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The ASSESS project: assessment for seismic risk reduction of school buildings in the Friuli Venezia Giulia region (NE Italy)

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ABSTRACT The seismic risk reduction of important community buildings and critical facilities is one of the most delicate problems that administrators are being asked to tackle. The ASSESS project, aimed at assessing the seismic risk of school buildings in the Friuli Venezia Giulia region (NE of Italy), is a prototypal study, developed on sound technical and scientific bases, and useful for defining decision-making tools for preventive purposes. In particular, the ASSESS methodology identifies the possible actions for improving seismic safety, it makes an economic evaluation of these actions, and, moreover, defines through specific indicators the intervention priorities for reducing the seismic risk of school buildings throughout the studied area.

Key words: decision making support, seismic safety, seismic risk, school buildings, Friuli Venezia Giulia, NE Italy.

1. Introduction

In a seismic area, a major concern of the public administrators is to ensure the safety of people in the case of earthquake, especially in public buildings and, in particular, in school buildings. In practice, public authorities face a complex problem and are challenged to answer difficult questions: "Which school should be retrofitted first? Why? What type of intervention is needed? What level of safety can be achieved? What is the cost of the intervention? What kind of retrofit is feasible with the available resources? How should the most difficult cases be dealt with? How should the estimated level of risk be communicated to the population?". These questions point out that the definition of a rational and effective strategy for seismic risk mitigation needs to assess in advance the level of risk along with the weaknesses and/or elements of concern for public safety, and the necessary countermeasures and related costs both at the level of a single building and globally.

This problem has been addressed in the ASSESS project [Analysis of Seismic Scenarios of School Buildings for a definition of intervention priorities for Seismic risk reduction - see Grimaz *et al.* (2010, 2012) and Slejko *et al.* (2012)], aimed at knowing, as a preventive measure, the level of seismic risk of school buildings in the Friuli Venezia Giulia region (north-eastern Italy). The project, based on an interdisciplinary and holistic approach, has led to the development of specific and innovative decision-making tools aimed at helping public administrators in the development and management of strategies for seismic risk mitigation of schools.

2. Analysis of schools in terms of safety

Public administrators, facing the problem of seismic risk mitigation in school buildings, should be asking: "What does public safety mean in the case of an earthquake?". The question may seem trivial, but it allows us to deal with the problem from the correct point of view. In fact, if we pay attention to the safety of people, we have to consider all the situations that, in the case of a seismic event, can cause injury or death. This approach determines that an interdisciplinary and holistic approach to the problem is not only appropriate but also necessary. It is well known that risk depends on three components: hazard, vulnerability, and exposed value; the problem, therefore, must be approached with an interdisciplinary methodology. In particular, when it is necessary to identify intervention priorities to reduce risk, all three components need to be considered simultaneously and attention must be focused on the evaluation of the consequences. In other words, to define effective intervention strategies, a preliminary global assessment of the expected damage is necessary, especially if the facilities are spread over a vast territory possessing several different geological and seismotectonic scenarios. The situations where the greatest dangers arise are, in fact, well known: they are caused by landslides, induced liquefaction phenomena, or simply by disruption of roads or other basic services (electricity, gas, water, sewer), sometimes even more dangerous than the structural damage caused by seismic shaking itself.

In the preliminary stages of study planning, in order to better allocate the available resources (time and money), it is necessary to find the right balance between the level of detail required by the investigation and the level of knowledge necessary to provide it. Often, it is not sufficient to use available public data (e.g., census data) because the evaluation can be affected by statistical uncertainties inherent in the methodology used, and sometimes the same statistical data can be affected by errors. On the other hand, specific structural analyses can sometimes be unnecessary for the evaluation of situations of greater risk; for these cases, given that checks are costly in terms of time and money, it is preferable to proceed directly with intervention. In order to establish priorities in the use of the available resources, it is sometimes appropriate to address the problem with an intermediate level of analysis: sufficiently detailed in order to provide robust results, but as cheap and fast as possible. In practice, these considerations suggest the adoption of a multi-level approach of survey and evaluation.

Public administrators need practical tools to handle the various situations as a whole; at the same time, however, it is important to know and evaluate all the essential elements needed to define an effective and contextualized strategy for risk mitigation. This requires the adoption of a global approach usable at various scales (single building, set of buildings located in a defined geographical area, etc.) and with reference to different homogeneous groups (owner of building, type of construction, type of intervention, etc.).

