ON THE DEVELOPMENT OF A CORRELATION MODEL BETWEEN GROUND MOTION PARAMETERS AND EMS98 INTENSITY OBSERVATIONS
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Introduction. The relation between observed macroseismic intensities and recorded ground motion parameters is a matter of interest in earthquake engineering, and it has been widely discussed in literature in the past. Several relationships already exist, correlating macroseismic intensity and peak ground motion parameters (i.e. PGA, PGV or PGD, respectively peak ground acceleration, velocity and displacement). However, most of these formulations are based on Mercalli-Cancani-Sieberg (MCS) scale, developed using regional databases and difficult to be
applied at large scale. In this work, a first attempt in developing a reliable correlation model between European Macroseismic Scale (EMS-98) with ground shaking parameters (PGMs) is illustrated. A PGM/EMS98-intensity dataset was assembled for this scope, collecting data from the Database of Macroseismic observations of Italy DBMI15 (Locati et al., 2016), and the Italian Accelerometric Archive ITACA (Luzi et al., 2017). The database includes 607 data pairs of observations from 35 different Italian seismic events. On this basis, a preliminary correlation model is set up via the use of the Orthogonal Distance Regression (ODR) technique.

**Building the cross-matched dataset.** A PGM/EMS98-intensity dataset was therefore assembled collecting instrumental records and results of macroseismic surveys at 607 sites, after 35 Italian earthquakes. Concerning peak ground motion parameters, PGV, PGA and PGD are considered. Such data are retrieved from the Italian Accelerometric Archive (ITACA ver. 2.2, see Luzi et al., 2017): ITACA contains data recorded by the National Accelerometric Network (RAN, operated by the Italian Civil Protection Department – DPC), the National Seismic Network (operated by Istituto Nazionale di Geofisica e Vulcanologia – INGV) and regional and international networks operated by several providers. This archive provides reliable evaluations of the above parameters, containing 32,271 three-component accelerometric waveforms generated by 1524 past Italian earthquakes, with magnitude greater than 3, in the time frame 1972-2016. Instead, macroseismic observations are collected from the Database of Macroseismic observations of Italy DBMI15 (Locati et al., 2016), which is a large and homogeneous macroseismic collection of past Italian earthquakes covering a time period ranging
from year 1005 to year 2014. A total number of 122,701 macroseismic records is contained in DBMI15, resulting from 3212 different earthquakes and revised from many studies, reports and bulletins. Part of the recorded seismic events follows the EMS98 scale, with intensities arranged in classes spaced by 0.5 intensity units (ranging from 1 to 12). However, non-numerical values may also be assigned to some localities (e.g. F-felt, HF-high felt, D-damage); in this case, corresponding intensities were assigned according to the convention described in the catalogue (Locati et al., 2016). By cross-matching these two types of data - macroseismic intensities and PGM parameters - an exhaustive and homogeneous database of 607 pairs of PGM/EMS98-intensity points, arising from 35 different Italian seismic events was derived.

Seismic events contained in the dataset cover a time span between 1983 and 2016 (3.2-6.1), with $I_{\text{EMS}} < 10$; recent earthquakes of Emilia (2012) and Amatrice (2016) are included too. Figure 1 shows the detailed spatial distribution of the events considered. The association between macroseismic intensity with PGM parameters was carried out only for such sites located within 6 kilometers from an accelerometric station. This choice ensures a reasonable congruence between the observed macroseismic intensity and PGM measures, allowing maintaining a relatively high number of data pairs. The sufficient numerosness of the dataset allows deriving reliable regression equations.

Within this distance there is a nearly uniform distribution of macroseismic intensities (see Fig. 2), with some scatters at the two extreme values ($I_{\text{EMS}} = 2.5$ and $I_{\text{EMS}} = 8.5$). Indeed, collected data are principally concentrated in an intensity interval between 2-8, even though the maximum value of $I_{\text{EMS}}$ covered by the database is 10. The same good spatial distribution was observed for PGM parameters.

