GEOTECHNICAL HAZARD REPRESENTATION FOR DAMAGE SCENARIO AND SEISMIC RISK ANALYSIS

Sonia GIOVINAZZI 1

ABSTRACT

Damage scenario and seismic risk analysis, along with the use of a GIS-environment to represent the results, are helpful tools to support the decision-making process for planning and prioritizing seismic risk management strategies. The common framework for developing seismic risk analysis and damage scenarios is based on the traditionally accepted definition of the seismic risk as a convolution of hazard, exposure, and vulnerability. This paper focuses on the importance of an appropriate geotechnical hazard representation within a seismic risk analysis process. After an overview of alternative methods for geotechnical zonation available in literature, with a different level of refinement depending on the information available, examples of their implementation are provided with reference to a case study. Significant differences in terms of the resulting microzoning can be observed. It is worth noting that in such methods, the definition of the site effect amplifications does not account for the characteristics of the built environment, affecting the soil-structure interaction. Alternative methods able to account for either the soil conditions and the characteristics of the built environment have been recently proposed and are herein discussed. Within a framework for seismic risk analysis, different formulation would thus derive depending on both the intensity measure (i.e., macroseismic intensity or response spectra) and the vulnerability approach (i.e., macroseismic/observational or mechanical-based approach) adopted. In conclusion, an immediate visualization of the importance of the geotechnical hazard evaluation within a seismic risk analysis is provided in terms of the variation of the expected damage and consequence distribution.

INTRODUCTION

Earthquake risk is a public safety issue that requires appropriate risk management measures and means to protect citizens, properties, infrastructures, and the built cultural heritage. The aim of a seismic risk and of a damage scenario analysis is the estimation and the hypothetical, quantitative description of the consequences of a seismic event upon a geographical area (a city, a region, a state, or a nation) in a certain period of time. The effects to be predicted are the physical damage to buildings and other facilities, the number of casualties, the potential economic losses due to the direct or indirect costs, including business interruption and downtime, the loss of function in lifelines and critical facilities as well as the impacts at the social, organizational, and institutional levels.

The results provided by a seismic risk analysis and damage scenarios could thus be regarded as helpful guidelines during all the phases of risk management, before and after the critical event. It is worth noting that, the choice between risk analysis and scenario analysis depends on the aims of the study. When prevention measure at a territorial scale are of interest, a risk analysis is

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preferable in that it brings together the effects of all the potential seismic sources of the area and supplies a comparable evaluation between all the different communities interested by the study. On the other hand, when issues related to emergency management are of interest, a scenario analysis (simulating a representative earthquake) is the most meaningful, in that it reproduces a realistic distribution of the effects on the territory.

The common framework of damage scenario and seismic risk analysis is based on the traditionally accepted definition of seismic risk as the convolution of hazard, exposure and vulnerability. The hazard analysis aims to characterize the seismic motion expected in the region, in terms of physical measures or in terms of macroseismic intensity (I), possibly including the local amplifications (microzoning). It is well established that local site conditions and, to a more limited extend, irregular surface topography can substantially influence the amplitude, the frequency content and the duration of a strong ground motion and consequently can exert a crucial influence on the severity of the damage caused by the earthquake on the single structure. Similarly, when considering a territorial scale seismic risk analyses, regardless of the approach used for the estimation of the seismic hazard and of the intensity measure parameter (IM) adopted, the influence of site conditions cannot be disregarded. The exposure analysis aims to evaluate the number and characteristics of the built environment in a given area, both in quantitative and qualitative terms, while the vulnerability analysis aims to estimate the intrinsic likelihood of the structures to be damaged due to an earthquake motion by correlating the severity of the seismic motion (IM) with the expected structural and non-structural damage. By convolution of the seismic hazard with the vulnerability and exposure, an estimation of the distribution of damage, of the related economical losses and of the consequences to buildings and people can be carried out.

