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Paper No. 1466. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

ENGINEERING-DEVELOPED RELATIONS DERIVED FROM THE STRONGEST INSTRUMENTALLY-DETECTED ITALIAN EARTHQUAKES

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ABSTRACT

The data collection concerning the quantitative and qualitative parameters of the strongest Italian earthquakes of the present century is here presented. This project supplies a data-bank that goes beyond the limits of present earthquake catalogues, particularly through the retrieval of historical instrumental data. The project has the purpose to realize the best retrieval of seismometric, macroseismic, accelerometric data and information on induced phenomena. Moreover the data base allows to compute some relevant seismological relationships, most of them already obtained with foreign data or data valid for territorially restricted Italian zones, providing a characterization of the Italian seismicity. The computed coefficients, implementing functional forms known in literature, provided useful relations of national validity tested “ad hoc” for Italian seismicity. The computed relations, fitted through simple and multiple regressions, are: “local-surface waves magnitude”, “magnitude-intensity-depth”, “seismic moment-magnitude”, attenuation of peak horizontal acceleration and intensity vs. peak horizontal acceleration.

KEYWORDS

Earthquake’s database; instrumental data; macroseismic information; least squares fits; magnitude conversions; seismic moment; attenuation laws.

DATABASE STRUCTURE AND CONTENT

The selected earthquakes come from the following available Italian catalogues: Geodynamic Finalized Project, by National Council of Research and ENEL (National Electric Power Company) catalogues, from 1900 to 1982; ING (National Institute of Geophysics), from 1983 to 1991.

The first selection of 20th century earthquakes included only events with available instrumental data (magnitude determination). We then considered the events with magnitude M greater than or equal to 4.5 . This threshold has been chosen by analyzing the probability distribution of M-I relation, from which results that the magnitude 4.5 has a 50% probability to correspond to VI -MCS scale- intensity and a 50% probability to correspond to VII -MCS scale- intensity, corresponding to a significant threshold value for engineering purposes. We didn't consider earthquakes with intensity greater than or equal to VI-VII in MCS scale when characterized by only macroseismic information. Finally we excluded foreign earthquakes, those with offshore epicenter when not related to macroseismic effects on land and earthquakes with hypocenter deeper than 100 km, unless relevant macroseismic effects were observed. The above selection criteria provided a data set of 327 earthquakes, widely distributed on the entire country (figure 1).

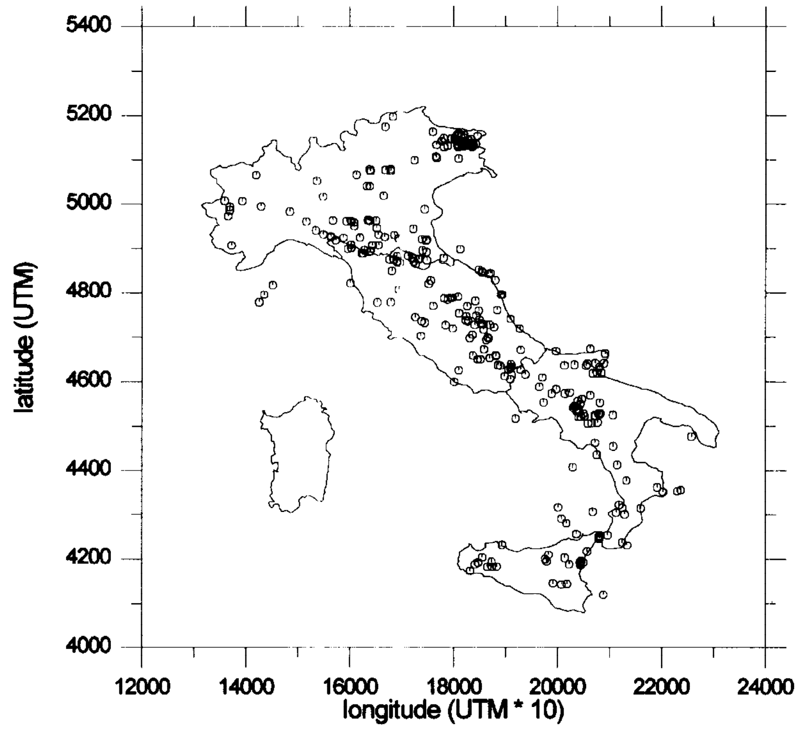

Fig. 1. Epicenter locations of the earthquakes contained in the data base.

