_x^{\sim}$ (φ', φ''), where the argument φ is measured in Hz. The various intensity characteristics dealt with are defined as functions of some kinematic characteristics of ground motion Q_X or q_x (φ), defined subsequently. All of the functions Q_X and q_x (φ), referred to subsequently in order to characterize the kinematics of ground motion have a physical dimension <$L^2 \times T^{-3}$>, while the various intensity measures J_X, j_x (φ) etc. are non-dimensional. The variable subscripts X, x are replaced by other ones, according to Table 1. A common way adopted in order to assess *global intensity*, J_X, was to use the expression (3) or, in order to assess *frequency related intensity*, j_x (φ), to use the expression (4). The expressions defining the basic intensity measures J_X, j_x (φ) are

$$J_X = \log_b Q_X + J_{X0} \tag{3}$$

$$j_x(\varphi) = \log_b q_x(\varphi) + j_{x0} \tag{4}$$

(the expression of $j_x^{\sim}$ (φ', φ'') is similar to (4), with the same free term j_{x0})
The value of the subscript b was initially adopted as $b = 4$, in order to correspond to the product of the geometric ratios $\rho_a = \rho_v = 2$, of the kinematic criteria *PSA* and *PSV* the MSK scale [12], while the free term J_{X0} had to be calibrated such as to obtain the highest possible correlation coefficient between the values corresponding to different criteria Q_X, q_x (φ) etc. The subscript X, corresponding to global intensities, and the subscript x, corresponding to frequency related intensities, had to be replaced by some different subscripts respectively, corresponding to the alternative types of criteria (see Table 1, [14]).

Table 2 System of instrumental criteria for intensity assessment

Name	Symbols used for intensities: * global; ** related to a frequency; *** averaged upon a frequency interval.			Source of definition / comments
	*	**	***	
Spectrum based intensities	J_S	j_s (φ)	$j_s^{\sim}$ (φ', φ")	Product of maxima (with respect to φ) of linear response spectra for absolute accelerations and for absolute velocities. Product of linear response spectra for absolute accelerations and for absolute velocities.

Name	Symbols used for intensities: * global; ** related to a frequency; *** averaged upon a frequency interval.			Source of definition / comments
Intensities based on Arias' type integral [Arias, 1970]	J_A	$j_d(\varphi)$	$j_d^{\sim}(\varphi', \varphi'')$	Integral of square of acceleration of ground (for J_A). Integral of square of acceleration of pendulum of natural frequency φ (for $j_d(\varphi)$). Both extensible to tensorial definitions; averaging rules specified.
Intensities based on integral of squares of Fourier transforms	J_F ($\equiv J_A$)	$j_f(\varphi)$	$j_f^{\sim}(\varphi', \varphi'')$	Integral of Fourier image of acceleration (for J_F). Integral of square of Fourier images (for $j_f(\varphi)$). Both extensible to tensorial definitions; averaging rules specified.

It is possible to meet situations in which averaging intensities is of interest. Averaging can be performed upon spectral intervals or upon directions of motion. The spectral averaging is to be performed, for parameters that are specific to intensities $j_x(\varphi)$, by means of the relation

$$q_x^{\sim}(\varphi', \varphi'') = [1 / \ln(\varphi'' / \varphi')] \times \int_{\varphi'}^{\varphi''} q_s(\varphi)\, \mathrm{d}\varphi/\varphi \qquad (5)$$

and / or averaging upon two orthogonal, horizontal, directions denoted <1> and <2>, by means of the relations

$$Q_{X,1,2} = (Q_{X,1} + Q_{X,2}) / 2 \qquad (6.a)$$

$$q_{x,1,2}(\varphi) = [q_{x,1}(\varphi) + q_{x,2}(\varphi)] / 2 \qquad (6.b)$$

The relation (6.b) can be applied also to intensities averaged upon a time interval, determined by means of relation (5).