In this paper the attention will be focused on the effects of alternative methodology and level of geotechnical zonation on the final results of a seismic risk analysis, with reference to site effects amplifications due to soil and morphological condition. After an overview of alternative geotechnical zonation methods, differently defined depending on the available level of knowledge/information, it is discussed how to account for site effects within a seismic risk analysis. In particular, reference is made to the seismic motion representation in terms of macroseismic intensity where the building vulnerability is assessed according to a macroseismic approach (Giovinazzi and Lagomarsino 2004) and then to a seismic motion representation in terms of peak ground acceleration or spectral ordinates with the building vulnerability represented in terms of capacity curves, typical of force-based approach as those proposed in the capacity spectrum method implemented in HAZUS (NIBS 1999). The influence of accounting for the actual soil conditions within a seismic risk analysis is presented in terms of variation of the resulting probabilities of expected damage levels.

REPRESENTATION OF ALTERNATIVE SOURCES OF GEOTECHNICAL HAZARD WITHIN A SEISMIC RISK ANALYSIS

Local ground motion amplification due to soil conditions
As mentioned, a scenario study aims at estimating the level and distribution of damage at a territorial scale, instead of predicting the response of a specific structure at a specific site. When the scope is to generate a geotechnical zonation to be employed for vulnerability assessment and seismic risk purposes, the representation of the ground conditions, needs to be no more detailed than that required by design seismic code provisions. Furthermore, simplified approaches for predicting the ground and the structural response at specific sites can actually be implemented.

In order to map out geological units associated to local ground motion amplification, the Manual for Zonation on Seismic Geotechnical Hazards TC4-ISSMGE (1999) suggests, for example, three different levels of methodologies, depending on the level of available data on the soil site characteristics. A basic, “grade I”, zonation level can be achieved by the compilation
and interpretation of existing information available from historic documents (i.e. compiled data on the distribution of damage induced during past destructive earthquake), published reports and other available databases or by direct reference to the site surface geology. A more refined, “grade II”, zonation level, comprises of additional sources of data obtainable at moderate cost. A very high and detailed zonation level, referred to as “grade III”, typical of site and structural specific studies, is instead judged not to feasible and affordable for investigation on large areas. Once the geotechnical zonation is defined, the TC4-ISSMGE (1999) proposes different methods to account for the local ground motion amplification depending on the parameters employed for the hazard description. When the expected hazard is represented in terms of macroseismic intensity, empirical correlations between the surface geology and the increment of the seismic intensity, based on post-event observations, are proposed. Table 1 shows, as an example, the intensity increments proposed by Medvedev (1962) and Evender and Thomson (1985). Alternatively, relative amplification factors (Midorikawa 1978) related to surface geology are suggested to be adopted when the hazard is represented in terms of peak ground acceleration or spectral ordinates.

Table 1: Intensity increments $\Delta I$ for geology units (from TC4-ISSMGE,1999)

<table>
<thead>
<tr>
<th>Medvedev (1962)</th>
<th>$\Delta I_{M.S.K.}$</th>
<th>Evernden and Thomson (1985)</th>
<th>$\Delta I_{M.M.}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granites</td>
<td>0</td>
<td>Granitic &amp; metamorphic rocks</td>
<td>0</td>
</tr>
<tr>
<td>Limestone, Sandstone, Shale</td>
<td>0.2±1.3</td>
<td>Paleozoic Rock</td>
<td>0.4</td>
</tr>
<tr>
<td>Gypsum, Marl</td>
<td>0.6±1.4</td>
<td>Early Mesozoic rocks</td>
<td>0.8</td>
</tr>
<tr>
<td>Coarse-material ground</td>
<td>1±1.6</td>
<td>Cretaceous to Eocene rocks</td>
<td>1.2</td>
</tr>
<tr>
<td>Sandy Ground</td>
<td>1.2±1.8</td>
<td>Undivided Tertiary rocks</td>
<td>1.3</td>
</tr>
<tr>
<td>Clayey Ground</td>
<td>1.2±2.1</td>
<td>Oligocene to middle pleocene rocks</td>
<td>1.5</td>
</tr>
<tr>
<td>Fill</td>
<td>2.3±3</td>
<td>Pliocene-Pleistocene rocks</td>
<td>2</td>
</tr>
<tr>
<td>Moist ground (gravel, sand, clay)</td>
<td>1.7±2.8</td>
<td>Tertiary volcanic rocks</td>
<td>0.3</td>
</tr>
<tr>
<td>Moist fill and soil ground</td>
<td>3.3±3.9</td>
<td>Quaternary volcanic rocks</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alluvium (water table&lt;30ft)</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alluvium (30ft&lt;water table&lt;100ft)</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alluvium (100ft&lt;water table)</td>
<td>1.5</td>
</tr>
</tbody>
</table>