The data-bank collects 92 fault-plane solutions proposed by many authors, particularly Gasparini *et al.* (1985), Cagnetti *et al.*(1978). Moreover the database shows those parameters, such as seismic moment, stress drop, focal mechanism, peak accelerations and so on, that nowadays are not included in common available catalogues and which are useful to better describe seismic focus, travel-path, site effects, as well as several kinds of magnitudes such as m_b, Ms, Ml, and so on.

LOCAL-SURFACE WAVES MAGNITUDE RELATION

The implemented data permitted to highlight the relation between local and surface waves magnitudes as plotted in figure 2. The graph shows a wide scatter for medium-low magnitude values (m<5.5) while a better correlation for higher magnitude values (m>5.5) is observed. This represents a confirmation of the unstableness of the magnitude variation which can not be considered a valid evaluating parameter for the earthquake size or, at least, the only one.
The computed best-fit is the following:

$$Ms = 0.477\ (\pm 0.217) + 0.911\ (\pm 0.042)\ Ml \qquad (1)$$

N= 98; r^2= 0.831; σ=0.268

Besides the linear relationship an exponential one is also showed, that however doesn't significantly increase the fit. A wide scatter in local magnitude is observable, due to the fact that Ml sometimes comes from the use of Richter's attenuation tables, often ignoring the geographically-dependent shape of the attenuation or the local site conditions. A more precise determination of the surface waves magnitude is usually expected, especially for higher magnitude values (approximately m>5.5) where also a saturation problem can arise from the use of local magnitude.

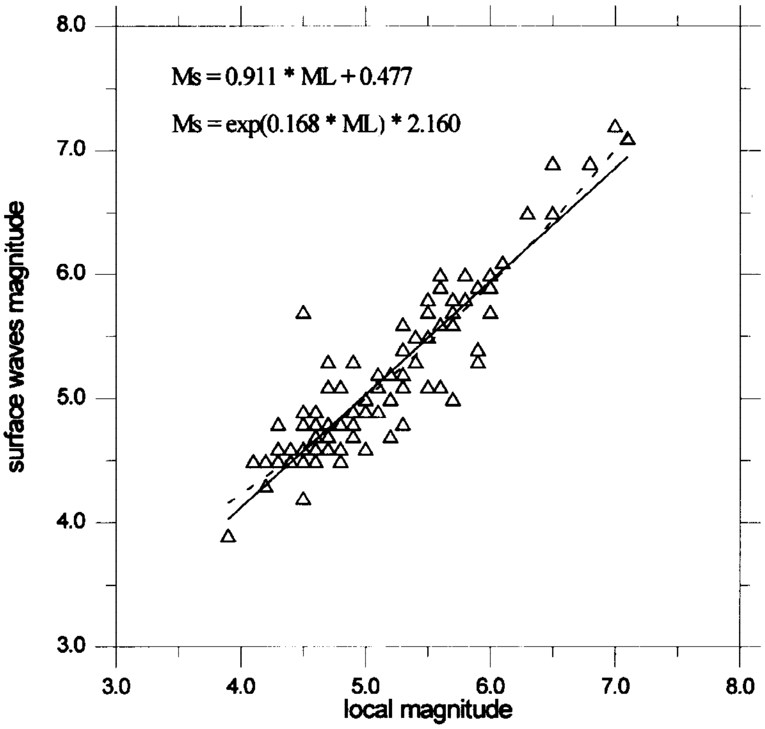

Fig. 2. Surface waves-local magnitude relation plot.

MAGNITUDE-INTENSITY RELATION

Many authors (Karnik, 1969; Peronaci, 1973; Ambraseys, 1985) have proposed relations for the estimation of macroseismic magnitude from epicentral intensity. The estimation of macroseismic magnitude in the linear form $\mathbf{M = a + b\,I_0}$ can be considered reasonable since the predictor parameters are very easily retrievable in the historical seismic literature. Despite other parameters as isoseismals radii, local intensities related to hypocentral distances, energy absorption and geometrical spreading are in fact more realistic predictors of macroseismic magnitude, their use is often annihilated by the unavailableness of such data.