2.2. Global intensities

<1> A first idea to look for a measure of a unique, or *global, measure of intensity* was suggested by the way in which the system of design spectra for industrial equipment was specified in some cases, which led to the use of a product of peak spectral acceleration and peak spectral velocity,

$$Q_S = (PSA / 2.5) \times (PSV / 2.5) \qquad (7)$$

Note that the corner frequency T_S is given here by the expression

$$T_S = (2\pi) \times PSV / PSA \qquad (8)$$

<2> Another idea, suggested by the Arias definition of intensity [6], starts from the *integral of the square of ground acceleration*, $a(t)$,

$$Q_A = \int [a(t)]^2\, \mathrm{d}t, \qquad (9)$$

<3> A quite similar starting point relies on the use of the *Fourier transform* $a^{(\varphi)}(\varphi)$ *of the accelerogram*,

$$a^{(\varphi)}(\varphi) = \int_{-\infty}^{\infty} \exp(-2\mathrm{i}\pi\varphi t)\, a(t)\, \mathrm{d}t \qquad (10)$$

of which the integral of the square (argument φ: Hz)

$$Q_\varphi = \int [|a^{(\varphi)}(\varphi)|]^2\, \mathrm{d}\varphi \qquad (11)$$

is used (note that, due to analytical reasons, $Q_\varphi \equiv Q_A / 2$).

2.3. Intensities related to spectral bands

The intensities depending on frequency can be considered, in analytical terms, to be homologous to the global intensities previously referred to.
<4> In order to define intensities homologous to the version <1>, *the motion of a pendulum of undamped frequency* φ *and of 0.05 critical damping* is used, for which the product of peak values of response spectra for the absolute acceleration and the absolute velocity, $\max_t |w\ (t, \varphi, 0.05)|$, $\max_t |v\ (t, \varphi, 0.05)|$ respectively, are considered:

$$q_s\ (\varphi) = \max_t |w\ (t, \varphi, 0.05)| \times \max_t |v\ (t, \varphi, 0.05)| \qquad (12)$$

<5> In order to define intensities homologous to the version <2>, *the acceleration* $a^{(\varphi)}\ (t, \varphi, 0.05)$ *of motion of a pendulum of undamped frequency* φ *and of 0.05 critical damping*, for which the integral

$$q_d\ (\varphi) = \int [a^{(\varphi)}\ (t, \varphi, 0.05)]^2\ \mathrm{d}t \qquad (13)$$

is used.
<6> In order to define intensities homologous to the version <3>, *the function*

$$q_f\ (\varphi) = \varphi\ |a^{(\varphi)}\ (\varphi)|^2 \qquad (14)$$

is adopted.

2.4. Intensity spectra

The intensities $j_x\ (\varphi)$ previously defined may be referred to as *continuous intensity spectra*. An alternative approach is to use *discrete intensity spectra* $j_x^{\sim}\ (\varphi', \varphi'')$, related to averaging upon *a system of frequency intervals* (φ', φ''). It is desirable to organize the sequence of limits $<\varphi', \varphi''>$ as a *geometric sequence*. As a recommendable example, the discrete intensity spectra $j_x^{\sim}\ (\varphi', \varphi'')$ used subsequently, correspond to a geometric ratio $\varphi''/\varphi' = 2$ (or to a band of 6 dB). More concretely, the sequence of limits adopted is <0.25 Hz, 0.5 Hz, … 16.0 Hz>, where a central value (in logarithmic scale) is 2.0 Hz. The sequence φ presented includes practically the most significant spectral domain of accelerograms. Some illustrative examples of intensity spectra are presented in next section.

2.5. Correlation analysis

It is interesting to perform an analysis of correlation between the various kinds of intensities referred to. A high value of correlation coefficients would mean a tendency to stability of the system dealt with and a satisfactory credibility of the results. A correlation analysis was performed using the strong motion instrumental results obtained in Romania during the earthquakes of 1986.08.30, 1990.05.30 and 1990.05.31 (a total of more than one hundred accelerograms). The outcome of analysis is presented in Tables 3, 4, 5 and 6.
The correlation coefficients and the standard deviations are given in Table 3 for various kinds of intensities and in Table 4 for various spectral bands.

Table 3. Correlation coefficients (upper triangle) and standard deviations (lower triangle)for global intensities and for average intensities upon spectral band (0.25 Hz, 16. Hz)

	J_S	J_A	j_s*(0.25 Hz, 16. Hz)	j_d*(0.25 Hz, 16. Hz)	j_f*(0.25 Hz, 16. Hz)
J_S	*	0.94...0.98	0.96...0.98	0.94...0.97	0.93...0.97
J_A	0.14...0.18	*	0.93...0.98	1.00	0.99...1.00
j_s*(0.25 Hz, 16. Hz)	0.12...0.14	0.15...0.23	*	0.93...0.98	0.92...0.97
j_d*(0.25 Hz, 16. Hz)	0.14...0.17	0.02...0.03	0.15...0.23	*	0.99...1.00
j_f*(0.25 Hz, 16. Hz)	0.15...0.17	0.04...0.05	0.16...0.23	0.04...0.05	*

Table 4. Correlation coefficients for various spectral bands

(φ‘, φ‘‘), Hz	j_{sq}*↔ j_{dq}*	j_{sq}*↔j_{fq}*	j_{dq}*↔j_{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 of Tables 3 and 4 are presented also in graphic terms (Figures 1 and 2).