On a similar trend, the handbook for earthquake ground motion scenarios (Faccioli and Pessina, 2003), prepared within the framework of the European project Risk-UE (2004) distinguishes between two different levels of approaches depending on the data and information available as well as on the scope of the scenario study. In particular, a “level I” zonation can be obtained by the interpretation of the near-surface formations from the geological map in terms of approximate geotechnical units, using available geotechnical parameters, or some seismic response measure. A “level II” approach requires, instead, that as much data as possible on the subsoil are collected from public and private sources. Useful data for the latter level could be given by soil borings, water wells, field geophysical investigations, geotechnical laboratory tests and geotechnical borings, especially when reaching formations regarded as “seismic bedrock”. The collected data has to be careful selected, assembled and processed according to different steps that allow to draw contours of the shear wave velocity in the uppermost 30 m ($V_{S30}$), throughout the analysed area. The approximate geotechnical units defined either according to a level I approach and to the $V_{S30}$ contours resulting from the level II approach can then be rearranged according to the typical soil classifications adopted in code standards. According to this document, the local ground motion amplification can be accounted for as follows, depending on the parameters employed for the hazard description: a) when the expected hazard is represented in terms of macroseismic intensity, an increment of 0.5 intensity degree ($\Delta I=0.5$) is suggested for medium stiff clays and medium dense cohesionless soils when compared to the stiff soils and rock benchmark, in line with what suggested by Bard (1998); b) when the hazard
is represented in terms of physical parameters, elastic response spectra $S_{ae}(T)$ derived from code provisions or predictive equations, have to be directly related to classes of soil.

**Effects of alternative approaches for the definition of site effects: a case study**

It is evident that the different proposals available in literature as well as, within the same method, the different levels of refinement achievable to assess the geotechnical hazard can lead to substantially different representation of the zonation and of the amplification effects. As an example, a comparison of the effects of the implementation of the two previously described methods (TC4-ISSMGE, 1999 and WP2-handbook by Faccioli and Pessina, 2003) on the microzonation of a specific area is carried out and herein discussed with reference to a case study. The region is represented by the Argentina Valley (Western Liguria, Italy), an area of about 30 Km$^2$, along the Argentina River, characterized by geological and topographic heterogeneity (Isella et al. 2004). Based on the available geological-geomorphological map (Fig.1) a level/grade I zonation has been performed according to both the methodologies.

Figure 1: Geological-geomorphological map of the Argentina Valley and identification of noise measurements (red points) and velocimetric stations (blue stars)

Figure 2: Level-I zonation for the Argentina Valley according to: a) Midorikawa (1962); b) Evernden and Thomson (1985); c) Faccioli e Pessina (2003)
Figure 2 shows a TC4 grade-I zonation, performed making reference to the available geological-geomorphological map in Figure 1, according to the indications provided by Midorikawa (1978) (Fig. 2-a) and by Evender and Thomson (1985) (Fig. 2-b). Figure 2-c shows a level-I zonation performed according to the handbook for earthquake ground motion scenarios of the Risk–UE project (Faccioli and Pessina, 2003). The near-surface formations of the available geological map (Fig. 1) have been interpreted in terms of approximate geotechnical units corresponding to EC8 (CEN 2003) ground classes.