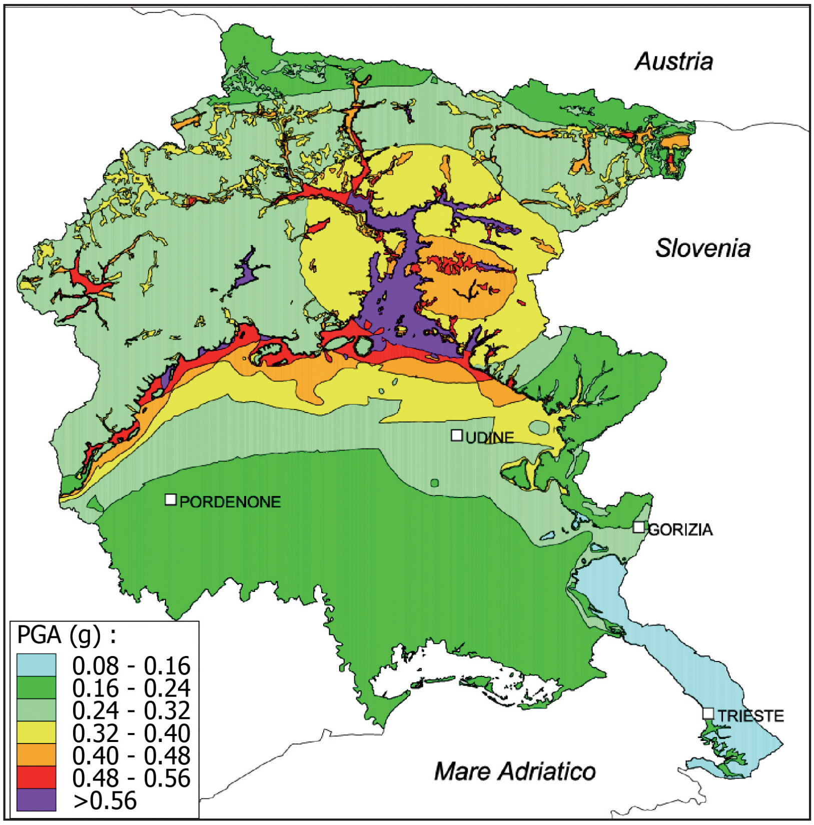


Fig. 1 – Soil-hazard map calculated as part of the project aimed at estimating the seismic risk in the Friuli Venezia Giulia region. The map was obtained by averaging the results achieved using two different methodologies to estimate the local litho-stratigraphic amplification (modified from Carulli *et al.*, 2002).

3. Previous studies of seismic risk in Friuli Venezia Giulia

The Civil Protection agency of the Friuli Venezia Giulia Region funded two seismological studies of regional significance in the years 1998-2008: the first was intended to assess the seismic risk for masonry residential private buildings (Carulli *et al.*, 2003), and the second was devoted to the review of the regional seismic zonation (Slejko *et al.*, 2011).

The estimation of regional seismic hazard played a key role in both studies. More precisely, seismic hazard maps at different levels of detail were developed: the rock-hazard map refers to a uniform rocky soil, the soil-hazard map considers the type of litho-stratigraphic specific soil present at the site, and the site-hazard map takes also into account the morphological characteristics of the site.

The soil-hazard map (Rebez *et al.*, 2001; Carulli *et al.*, 2002), which was used for the evaluation of the regional seismic risk (Carulli *et al.*, 2003), was obtained as the average of the values calculated using two different approaches (Fig. 1). The first considered different attenuation relationships for different soil types (rock, stiff soil, and soft soil) while, in the second, amplification factors (AFs) were calculated using simplified 1D modelling on the basis of local stratigraphic data and were applied to the various terrains present in the region.