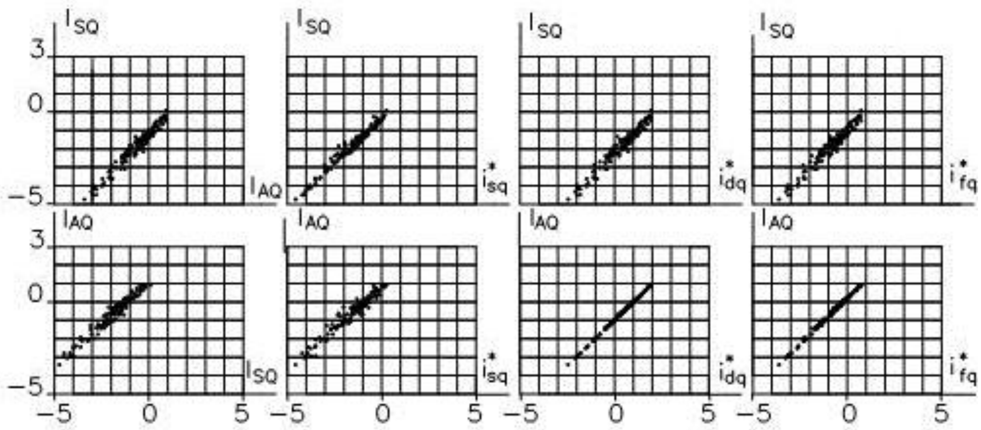


Fig. 1. Correlation of I_{SQ} and I_{AQ} between themselves and with frequency dependent parameters, averaged for the interval (0.25 Hz, 16.0 Hz).

Note also that a comparison of the macroseismic assessment of intensities with the outcome of instrumental estimates for several cases (Table 5) was an encouraging one (the values derived by using the equations given previously are presented under parentheses).

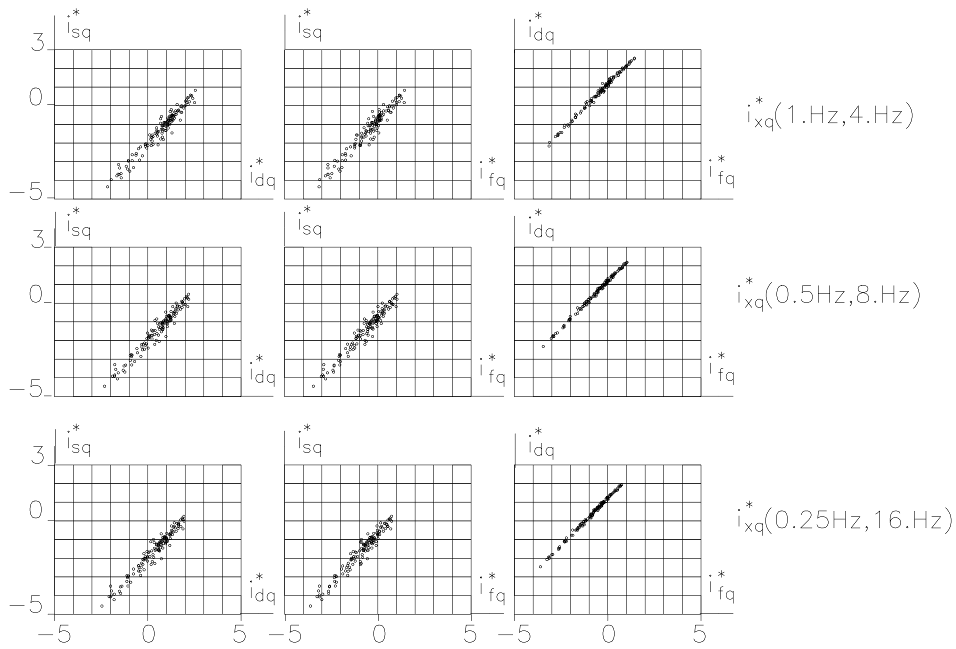


Fig. 2. Correlation between $j^*_{sq}(\varphi', \varphi'')$, $j^*_{dq}(\varphi', \varphi'')$ and $j^*_{fq}(\varphi', \varphi'')$ for various intervals (φ', φ'').