A level-II zonation, according to the same guidelines, has been drawn (Fig. 3) by using available geophysical profiles and seismic measurements (Isella et al. 2004). In particular, the seismic data set consisted of weak motion recordings, collected by a local temporary network, and of micro-tremor data recorded at 150 noise measurements points (Fig. 1). The method proposed by Nakamura (1989), has been implemented for the evaluation of the site response from the acquired microtremors, in terms of the Fourier spectral ratio of horizontal versus vertical component (H/V spectral ratio). The reliability of the site response estimation so obtained has been cross-validated with the ratio of the horizontal spectra from the weak motion recordings. Moreover, a good agreement has been observed comparing the H/V spectral ratios with the transfer functions obtained from one-dimensional numerical simulations. From the frequencies of the dominant peak in the spectral ratios of horizontal to vertical motion evaluated on the irregular grid of observation points, a continuous map of the fundamental resonance frequency (Fig. 3-a) was derived by interpolation using the features of the Geographical Information System (GIS) software Mapinfo ®. Moreover, the use of the GIS software allowed for the construction of a subsurface model by integrating geological and geophysical profiles (Fig 3-b), available from a previous study (Peloso et al.1998). The subsurface model led to the definition of a map of the soil thickness. The average shear wave velocity in the uppermost 30 m Vs30 map (Fig 3-c) was obtained, for the studied region, combining the information provided by the frequency and the thickness maps.

For the same area and relying on the same set of available data, a level-II microzoning has been performed in terms of resonance frequencies (Pelli et al. 2006), considered a more reliable parameter for soil classification than Vs30 (Eva et al. 2006).
Local ground motion amplification due to surface irregularities
A further main source of local amplification is due to surface irregularities. Amplification factors are available in code provisions when the seismic intensity is described in terms of peak ground acceleration or spectral ordinates. In the EC8, factors $f_a$ in the range of 1.2 ÷ 1.4 have been derived from numerical simulations on different irregular profiles. Results of refined numerical 2D and 3D simulations of the expected ground motion amplification in the real case of four steep topographic configurations (Paolucci et al., 2002) provided satisfactory confirmations of these values (Table 2).

Table 2. Topographic amplification factors suggested by Paolucci et al. (2002).

<table>
<thead>
<tr>
<th>Site morphology</th>
<th>EC8</th>
<th>3D</th>
<th>2D SH</th>
<th>2D SV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated Cliff</td>
<td>1.2</td>
<td>1.3</td>
<td>1.22</td>
<td>1.22</td>
</tr>
<tr>
<td>Ridge crest width &lt;&lt; base width average slope angle &gt; 30°</td>
<td>1.4</td>
<td>1.58</td>
<td>1.18</td>
<td>1.32</td>
</tr>
<tr>
<td>Ridge crest width &lt;&lt; base width average slope angle &lt; 30°</td>
<td>1.2</td>
<td>1.25</td>
<td>1.09</td>
<td>1.28</td>
</tr>
</tbody>
</table>

In order to empirically derive intensity increments ($\Delta I$) for a hazard assessment in terms of macroseismic intensity, the evidence of topographic amplification have to be found within available data from historical earthquakes. Based on the macroseismic observations of the 1887 Western Liguria earthquake event, Faccioli et al. (2002) have established that within an epicenter distance of few tenths of kilometers, amplification on markedly irregular topography (i.e. hilltop, crests and severely sloping ground) can in general lead to an intensity increment $\Delta I = 1$ and, only exceptionally, to $\Delta I = 1.5$ or more (Fig. 4-a).

Within a seismic risk analysis or scenario study, the shape profile and the slope angle of the surface irregularities can be directly evaluated by using a GIS-based software, assuming that a Digital Elevation Model (DEM) is available for the target region (Fig. 4-b).