On the basis of the available data set the following relation between local magnitude and epicentral intensity has been derived (figure 3), neglecting the influence of the hypocentral depth so to provide an easy to apply relation in an engineering decision making:

$$Ml = 2.483\ (\pm 0.180) + 0.349\ (\pm 0.025)\ I_o \qquad (2)$$

N= 163; r^2= 0.549; σ=0.381

The wide scatter reflected by the relatively low correlation coefficient and the high standard error can be removed averaging the intensity levels determinations for each magnitude class. We hypothesized that the error in intensity determination was normally distributed, so that the mean value represents the 50% probability of being the best estimate of the true correspondence between intensity and magnitude, thus artificially removing the intensity-magnitude scatter for low intensity levels, due to a larger number of events and to a less precise determination of the intensity level itself. This inaccuracy is greater for the low-intensity levels than for the high-intensity ones. This leads to better fit, that range $6.5 \leq I_0 \leq 11$, which is recalculated as follows:

$$Ml = 1.434\,(\pm 0.274) + 0.515\,(\pm 0.033)\,I_0 \qquad (3)$$

$N= 22;\ r^2= 0.923;\ \sigma=0.219$

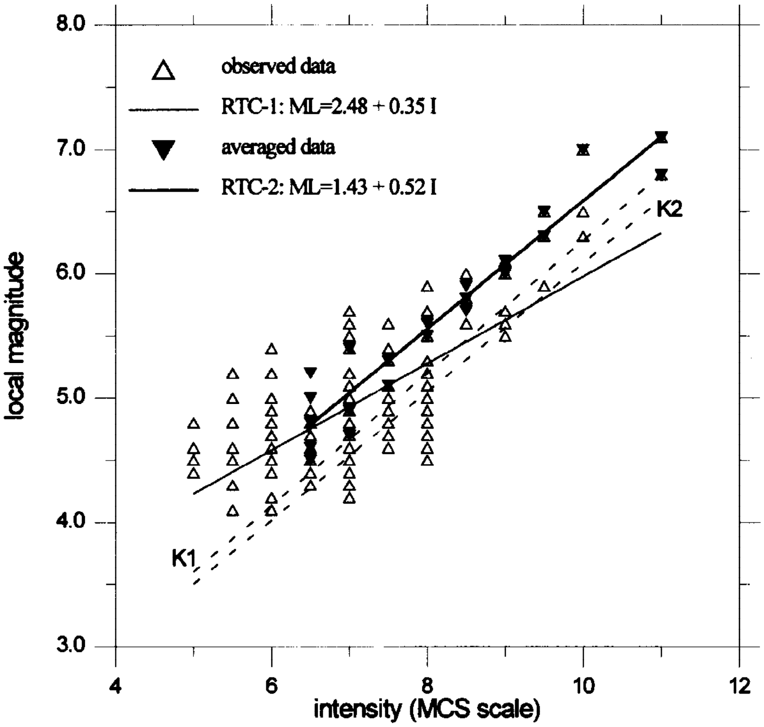

Fig. 3. Local magnitude versus epicentral intensity -MCS scale-: RTC-1, total fitting; RTC-2, averaged fitting; K1 and K2 Karnik's, 1969 relations for respectively Northern Italy and Southern Italy.

For comparison in figure 3 are also shown the two Karnik's (1969) relations, commonly used in Italy to convert intensity into magnitude and valid for Northern and Southern Italy (respectively north and south of 42nd parallel).

MAGNITUDE-SEISMIC MOMENT RELATION

The seismic moment M_0 is directly connected with the seismic source dimension, so providing an equivalence between the elastic dislocation and a double force-couple. Consequently this represents the most useful and reliable source parameter instrumentally determined. In fact, from a seismogenetic view-point, M_0 allows a more accurate classification of earthquakes, compared to magnitude. Later on, conversion from the seismic moment scale to the conventional magnitude scales came out very useful in all research fields in seismology. In fact, the magnitude scales have been widely used for more than 50 years not only for applied and theoretical seismology, but also in engineering seismology.

As a result, since the end of the sixties, there have been many attempts of empirical correlation between seismic moment and magnitude (Wyss and Brune, 1968; Thatcher and Hanks, 1973; Bakun and Lindh, 1977; Kanamori, 1978; Purcaru and Berckhemer, 1978; Hanks and Kanamori, 1979), either for strong and moderate earthquakes or for small events. Nowadays a large number of relations like this: $\mathbf{Mw = a \log M_0 - b}$ are available, where ‘a’ and ‘b’ coefficients have been determined in many seismogenetic zones in the world.

