NEW METHODOLOGY FOR LOSS SIMULATION SCENARIOS
VALIDATED WITH RECENT ITALIAN EARTHQUAKES
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In the first 1-2 hours after the notification of the magnitude and coordinates of an earthquake, is particularly useful to have a tool that allows to evaluate a first estimate of the expected losses, in order to plan a tight schedule of the actions to be taken for the emergency management. In this paper the last development of a loss simulation tool, based on a Geographical Information System (GIS) and developed by the Italian Department of Civil Protection (DPC), is analysed evaluating its performance in matching the damage data of recent Italian earthquakes.

At the DPC has been in use for more than 10 years the application SIGE (Sistema Informativo per la Gestione dell’Emergenza) that allows you to calculate the losses in terms of the expected number of collapsed, unusable and damaged houses, as well as victims, injured and homeless (Lucantoni et al. 2001). This tool also provides a comprehensive picture of the affected area in terms of seismicity, monitoring networks, schools, hospitals, roads and railways, dams, industries at risk, etc. SIGE is based on an empirical approach using a conversion magnitude-macroseismic intensity, an intensity attenuation relationship, and Damage Probability Matrices (DPM - Di Pasquale et al. 2000) providing, on the basis of data collected during post-earthquake damage surveys, the probability of a given damage level as a function of intensity and building typological class. It has to be remarked that, considering the lack of reliable geological and geotechnical data at the national scale, SIGE doesn’t take into account the local site effects.

The former version of SIGE has been updated in order to improve the losses forecast particularly for small to medium sized earthquakes. This has been achieved through a careful analysis of the damage surveys performed after some recent Italian earthquakes (Tab. 1) and the following calibration of the scenario results. The data reported in Tab. 1 have been obtained as follows: MI is the value provided by the INGV message on which the SIGE has been launched; Mw is calculated from MI on the basis of the relationship provided by Gasperini et al. (2013) except for the L’Aquila earthquake; epicentral intensity Io is estimated from a Mw-Io relationship [catalogue CPT11: Rovida et al. (2011)] except for the 2012 Emilia earthquake where Io has been reduced on the basis of the macroseismic observations; depth is taken from INGV-ISIDE (http://iside.rm.ingv.it/); fatalities and homeless are taken from several sources available in the WEB (e.g. Italian regions and DPC) and considering the resident people (ISTAT 2001 census) in the unusable buildings (habitability states B, C, E) reported in the AeDES forms (Baggio et al., 2009) used in Italy for damage and safety assessment of buildings.

Tab. 1 - Italian earthquakes considered for the calibration of the loss scenario.

<table>
<thead>
<tr>
<th>Earthquake</th>
<th>Date</th>
<th>MI</th>
<th>Mw</th>
<th>Io MCS</th>
<th>Depth (km)</th>
<th>Fatalities</th>
<th>Homeless</th>
</tr>
</thead>
<tbody>
<tr>
<td>Narni</td>
<td>16/12/2000</td>
<td>4.1</td>
<td>4.2</td>
<td>4.8</td>
<td>8</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cerreto</td>
<td>11/03/2000</td>
<td>4.1</td>
<td>4.2</td>
<td>4.8</td>
<td>5</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>Arezzo</td>
<td>26/11/2001</td>
<td>4.4</td>
<td>4.5</td>
<td>5.5</td>
<td>5</td>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>Salò</td>
<td>24/11/2004</td>
<td>4.8</td>
<td>5.0</td>
<td>6.4</td>
<td>5</td>
<td>5</td>
<td>974</td>
</tr>
<tr>
<td>Pollino</td>
<td>26/10/2012</td>
<td>5.0</td>
<td>5.2</td>
<td>6.9</td>
<td>6</td>
<td>0</td>
<td>150</td>
</tr>
<tr>
<td>Lunigiana</td>
<td>21/06/2013</td>
<td>5.2</td>
<td>5.4</td>
<td>7.3</td>
<td>5</td>
<td>21</td>
<td>638</td>
</tr>
<tr>
<td>Lagnonegro</td>
<td>09/09/1998</td>
<td>5.5</td>
<td>5.7</td>
<td>8.0</td>
<td>7</td>
<td>11</td>
<td>651</td>
</tr>
<tr>
<td>Molise</td>
<td>31/10/2002</td>
<td>5.4</td>
<td>5.6</td>
<td>7.8</td>
<td>10</td>
<td>130</td>
<td>3000</td>
</tr>
<tr>
<td>Palermo</td>
<td>06/09/2002</td>
<td>5.6</td>
<td>5.8</td>
<td>8.2</td>
<td>5</td>
<td>0</td>
<td>209</td>
</tr>
<tr>
<td>Emilia</td>
<td>20/05/2012</td>
<td>5.9</td>
<td>6.1</td>
<td>7.5</td>
<td>6</td>
<td>57</td>
<td>42000</td>
</tr>
<tr>
<td>L’Aquila</td>
<td>06/04/2009</td>
<td>5.8</td>
<td>6.3</td>
<td>9.3</td>
<td>9</td>
<td>1908</td>
<td>67459</td>
</tr>
</tbody>
</table>
The main features introduced in the new version of SIGE are the following:

- Input: magnitude (Ml or Mw), epicentral coordinates, focal depth.
- Ml-Mw transformation (Gasperini et al., 2013).
- Mw-Io relationship obtained by a regression on the seismic catalog CPT11 (Io = 2.1241*Mw - 4.106).
- Relationship for the attenuation of macroseismic intensity: Gomez Capera (2007) if ML ≤ 5.5 (Io ≤ VIII); Pasolini et al. (2008), modified with the introduction of a no-attenuation area as a function of Io, if ML > 5.5 (Io > VIII).
- Introduction of a calibration to take into account the earthquake focal depth (if h > 20 km Io’ = Io - 0.0259*(h-20)).
- Introduction of different Mw-Io relations and different attenuation for the volcanic zones (Gomez Capera, 2007).
- Vulnerability classes of the Italian real estate based on ISTAT 2001 census data (building typology, age of construction, number of stories).
- Damage represented in terms of the 5 damage levels of the macroseismic scale EMS-98 (Grünthal, 1998).
- Probability of a given damage level for each vulnerability class derived by Damage Probability Matrices (Di Pasquale et al., 2000).
- Loss output in terms of collapsed dwellings (damage level D5), unusable dwellings (damage levels D3, D4, D5), inhabitants in collapsed dwellings (fatalities), inhabitants in unusable dwellings (homeless).
- Introduction of the Seismic Emergency Scale (ES) combining in a single indicator, taking values from 1 to 5, the estimates of damaged dwellings, homeless and people involved in building collapse.
- Uncertainty of the results assessed in terms of both hazard (half degree of the macroseismic intensity evaluated in each municipality) and vulnerability (min, med, max values corresponding to 16, 50 and 84 percentile considering the distribution and the standard deviation of the Damage Probability Matrices).

![Resident people in unusable dwellings](image)

Fig. 1 – Comparison, as a function of earthquake magnitude, of the number of people resident in unusable dwellings (homeless) obtained by SIGE with the real data surveyed on field. Lines indicated by “espo” correspond to an exponential fit on the data that becomes linear in a semi-log plot.
In Fig. 1 the number of inhabitants in unusable dwellings (diamonds) with the corresponding uncertainty (squares and circles and best fit dashed lines) is compared, as a function of magnitude, with the real data of the homeless derived from Tab. 1. Besides the large scatter of the real data that obviously are not a linear function of the magnitude, it can be seen that the agreement with SIGE output is quite good if the large uncertainty in the results (corresponding to about an order of magnitude) is taken into account. The scenario results are slightly overestimated for small magnitude earthquakes and underestimated for high magnitudes. Similar results are obtained in case of the collapsed dwellings and fatalities (victims and injured).

The graphical output of the new SIGE has been completely redesigned, changing from AML (ESRI) to Python programming language, producing new figures and maps updated with the last seismological and territorial data and a Geo-database organized also to receive information from the surveys in the epicentral area in order to update the first estimate of the scenario.

Fig. 2 – Map (ArcMap 10.1) produced by SIGE showing the location of the Lunigiana Mw=5.4 earthquake of June 2013 together with the individual and composite seismogenic sources DISS 3.1.1 (DISS Working Group, 2010) the epicenters of the historical earthquakes [catalogue CPT11: Rovida et al. (2011)] and the PGA contour lines corresponding to the different GMPEs selected.
In particular the final SIGE report has been updated both in the numerical and cartographycal
d part, generating, for each event located on the Italian territory, a set of 24 figures and maps
showing:
• event location;
• attenuation in terms of macroseismic intensity (Gomez Capera 2007, Pasolini et al.,
2008);
• attenuation in terms of PGA corresponding to different Ground Motion Prediction
Equations [GMPEs: Akkar and Bommer (2007), Bindi et al. (2011), Cauzzi and Faccioli
(2008) and Sabetta and Pugliese (2006)];
• seismic catalogues [CPT11: Rovida et al. (2011)] and seismogenic sources [DISS 3.1.1:
Basili et al. (2008) and DISS Working Group (2010)];
• seismic hazard and seismic zonation;
• location and characteristics of the Italian strong motion stations (RAN);
• absolute and percentage values of collapsed and unusable dwellings;
• absolute and percentage values of the population involved in collapsed (fatalities) and
damaged buildings (homeless);
• number of inhabitants, houses and buildings per each municipality;
• distribution of houses in the vulnerability classes;
• percentage values of houses built before the seismic zonation of the corresponding
municipality;
• territorial vulnerability due to landslides;
• large dams under the governmental jurisdiction;
• risk Industries (legislative decree 334/99);
• location and characteristics the historical and architectural goods.
Fig. 2 shows an example of a map, generated with ESRI ArcMap 10., illustrating: event
location, seimogenic sources, historical epicenters, and PGA attenuation.
A new version of SIGE has also been checked in the perspective of the use of real-time data
provided by the Italian strong motion network, allowing to overcome the issues connected to
attenuation anisotropy and lack of site effects consideration. Two GMPEs (Sabetta and Pugliese,
1996; Cauzzi and Faccioli, 2008) have been tested, and the only version currently available of
fragility curves correlating the damage level to PGA and matching the building classification
of the ISTAT census at national scale, has been considered (Sabetta et al., 1998). As can be
seen in Fig. 3, in case of the Lunigiana earthquake of June 2013, the results obtained with the

![Lunigiana earthquake 21/06/2013 Mw=5.38 Unusable buildings](image)

Fig. 3 – Comparison of the results obtained with PGA based simulation scenario, intensity based (old and new version
of SIGE, and real data, for the unusable buildings after the Lunigiana earthquake of June 2013. CF refers to the use of
above mentioned fragility curves are definitely overestimated respect to the real data and the results obtained with the intensity-based version of SIGE. An attempt of going back to intensity based DPM has also be made using relationships between macroseismic intensity and PGV or Housner intensity (Kaka and Atkinson, 2004; Chiauzzi et al., 2011). In this case the results are quite similar to those obtained with the direct use of the intensity attenuation adopted in the new version of SIGE, suggesting this approach as the best actually available until new fragility curves will be available.

References