![Figure 4](image)

Figure 4: Ground motion amplification due to surface irregularities: a) macroseismic intensity increments from historical data (Faccioli et al. 2002); b) DEM of Western Liguria Region and identification of villages (red lines) on markedly irregular sites

Earthquake-induced geotechnical hazard
The impact of induced hazard, such as significant soil permanent deformations, rock falls and landslides, ground settlements and ruptures due to liquefaction and lateral soil spreading, has to be accounted for within a seismic risk analysis. Due to the diversity and complexity of such phenomena, further developments are in general still required for the definition of accurate while simplified methods to be implemented in a seismic risk analysis framework.
A first step in the investigation would consist of searching for historical evidences of earthquake induced liquefaction and landsliding phenomena within, or in the vicinity of an analyzed area (Faccioli and Pessina, 2003). In addition, loose, water saturated artificial fills in correspondence of old river (or creek) beds, characterized by the presence of 3-5 m or more of soft soil, should be accurately mapped (also according to the EC8) as highly vulnerable sites for permanent ground deformation and soil failures. On the other hand, highly vulnerable sites for seismically trigger landslides are the ones where slopes are predominantly subject to frictional types of failures. Examples of simplified procedures for the evaluation of earthquake-induced landslides and liquefaction phenomena within seismic risk analysis can be found in Siyahi and Ansal (1993), within TC4-ISSMGE, and Bird et al. (2006), respectively.

FORMULATION OF PERIOD-DEPENDENT SITE EFFECT AMPLIFICATIONS

Period dependent site effect amplifications for a mechanical-based vulnerability method

When a mechanical-based approach is adopted for the vulnerability assessment, such as the capacity spectrum method, implemented within HAZUS (NIBS 1999) and Risk-UE project (2004), the hazard is described in terms of an elastic response spectra $S_{ae}(T)$ for different classes of soil, thus directly allowing for the evaluation of period-dependent site effects.

As mentioned in the previous paragraph, both soil conditions and morphological properties can be taken into account directly by assuming and properly modifying pre-defined spectral shapes. However, when elastic response spectra need to be derived by predictive equations (attenuation laws), only a discrete numbers of the fundamental period are available. In the latter case, as discussed in Giovinazzi (2005), the definition of the characteristic period $T_C$, which defines the starting point of the decay of the spectral acceleration ordinates, can be of significant importance when trying to implement a closed-form solution for the evaluation of the performance point. In this case, the definition of the characteristic period $T_C$ is subjected to various proposals, i.e HAZUS (NIBS 1999) and Giovinazzi (2005).

Period-dependent site effect amplifications for macroseismic vulnerability method

On the other hand, when the seismic hazard is represented in terms of macroseismic intensity, soil amplifications can be taken into account by increasing, locally, the intensity, $I$, evaluated on the bed-rock. However, such approaches do not account for the differences in the dynamic amplification related to the fundamental frequencies of both the soil and the structure, nor due to more complex soil structure interaction effects.

In order to overcome these limitations, an alternative method has been proposed by Giovinazzi and Lagomarsino (2004) where macroseismic intensity increments are derived via “peak ground acceleration multiplier factors” $f_{ag}$ defined for different building types and soil condition. Referring to a predefined spectral shape provided by seismic code prescriptions, the factor $f_{ag}$ is evaluated as the ratio between the elastic response spectrum $S_{ae}$ evaluated for the fundamental period $T$ for a certain soil class $k$, $S_{ae}(T)_k$, and the elastic response spectrum $S_{ae}$ evaluated for the fundamental period $T$ and for rock conditions, $S_{ae}(T)_\lambda$, (Eq. 1).