In this study we have examined just 30 available values of seismic moment determined for the earthquakes that struck Italy from 1904 to 1991 with magnitude between 4.3 and 7.1. For magnitudes above 5.5 we used surface waves magnitude and local magnitude otherwise. Most of the seismic moment values have been determined by De Natale *et al.* (1987) and Rovelli *et al.* (1988). In both papers they used data from strong-motion accelerograms recorded in Italy.

Figure 4 shows the seismic moment vs. magnitude plot and the derived moment magnitude relation is the following:

$$Mw = 0.700\ (\pm\ 0.060)\ \log M_0 - 11.495\ (\pm\ 1.441) \qquad (4)$$

$N = 30;\ r^2 = 0.828;\ \sigma = 0.327$

In order also to provide a correlation between moment magnitude and more used kinds of magnitudes such as local and surface waves magnitude, a plot between Mw and Ml-Ms has been provided (figure 5), which gives the opportunity to convert Ml or Ms into Mw:

$$Mw = 0.897\ (\pm\ 0.376) + 0.828\ (\pm\ 0.071)\ M \qquad (5)$$

$N = 30;\ r^2 = 0.828;\ \sigma = 0.327$

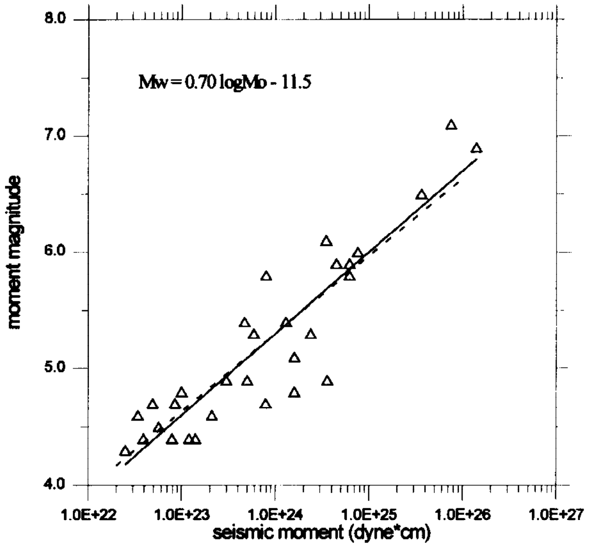

Fig. 4. Moment magnitude relationship; dashed line shows the famous Hanks and Kanamori's (1979); Mw=2/3 log M_o - 10.7) relation.

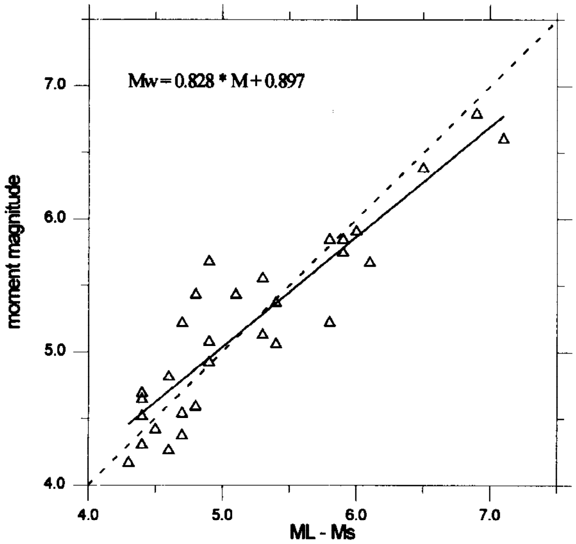

Fig. 5. Relation between moment magnitude and local (m≤5.5) or surface waves (m>5.5) magnitude.

Equality between moment magnitude and Ml-Ms is reached around m=5.5, while determination of the earthquake size in terms of moment magnitude leads to smaller values than surface waves magnitude.