Table 5. Illustrative cases of assessment of spectrum based intensities, I_S.

No.	Event	Record	Direction	*PSA* (m/s^2)	*EPVS* (m/s)	ω_c (s^{-1})	J_S	*PGA* (m/s^2)
1	Romania, 1977.03.04 [7]	Bucharest / INCERC	N – S	2.5	(0.625)	4.	(8.3)	2.1
2	"	"	E – W	1.6	(0.32)	5.	(7.6)	1.7
3	"	"	Horiz. Plane	-	-	-	(8.0)	-
4	Off Adriatic Coast, 1979.04.15 [Petrovski & Paskalov 1981]	Petrovac / Hotel Oliva	Long.	7.	0.6	(11.7)	(9.0)	4.4
5	"	Ulcinj / Hotel Olympic	Long.	3.3	0.42	(7.9)	(8.2)	2.6
6	"	Bar, town assembly bldg.	Long.	4.	0.64	(6.25)	(8.7)	3.7
7	San Fernando, 1971.02.09 [Hudson 1973]	8244 Orion St., 11-st floor	W	(2.4)	0.4	6.	(8.0)	2.4
8	"	"	N	(2.4)	0.4	6.	(8.0)	2.7
9	"	Figueroa St. Station	N52W	(1.26)	0.17	8.	(6.9)	1.5

No.	Event	Record	Direction	*PSA* (m/s^2)	*EPVS* (m/s)	ω_c (s^{-1})	J_S	*PGA* (m/s^2)
10	"	"	S38W	(1.08)	0.18	6.	(6.8)	1.3
11	"	Pacoima dam [25	S74W	(11.2)	0.75	15.	(9.5)	12.5
12	"	"	S16E	(11.9)	0.7	17.	(9.5)	12.4
13	Mexico City, 1985.09.19 [13]	Segretería Comuni-caciones y Transportes	N - S	2.8	0.8	(3.5)	(8.6)	1.1
14	"	"	E - W	4.2	1.3	(3.2)	(9.2)	1.8
15	"	UNAM	N – S	0.48	0.13	(3.7)	(6.0)	0.35
16	"	"	E - W	0.48	0.10	(4.8)	(5.8)	0.35
17	Romania, 1986.08.30	Bucharest / INCERC	N – S	1.0	(.25)	4.	(7.)	0.9
18	"	"	E – W	1.1	(.14)	8.	(6.6)	1.
19	"	Bucharest / Main Exhibition	N – S	1.3	(.15)	9.	(7.)	1.1
20	"	"	E – W	1.6	(.16)	10.	(6.6)	1.7
21	"	Vălenii de Munte	E70N	2.1	(.24)	9	(6.8)	1.7
22	"	"	S70E	2.0	(.25)	8.	(7.)	2.
23	"	Focșani / UCA	E - W	2.9	(.22)	13.	(7.7)	2.9
24	"	"	N - S	2.6	(.26)	10.	(7.7)	2.2

2.6. Calibration of characteristic parameters

In order to make the presented system usable, it is necessary to calibrate the logarithm basis b and the conversion constants J_{X0} and j_{x0}. For the parameter b the value $b = 4$, that corresponds to the geometric ratios adopted for the MSK scale, has been adopted initially. Note that the value of b is equal to the product of geometric ratios ρ_a and ρ_v of acceleration and velocity corresponding to the various intensity values referred to in the scale, namely $b = \rho_a \times \rho_v = 2 \times 2 = 4$ (this corresponds to the definition (7) of Q_S).

The table 4 presents the differences between the conversion constants J_{X0} and j_{x0} of relations (3), (4). In the upper triangle one can see the ranges of intervals, while in the lower triangle one can see the differences adopted, which correspond to the values rounded up to multiples of 0.05. The table 5 presents the values adopted for the free terms J_{X0} and j_{x0}.