![Fig. 2 - Distribution of the observed EMS98 intensities with the distance from the nearest accelerometric station (NF = not felt).](image)

**Data processing.** Two approaches can be applied for the regression analysis, and depend on the method used for data processing. Indeed, it is possible to arrange the intensity observations in classes and, for each, the mean value of the recorded ground motion parameter is associated. Alternatively, the whole dataset can be used, without any grouping procedure, even if a robust statistic method for outliers detection and removal should be applied. In this work, the former
Fig. 3 - Fully-reversible ground motion-to-intensity relations for: a) PGA; b) PGV; c) PGD.
approach is used, as done also in Faenza and Michelini 2010, i.e. the mean value of logarithm of PGMs $\mu_g$ and their standard deviation values $\sigma_g$ are used, and EMS98 intensities are grouped in classes at 0.5 intensity bins. This choice is motivated by the distribution of PGMs data about the logarithmic means, which is in agreement with theoretical normal distribution curves. To verify the likelihood of the normal distributions, the 1-sample Kolmogorov-Smirnov normal test is carried out, confirming the above hypothesis. It is worth to recall that, for some intensity classes and ground motion measures it was not possible to compute mean values: indeed, the number of observations was considered insufficient to allow a reliable regression analysis of the data. These limits define the range of applicability of the proposed equations, as it will be further explained in the next Section. As a control tool, data points were also used for regression analysis without any data binning and averaging procedure.

**Results.** The ODR regression (Boggs *et al.*, 1988), applied to pre-processed data, allows obtaining linear relationships that correlate EMS98 intensity ($I_{EMS}$) and base-10 logarithm of PGMs. Hence, the following regression equations, determined using the mean values of the EMS98 classes, are obtained for PGV, PGA and PGD:

\[
\begin{align*}
I_{PGV} &= 4.21 + 0.09 \cdot log(PGV), \quad \sigma = 0.362 \\
I_{PGA} &= 1.84 + 0.24 \cdot log(PGA), \quad \sigma = 0.274 \\
I_{PGD} &= 5.87 + 0.21 \cdot log(PGD), \quad \sigma = 0.289
\end{align*}
\]

For each formulation, standard deviation values are given. The range of applicability of such Equations is derived according to the defined $I_{EMS}$ intensity bins, being between 2.5 and 8. Additionally, as a control tool, the same correlations are obtained considering the whole dataset, without any averaging:

\[
\begin{align*}
I_{PGV} &= 4.26 + 0.05 \cdot log(PGV), \quad \sigma = 0.307 \\
I_{PGA} &= 2.10 + 0.11 \cdot log(PGA), \quad \sigma = 0.245 \\
I_{PGD} &= 5.97 + 0.08 \cdot log(PGD), \quad \sigma = 0.273
\end{align*}
\]

The range of applicability of Eqs. 4-6 is the one defined by the whole dataset, i.e. between 2 and 10. All the above formulations (Eqs. 4-6) are obtained with the ODR technique, thus this means that they represent fully-reversible ground motion-to-intensity conversion equations. As a control tool, data points were also used for regression analysis without any data binning and averaging procedure. Fig. 3 shows the resulting ground motion-to-intensity relations.

**Conclusions.** This work presented new fully-invertible relations that correlate ground motion intensity measures and macroseismic intensity values expressed with EMS98 scale, which are developed starting from data collected for the Italian context, and a defined range of applicability. The importance of these formulations depends on the lack of any regression equation between peak ground motion (PGM) parameter and the most currently used EMS98 macroseismic intensity scale, which is one of the few that takes into account structural features of buildings, and thus accounts for their seismic vulnerability in the assignment of macroseismic intensity values. Such relationships can be considered, at the same time, both Intensity-to-Ground Motion Conversion Equations (IGMCEs) and Ground Motion-to-Intensity Conversion Equations (GMICEs), as they were developed through the Orthogonal Distance Regression technique.

**References**