ATTENUATION OF PEAK HORIZONTAL ACCELERATION

According to the above chapter, the Sabetta and Pugliese (1987) Italian attenuation law has been recomputed in terms of moment magnitude. This provides an already converted attenuation law to be directly used when estimations of peak horizontal accelerations in terms of moment magnitude are required. The standard functional form has been implemented, considering the estimated peak horizontal acceleration to be dependent from site conditions, too. The derived relations, with regard to respectively fault distance (D) and epicentral distance (R), are the following:

$$\log PHA\ (g) = -1.870\ (\pm 0.182) + 0.366\ (\pm 0.032)\ Mw - \log(D^2+6^2)^{1/2} + 0.168\ (\pm 0.045)\ S \qquad (6)$$

$N=95$; $r^2= 0.770$; $\sigma=0.173$

$$\log PHA\ (g) = -2.238\ (\pm 0.200) + 0.438\ (\pm 0.035)\ Mw - \log(R^2+5^2)^{1/2} + 0.195\ (\pm 0.049)\ S \qquad (7)$$

$N=95$; $r^2= 0.719$; $\sigma=0.190$

The term 'S' refers to local site conditions and takes value '0' for rock or stiff soils and deep alluvia, '1' otherwise. According to a less estimate of magnitude provided by moment magnitude with regard to that provided by surface waves magnitude, estimates of PHA in terms of moment magnitude are greater than those expressed in terms of surface waves magnitude. In other words, a surface waves magnitude 7.0 corresponds to a moment magnitude 6.7, so the corresponding PHA(Ms=7.0) values are to be compared with the PHA(Mw=6.7) values.

Figures 6 and 7 show the comparison between the computed relations and those obtained by Sabetta and Pugliese (1987).

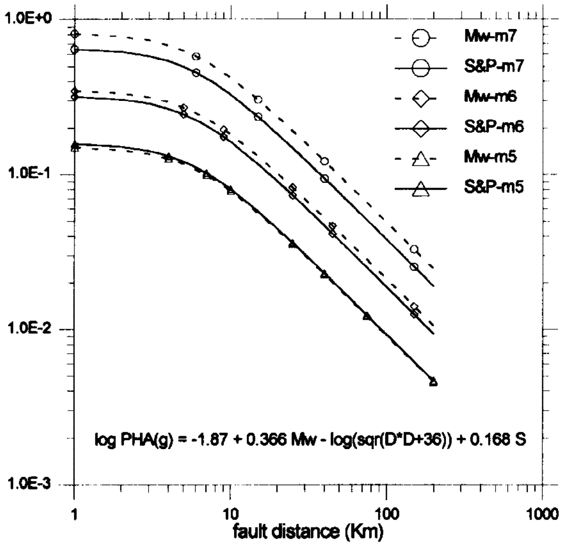

Fig. 6. PHA(g) vs. fault distance.

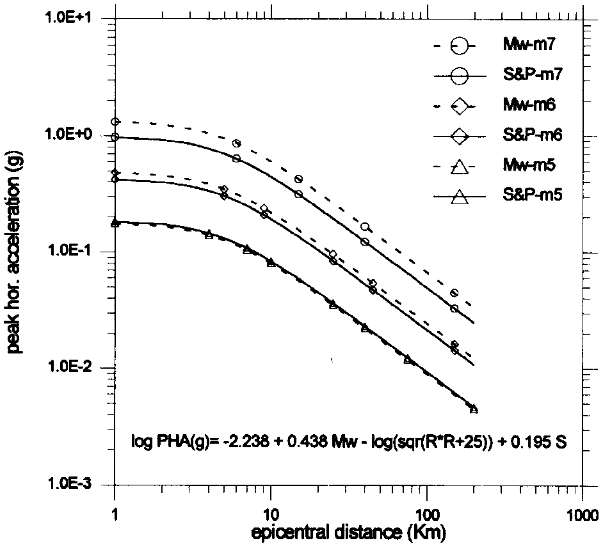

Fig. 7. PHA(g) vs. epicentral distance.

The increments regarding to soil conditions and standard deviation of PHA values (84 percentile), are of the same order, being in fact *0.168* the soil coefficient and *0.173* the $\sigma_{\log(PHA)}$.

INTENSITY VS. PEAK HORIZONTAL ACCELERATION

Where there are no or few accelerometric recordings, a relation between peak ground acceleration and macroseismic intensity (Ambraseys, 1975; Trifunac and Brady, 1975; Trifunac *et al.,* 1991) may have sense, in first approximation, for a ground motion estimation. General site intensities, defined as the macroseismic intensity detected in the nearest village to the accelerometric station, from 7 earthquakes have been taken into account. Local site intensities, defined by Margottini *et al.* (1992) as the local damage determined in the vicinity of the station (few hundred meters around), have been here neglected. The usefulness of implementing general rather than local site intensity directly derives from the original macroseismic data reported in the macroseismic bulletins.