The calibration presented cannot be stated to be the final one. A significant attempt to revise the calibration $b = 4$ is given in [2], where a statistical analysis on a set of data of about 1500 cases was performed. For each case a macroseismic estimate (ranging from intensity II to intensity IX) and instrumental data on *PGA*, *PGV*, *PGD*, *P*, (where $P = PGA \times PGV$), were available. It turned out that the type of expression (3) is appropriate and that the values of geometric ratios were about $\rho_a \approx 2.5$ and $\rho_v \approx 3.0$. This should imply a value of b of about $2.5 \times 3.0 \approx 7.5$. This means, among other, that the velocity / acceleration corner period T_c tends to increase (as known) with increasing intensity.

Table 4. Differences between the conversion constants for various intensity variants

	J_{S0}	J_{A0}	j_{s0}*	j_{d0}*	j_{f0}*
J_{S0}	*	-1.26...-1.22	-0.31...-0.22	-2.27...-2.20	-1.06...-1.01
J_{A0}	1.25	*	0.93...1.00	-1.00...-0.98	0.21...0.22
j_{s0}*	0.30	-0.95	*	-1.98...-1.93	-0.79...-0.72
j_{d0}*	2.25	1.00	1.95	*	1.19...1.22
j_{f0}*	1.05	-0.20	0.75	-1.20	*

Table 5. Calibrations adopted for the constants J_{X0} and j_{x0}

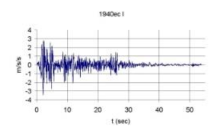
Parameter	J_{S0}	J_{A0}	j_{s0}	j_{d0}	j_{f0}
Calibration	8.00	6.75	7.70	5.75	6.95

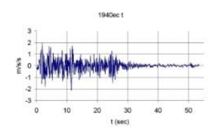
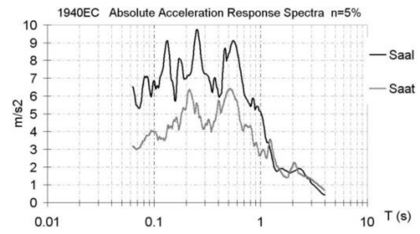
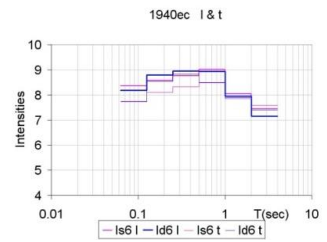
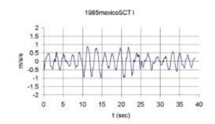
Revising the value of b involves also a revision of $J_{X0.}$ In case one passes from a couple of values (b', J_{X0}') to a couple (b'', J_{X0}''), there will occur a non-proportionality of the values and a value of Q_X for which the two expressions yield the same value, which correspond to a crossing of the corresponding plots. The crossing value is to be opted for. The author examined this problem too (on a set of fewer cases). It turned out that the value b should rather be around 6.0. It is desirable to continue further these studies.

3. Illustrative cases

The cases dealt with subsequently, in Table 6, are intended to illustrate a way in which the previous analytical developments may be used in order to explore the features of seismic ground motions. The cases successively presented concern:
<1> the reference motion of El Centro during the Imperial Valley (California) event, 1940.05.18;
<2> the long period motion of Segretería Comunicaciones y Transportes, Mexico City, 1985.09.19;
<3> the first strong ground motion recorded in Romania, Bucharest – INCERC, 1977.03.04;
<4> the second strong motion recorded at the same place on 1986.08.30;
<5> the third strong motion recorded at the same place on 1990.05.30;
<6> the first strong motion recorded at the Town Hall of Cernavodă on 1986.08.30;
<7> the second strong motion recorded at the Town Hall of Cernavodă on 1990.05.30;
<8> the third strong motion recorded at the Town Hall of Cernavodă on 1990.05.31.
In all these cases, the initial data (accelerograms), as well as the outcome of processing, concern the two horizontal orthogonal directions along which the accelerations were recorded. Response spectra of absolute accelerations (for 0.05 critical damping) are reproduced for these directions. Discrete intensity spectra $j_d\tilde{}$ (φ', φ'') and $j_f\tilde{}$ (φ', φ'') are given for sequences of 6 dB periods intervals.