$$f_{ag} = \frac{S_{ae}(T)_k}{S_{ae}(T)_\lambda}$$

An appropriate estimation of the elastic period of the structures is thus required as a first step. In this contribution, the evaluation of peak ground acceleration amplification factors have been derived for different type of buildings, i.e. unreinforced masonry (URM), pre-1970s reinforced concrete (RCp) and reinforced concrete buildings designed according to more recent seismic...
code previsions (RC) are distinguished. For each building typology the fundamental period $T$ has been evaluated according to the following Eq. 2:

$$T = \alpha H^\beta$$  

(2)

where $H$ is the building height, evaluated assuming: an average number of floors $N$ as representative of low (_L), medium (_M) and high-rise (_H) buildings ($N=2, 4, 6$ and $N=3, 5, 8$ respectively for masonry and reinforce concrete types), a characteristic inter-storey-drift for each typology ($h=3$m for masonry types, $h=3.5$m for reinforce concrete ones), $\alpha$ and $\beta$ are coefficients differently specified depending on the building typology. In particular, $\alpha=0.05$, $\beta=0.75$ for masonry types and $\alpha=0.075$, $\beta=0.75$ for well-designed r.c. buildings according to EC8 prescriptions, while $\alpha=0.065$ and $\beta=0.9$ for reinforced concrete buildings designed prior to the introduction of modern seismic prescriptions (in the mid-1970 in most seismic prone countries), in order to accounting for the extensive cracking of the structural members and thus obtain a conservative estimation of the building displacement demand (Chopra and Goel 1999).

The so derived $f_{ag}$ factors can be also translated in terms of intensity increments $\Delta I$ by assuming a correlation between the macroseismic intensity $I$ and the peak ground acceleration $a_g$ ($I-a_g$). A generalized expression of the $I-a_g$ correlations, able to fit most of the relationships proposed in literature, can be suggested in the form of:

$$a_g = c_1 c_2^{(I-I_o)}$$

(3)

where $c_1$ represents the peak ground acceleration value $a_g$ corresponding to the reference intensity $I_o$ and $c_2$ measures the rate of increase of the peak ground acceleration $a_g$ with the intensity $I$. Given the expression above, the intensity increment $\Delta I$ corresponding to the $f_{ag}$, derived according to Eq. 1, can thus be evaluated as:

$$\Delta I = \frac{\ln f_{ag}}{\ln c_2}$$

(4)

Table 3 shows the $f_{ag}$ factors and the corresponding $\Delta I$ values (when assuming $c_1=0.03$, $c_2=1.6$ for the $I-a_g$ correlation) referred to the EC8 spectral shape for a magnitude $M_s$ greater than 5.5. Alternatively, predictive equations (law attenuation) can be used. Table 4 shows the $f_{ag}$ factors and the corresponding $\Delta I$ increments when using the predictive equations (attenuation laws) proposed by Ambraseys et al. (1996), which provide acceleration response ordinates for discrete values of the fundamental period $T$ and refers to four soil classes almost coincident with the EC8 classification. It is worth noting that the $f_{ag}$ factors and the $\Delta I$ increments are invariable for different values of the magnitude $M$ and of the site-source distances $R$.

When comparing the $f_{ag}$ values evaluated according to the two methods, it can be noted that the latter ones are lower and in general less sensitive to the fundamental period $T$ of the structure type. On the other hand, both peak ground acceleration factors $f_{ag}$ and macroseismic intensity increments $\Delta I$ are consistent with those proposed by Evender and Thomson (1985) and shown in Tab. 1 as well as with the amplification factors defined by Midorikawa (1987) and suggested by TC4-ISSMGE.
Table 3. $f_{ag}$ factors and macroseismic intensity increments $\Delta I$ evaluated according to EC8 type 1 spectrum (Ms>5.5), for the different soil classes and for different building categories