The data set is composed of 42 recordings and the relation between peak horizontal (PHA) acceleration (in analogy with the attenuation law) and general site intensity (Is in the MCS scale) is the following:

$$\log \mathrm{PHA}(\mathrm{cm/s}^2) = 0.460\ (\pm 0.307) + 0.214\ (\pm 0.047)\ \mathrm{Is} \qquad (8)$$

N= 42; r^2= 0.342; σ=0.268

The data scattering (figure 8) leads to a low correlation coefficient and a high standard deviation, making the estimate too uncertain. The main reasons are the uncertainty in the intermediate degrees determination (5-6, 6-7 and so on) and in the discrete nature of the intensity scales. Therefore, in analogy with the magnitude into intensity conversion, peak horizontal acceleration has been considered, for each intensity class, as a stochastic variable with normal distribution. The regression on the averaged data (figure 8, RTC-2) gives:

$$\log \mathrm{PHA}(\mathrm{cm/s}^2) = 0.660\ (\pm 0.265) + 0.196\ (\pm 0.040)\ \mathrm{Is} \qquad (9)$$

r^2= 0.923; σ=0.090

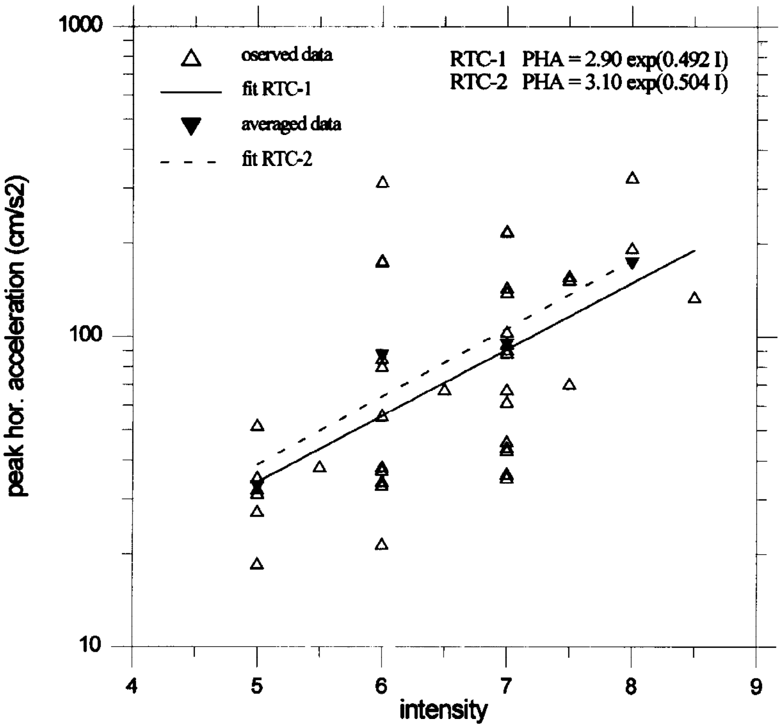

Fig. 8. Peak horizontal acceleration vs. general site intensity -MCS scale- (RTC-1, total fitting and RTC-2, averaged fitting).

Although it represents a statistical artifice for reducing uncertainty, advantages arise from: a better fit to the highest intensity levels; a more conservative estimate of the PHA values; a statistical meaning that follows the individual distributions of each intensity class; a better function that incorporates the information (not yet available) of the PHA values for intensities greater than 8, which are, in agreement to the log-normal distribution law, much higher.

CONCLUSIONS

Use of unhomogeneous parameters makes arduous every empirical correlation among seismological entities. Nevertheless the usefulness of such relations comes out when qualitative and/or quantitative information to be implemented for theoretical or applied researches are not sufficient for their direct use but conversion from other parameters are required. Such a procedure is particularly recurrent when long time seismic series must be analyzed or seismicity information is prevalently based on historical data.

In this context, the present work has intended to provide a contribution to the relationships among seismological parameters commonly used in engineering practice and specifically derived by Italian seismicity data.

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