Table 6. Illustrative ground motion characteristics

<table>
<tr><th rowspan="2">No.</th><th rowspan="2">General data on event and on record site</th><th colspan="3">Characteristics of ground motion along two orthogonal horizontal directions</th><th rowspan="2">Magnitudes and global intensities</th></tr>
<tr><th>Accelerograms</th><th>Response spectra for absolute acccelerations (5% critical damping)</th><th>Intensity spectra :?
$j_s\tilde{}$ (φ', φ''), red, and $j_d\tilde{}$ (φ', φ''), blue, averaged upon 6 dB intervals</th></tr>
<tr><td>1</td><td>Source:
USA, Ca, Imperial Valley
1940.05.18
φ , λ : 32.73, -115.45
Record site:
El Centro
Code:
1940ELC
φ , λ : 39.72, -115.55</td><td>


</td><td>
</td><td>
</td><td>M_S: 7.0
J_S: 8.01
(8.18, 7.80)
J_S1: 8.34
(8.52, 8.09)
J_A: 8.43
(8.55, 8.30)
J_D1: 8.44
(8.56, 8.31)</td></tr>
<tr><td>2</td><td>Source:
N. A. / Cocos Plates (Mexico)
1985.09.19
φ , λ : 18.08, -102.94
Record site:
Mex. City SCT
Code:
1985SCT
φ , λ : 19.43, -99.13</td><td>

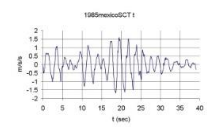
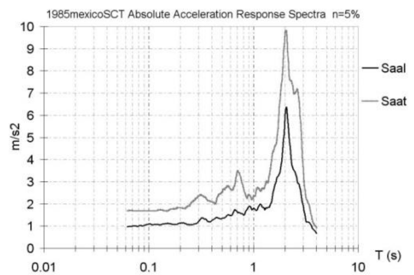
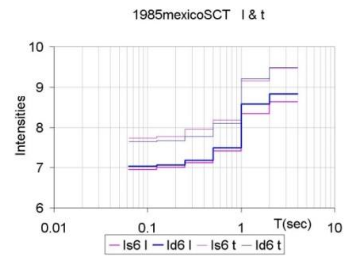

</td><td>
</td><td>
</td><td>M_S: 8.1
J_S: 8.92
(8.55, 9.16)
J_S1: 8.42
(7.90, 8.72)
J_A: 8.40
(8.03, 8.64)
J_D1: 8.47
(8.09, 8.72)</td></tr>
</table>

Table 6 (cont'd)

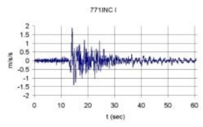
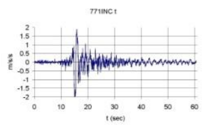
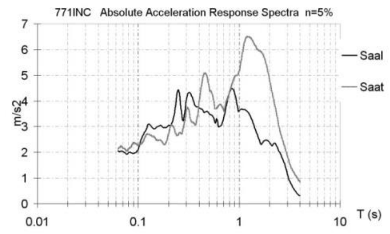
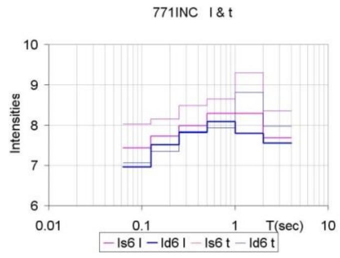
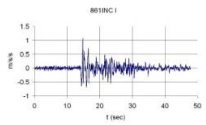
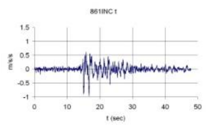
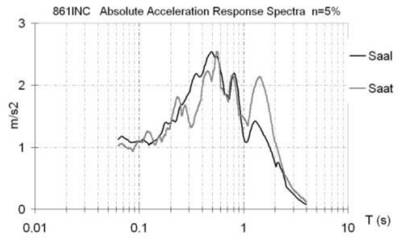
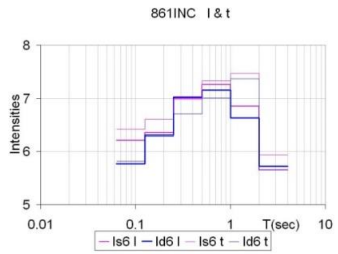
No.	General data on event and on frecord sites	Characteristics of ground motion along two orthogonal horizontal directions			Magnitudes and global intensities
		Accelerograms	Response spectra for absolute accelerations (5% critical damping)	Intensity spectra: $j_s{}^{\sim}(\varphi', \varphi'')$, red, and $j_d{}^{\sim}(\varphi', \varphi'')$, blue, averaged upon 6 dB intervals	
3	*Source*: Romania, VSZ φ, λ : 45.34, 26.30 1977.03.04 *Record site*: Bucharest / INCERC *Code*: 771INC φ, λ : 44.44, 26.16	 			$M_{G\text{-}R}$: 7.2 J_S: 8.09 (7.64, 8.37) $J_{S}1$: 8.37 (7.97, 8.63) J_A: 7.85 (7.67, 7.99) $J_{D}1$: 7.89 (7.67, 8.04)
4	*Source*: Romania, VSZ φ, λ : 45.53, 26.47 1986.08.30 *Record site*: Bucharest / INCERC *Code*: 861INC φ, λ : 44.44, 26.16	 			$M_{G\text{-}R}$: 7.0 J_S: 6.68 (6.48, 6.84) $J_{S}1$: 6.86 (6.73, 6.96) J_A: 6.65 (6.61, 6.68) $J_{D}1$: 6.68 (6.63, 6.72)