<table>
<thead>
<tr>
<th>N</th>
<th>h[m]</th>
<th>T[s]</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
</tr>
</thead>
<tbody>
<tr>
<td>URM_L</td>
<td>2</td>
<td>3</td>
<td>0.19</td>
<td>1.20</td>
<td>1.15</td>
<td>1.35</td>
<td>1.40</td>
<td>0.4</td>
<td>0.3</td>
<td>0.6</td>
</tr>
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<td>URM_M</td>
<td>4</td>
<td>3</td>
<td>0.32</td>
<td>1.20</td>
<td>1.15</td>
<td>1.35</td>
<td>1.40</td>
<td>0.4</td>
<td>0.3</td>
<td>0.6</td>
</tr>
<tr>
<td>URM_H</td>
<td>6</td>
<td>3</td>
<td>0.44</td>
<td>1.31</td>
<td>1.26</td>
<td>1.47</td>
<td>1.53</td>
<td>0.6</td>
<td>0.5</td>
<td>0.8</td>
</tr>
<tr>
<td>RC_L</td>
<td>3</td>
<td>3.5</td>
<td>0.44</td>
<td>1.31</td>
<td>1.26</td>
<td>1.48</td>
<td>1.53</td>
<td>0.6</td>
<td>0.5</td>
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</tr>
<tr>
<td>RC_M</td>
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<td>3.5</td>
<td>0.64</td>
<td>1.50</td>
<td>1.73</td>
<td>2.17</td>
<td>1.75</td>
<td>0.9</td>
<td>1.2</td>
<td>1.6</td>
</tr>
<tr>
<td>RC_H</td>
<td>8</td>
<td>3.5</td>
<td>0.91</td>
<td>1.50</td>
<td>1.73</td>
<td>2.70</td>
<td>1.75</td>
<td>0.9</td>
<td>1.2</td>
<td>2.1</td>
</tr>
<tr>
<td>RCp_L</td>
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<td>3.5</td>
<td>0.54</td>
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<td>1.55</td>
<td>1.82</td>
<td>1.75</td>
<td>0.9</td>
<td>0.9</td>
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<td>2.1</td>
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<tr>
<td>RCp_H</td>
<td>8</td>
<td>3.5</td>
<td>1.30</td>
<td>1.50</td>
<td>1.73</td>
<td>2.70</td>
<td>1.75</td>
<td>0.9</td>
<td>1.2</td>
<td>2.1</td>
</tr>
</tbody>
</table>

Table 4. $f_{ag}$ factors and macroseismic intensity increments $\Delta I$ evaluated according to Ambraseys et al. (1996) predictive equation, for the different soil classes and for different building categories

<table>
<thead>
<tr>
<th>N</th>
<th>h[m]</th>
<th>T[s]</th>
<th>f_{ag}</th>
<th>$\Delta I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>URM_L</td>
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<tr>
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<td>3</td>
<td>3.5</td>
<td>0.54</td>
<td>1.40</td>
</tr>
<tr>
<td>RCp_M</td>
<td>5</td>
<td>3.5</td>
<td>0.85</td>
<td>1.34</td>
</tr>
<tr>
<td>RCp_H</td>
<td>8</td>
<td>3.5</td>
<td>1.30</td>
<td>1.29</td>
</tr>
</tbody>
</table>

**Representation of the site effects amplifications related to the exposed built environment**

As underlined in paragraphs 3.1 and 3.2, in the framework of a seismic risk analysis, the geotechnical zonation has to be interfaced with the characteristics of the exposed building stock (building type and height). A minimum common unit of analysis has to be identified amongst the building data units and the soil characterization (geotechnical) units.

When data are available on each single building (Fig 5-a), the soil conditions underneath the analyzed building can be used to evaluate the corresponding intensity increment $\Delta I$ or, similarly, a soil amplification factor $f_{ag}$ as a function both of the identified soil class and the type and height of the building.

When statistical data are available on small areas, e.g. census tracts, these have to be split into portions corresponding to the different soil categories therein identified (Fig. 5-b). Figure 6-b shows the census tract number 0028 of the Taggia town (in Argentina valley), split in 5 portions in order to account for its non-homogeneous soil conditions. Centroid of these portions are therefore adopted as reference grid-points for the hazard evaluation and for the representation of...
the ground motion amplification due to soil conditions (either in terms of increments $\Delta I$ for the macroseismic intensity or in terms of amplification factor $f_{ag}$ for response spectra).