Table 6 (cont'd)

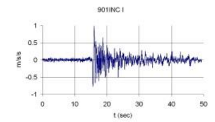
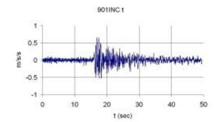
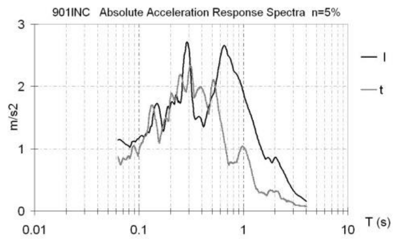
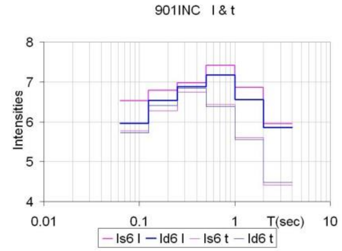
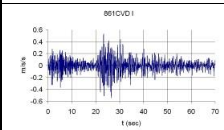
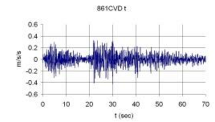
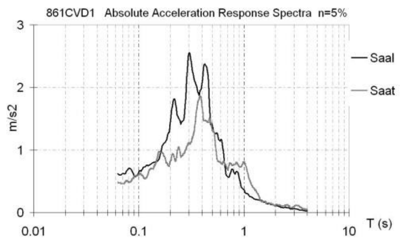
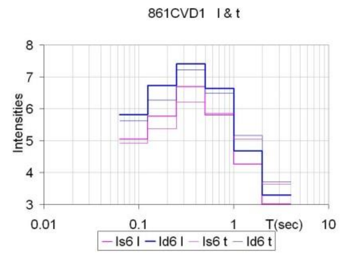
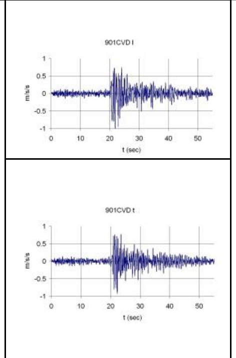
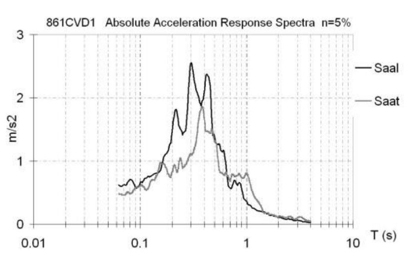
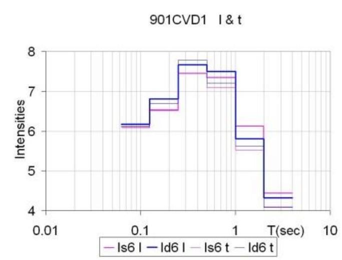
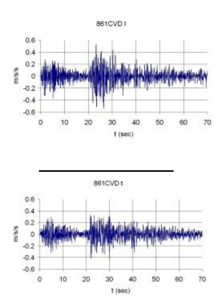
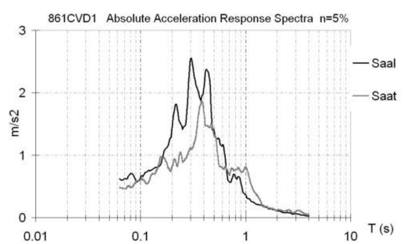
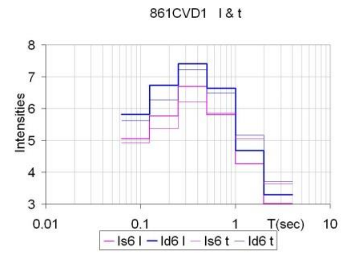
No.	General data on event and on frecord sites	Characteristics of ground motion along two orthogonal horizontal directions: Accelerograms	Response spectra for absolute acccelerations (5% critical damping)	Intensity spectra: $j_s\tilde{}\,(\varphi', \varphi'')$, red, and $j_d\tilde{}\,(\varphi', \varphi'')$, blue, averaged upon 6 dB intervals	Magnitudes and global intensities
5	*Source*: Romania, VSZ φ, λ: 45.82, 26.90 1990.05.30 *Record site*: Bucharest / INCERC *Code*: 901INC1 φ, λ: 44.44, 26.16	 			$M_{G\text{-}R}$: 6.7 J_S: 6.33 (6.55, 6.02) $J_{S}1$: 6.61 (6.88, 6.16) J_A: 6.45 (6.62, 6.22) $J_{D}1$: 6.46 (6.64, 6.21)
6	*Source*: Romania, VSZ φ, λ: 45.53, 26.47 1986.08.30 *Record site*: Cernavodă / Town Hall *Code*: 861CVD1 φ, λ: 45.23, 28.03	 			$M_{G\text{-}R}$: 7.0 J_S: 5.87 (6.05, 5.64) $J_{S}1$: 5.67 (5.79, 5.53) J_A: 6.46 (6.56, 6.35) $J_{D}1$: 6.48 (6.57, 6.37)