**EFFECTS OF ALTERNATIVE GEOTECHNICAL ZONATION APPROACHES ON THE ESTIMATION OF LOSSES**

A damage scenario analysis performed on a real study case is a very effective way to show the impact on the final results (expected consequences and uncertainties characterizing their estimation), of a geotechnical zonation performed according to different approaches and for different level of knowledge (information) available on the local site conditions. As a first step, these effects can be appreciated by comparing fragility curves or expected probabilities of exceeding pre-defined levels of damage ($D_k$) or potential consequences thresholds. Figure 6 shows, as an example, the effects of different soil conditions (represented in terms of EC8 soil classes) on the expected levels of damage ($D_k$) to existing buildings; the local ground motion amplification that have been considered are the ones derived from EC8 predefined spectral shape (according to what described before) assuming a value of the EMS-98 macroseismic intensity (Grunthal 1998) $I_{\text{EMS-98}}=\text{VIII}$ evaluated on rock soil condition. The results are herein shown for the class of medium rise unreinforced masonry buildings as defined in Table 3.

It is worth noting the substantial changes in the expected damage distribution, with higher probabilities of achieving the higher damage levels $D_k$ (e.g. moving from $D_k=2$ to $D_k=3$) and a substantial increase in the probability of reaching a heavy damage grade $p[D_k=4]$ beyond reparability level. Fragility curves can similarly provide a useful confirmation of these results. Figure 7 shows fragility curves related to the expected collapses (Fig. 7-a) and uninhabitable
(unfit for use - UfU) buildings (Fig. 7-b), for medium-rise masonry building types, built on different soil conditions.

![Fragility curves for medium rise masonry buildings built on different soil classes (A, B, D according to EC8 prescriptions: a) unfit for use (UfU) buildings, b) collapsed (D5) buildings](image)

Figure 7. Fragility curves for medium rise masonry buildings built on different soil classes (A, B, D according to EC8 prescriptions: a) unfit for use (UfU) buildings, b) collapsed (D5) buildings

It is evident how a poor or improper definition of the geotechnical zonation and site conditions can play a major role within a seismic risk analysis at a territorial scale. Considering the impact and critical role of such analyses as a support to the decision making within urban or regional risk mitigation strategies (including seismic retrofit solutions), it can be argued that an appropriate reduction of the uncertainties related to the geotechnical hazard within a seismic risk framework can lead to more crucial and tangible benefits than in the case of the seismic response of a single building.

**CONCLUSIONS**

An appropriate representation of the geotechnical hazard, able to account for both the local ground motion amplification due to soil and morphological conditions as well as the induced potential hazards (e.g. liquefaction ground settlements and landslides phenomena) is a critical step of refined seismic risk scenario study. Lack of appropriate information as well as scarce zoning characterization can lead to substantially un-conservative results in terms of assessment of the seismic risk, thus impairing the implementation of cost-efficient risk mitigation strategies. In this contribution, focus has been given on the discussion of alternative methods for the evaluation at territorial scale of site effects due to soil and morphological conditions. An example of the effects of implementing different geotechnical zonation methods has been provided with reference to a case-study, identified with the Argentina Valley (Western Liguria, Italy). Significant differences have been observed in terms of either the microzoning maps as well as of the quantitative representation of the amplification effects.

Alternative methods able to account for either the soil conditions and the characteristics of the built environment have been also discussed, proposing different formulations depending on the vulnerability methods adopted. In particular, when a macroseismic vulnerability approach is used, macroseismic intensity increments ΔI can be evaluated for different building typologies and soil classes, referring to either seismic code response spectra or to attenuation laws available in literature. As a first phase of a more comprehensive analytical investigation undergoing, the influence of the geotechnical zonation on the results of a risk analysis have been shown in terms of the variation of the expected distribution of damage and casualties. A seismic risk analysis of a case study is undergoing and will be presented in future publications, in order to compare and discuss the difference on the results depending on higher refinement of the seismic zonation representation.
REFERENCES