Table 6 (cont'd)

No.	General data on event and on frecord sites	Characteristics of ground motion along two orthogonal horizontal directions: Accelerograms	Response spectra for absolute acccelerations (5% critical damping)	Intensity spectra: $j_s\tilde{}$ (φ', φ''), red, and $j_d\tilde{}$ (φ', φ''), blue, averaged upon 6 dB intervals	Magnitudes and global intensities
7	*Source*: Romania, VSZ φ, λ: 45.82, 26.90 1990.05.30 *Record site*: Cernavodă / Town Hall *Code*: 901CVD1 φ, λ: 45.23, 28.03				M_{G-R}: 6.7 J_S: 6.93 (6.92, 6.93) $J_{S}1$: 6.75 (6.81, 6.69) J_A: 6.93 (6.95, 6.90) $I_{D}1$: 6.95 (6.98,6.92)
8	*Source*: Romania, VSZ φ, λ: 45.83, 26.89 1990.05.31 *Record site*: Cernavodă / Town Hall *Code*: 902 φ, λ: 45.23, 28.03				M_{G-R}: 7.0 J_S: 5.87 (6.05, 5.64) $J_{S}1$: 5.67 (5.79, 5.53) J_A: 6.46 (6.56, 6.35) $J_{D}1$: 6.48 (6.57, 6.37)

Note on Table 6:
Indices used:

- *L* (longitudinal): direction *X* of record;
- *T* (transversal): direction *Y* of record;
- *1* (one): averaging of frequency dependent intensities over the frequency interval (0.25 Hz, 16.0 Hz);
- (no index): global intensities.

Units used for kinematic parameters: m, m/s, m/s^2.
Abscissa scale (periods) for response spectra and intensity spectra: logarithmic.
Ordinate scale: natural.

4. Final considerations

It may be stated that SIAS, the intensity assessment system briefly presented, offers a quite flexible instrument of ground motion characterization that makes it possible to provide information ranging from the approach of macroseismic analysis up to the approach required by engineering activities.

The instrumental data collected during earthquakes provide a rich source of information, but this information is rigorously valid just for the locations of instruments. On the contrary, the macroseismic analysis makes it possible, in favourable cases, to get a holistic view on the features of ground motion along certain areas.

The use of SIAS provides, obviously, more accurate information than the traditional macroseismic analysis of intensity. On the other hand, the instrumental information provided by strong motion networks of the type currently at hand is bound to be limited in the future too. It turns out that it is desirable to collect after earthquakes instrumental, as well as macroseismic data and to finally combine the data at hand.

The intensity scales of traditional type (like MSK [12] or EMS98 [9]) do not provide appropriate tools for a spectral characterization of ground motion. This, in spite of the fact that the comments attached to the latter scale recognize the capability of instrumental data to fully characterize a ground motion recorded. Note also that the new Russian scale [30] provides an instrumental criterion that is quite similar to J_S.

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