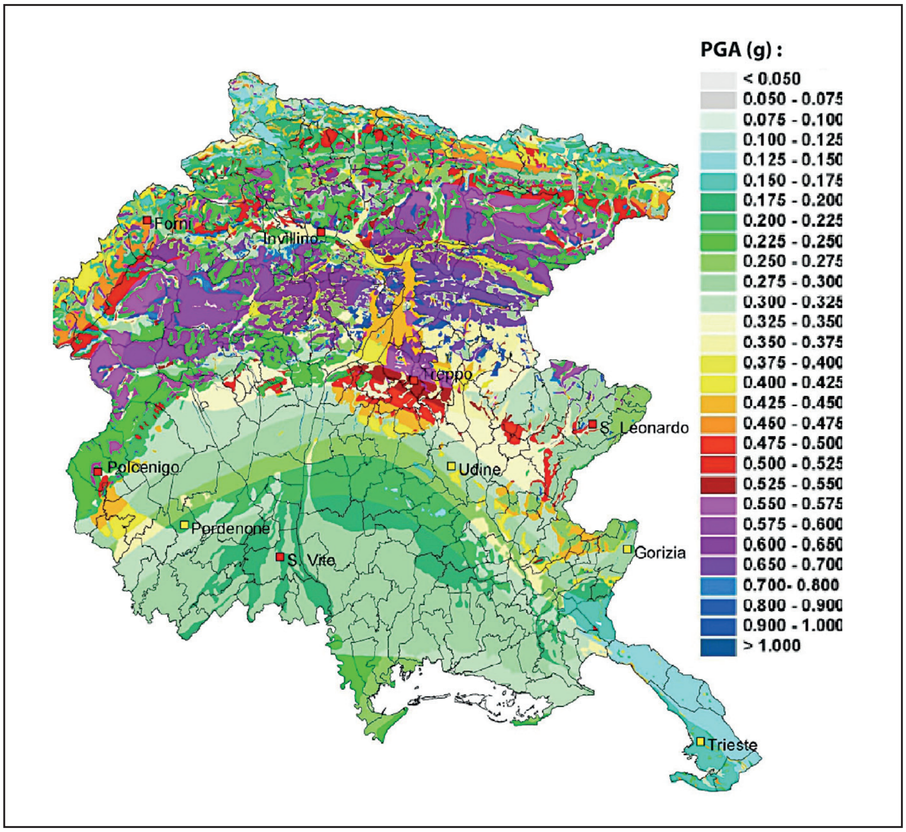


Fig. 2 – Site-hazard map calculated as part of the project aimed at revising the seismic zonation of the Friuli Venezia Giulia region. The map was obtained by taking into account both the local litho-stratigraphic and the geo-morphological amplifications (modified from Slejko *et al*., 2011).

In the site-hazard map, calculated in the study for the revision of the regional seismic zonation (Slejko *et al*., 2011), both litho-stratigraphic and morphological amplifications were taken into account and the associated AFs were estimated on the basis of regional geological, geophysical, and geotechnical data (Fig. 2). More precisely, specific geophysical surveys (down-hole, cross-hole, geoelectric soundings, and ambient noise measurements) were performed to characterize the local stratigraphy and to estimate the local litho-stratigraphic AFs by 1D or 2D modelling. The morphological AFs were, instead, obtained with statistical procedures, based on the damage suffered by buildings during the 1976 Friuli earthquake (Grimaz, 2009). It is worth noting that this study, like the previous one, was affected by the objective limit represented by the use of a small number of local measurements related to specific or limited portions of territory, and the results were applied to large-scale modelling.

The comparison between the two soil-hazard and site-hazard maps, prepared in different times and with different methodologies, showed the large influence of the AFs in the definition of the local shaking at the free surface. As a consequence, it became essential to identify a methodology suitable for achieving robust results for wide areas based on a limited number of detailed surveys.

The two studies mentioned above, made it clear that a strong variability of the local seismic hazard exists in the Friuli Venezia Giulia region. This aspect suggests paying particular attention to the definition of the specific level of expected ground shaking at the various sites, especially when a ranking of the expected damage is required for buildings or structures spread over a relatively large geographical area, as, for example, the school buildings in the study region.

4. The ASSESS project

The ASSESS project (Grimaz *et al.*, 2010; Slejko *et al.*, 2012) was funded by the Civil Protection agency of the Friuli Venezia Giulia Region in order to study the seismic risk of school buildings and define the intervention priorities for seismic risk reduction. ASSESS was developed over a period of three years. The survey and evaluation activities were structured and developed to assess the overall situation in terms of level of risk and intervention needs for each school building, through a limited number of indicators identified by way of a holistic approach, considering at the same time hazard, vulnerability, and exposed value.

The ASSESS project was inspired by many existing projects which evaluate the seismic safety of buildings with different investigation strategies and at different territorial scales. Some of these projects rely on data-mining methodologies, and are based on desk data (e.g., Mouroux and Le Brun, 2006, Grant *et al.*, 2007). Other projects are based on a rapid and visual collection of data [e.g., Rapid Visual Screening: FEMA 154, (2002)]. Very specific projects and methodologies rely on detailed evaluations of the conditions of each structure and on specific models and structural simulations [see Calvi *et al.* (2006), for an overview]. The ASSESS project adopts an intermediate approach to work at a territorial level on a large number of buildings in order to provide specific guidance to decision-makers in the definition of safety upgrading strategies.

In accordance with the approach of the ASSESS project, the study was organized on three levels of detail (Fig. 3). Level 1 (desk analysis) was based only on existing official documents, referring to the national seismic hazard map (Stucchi *et al.*, 2011) for the expected ground shaking, and to the Italian national census of schools (MIUR, 1996) for building vulnerability. The census collects information on 1,022 schools in the Friuli Venezia Giulia region. At Level 2 (expeditious analysis), the ground shaking was calculated by 1D modelling (Sanò and Pugliese, 1991) calibrated on site-specific velocity profiles, and the building vulnerability was estimated on the design documents of the building jointly with visual inspections carried out through a survey method developed *ad hoc* as part of the project (Grimaz *et al.*, 2011b). At Level 3 (detailed analysis), the structural behaviour of the building was assessed through detailed structural modelling. All assessments were carried out with the aim of identifying any element of concern for public safety in the event of an earthquake, and to indicate the relative intervention needed.

All of the 1,022 schools located in the Friuli Venezia Giulia region were analyzed at Level 1 (Fig. 4), for 10% of them the analysis was carried out at Level 2, for 10% of the latter the analysis was upgraded to Level 3.

The multilevel approach has proved to be very useful for identifying the cases where a higher level of investigation was opportune. Basically, with the ASSESS approach, the results of the evaluations obtained at Level 1 drove the choice of the buildings on which it was necessary to perform the Level 2 analysis. Furthermore, Level 2 results guided the identification of the buildings on which it was suggested to apply the Level 3 analysis in order to have a good test of the results obtained at Level 2.

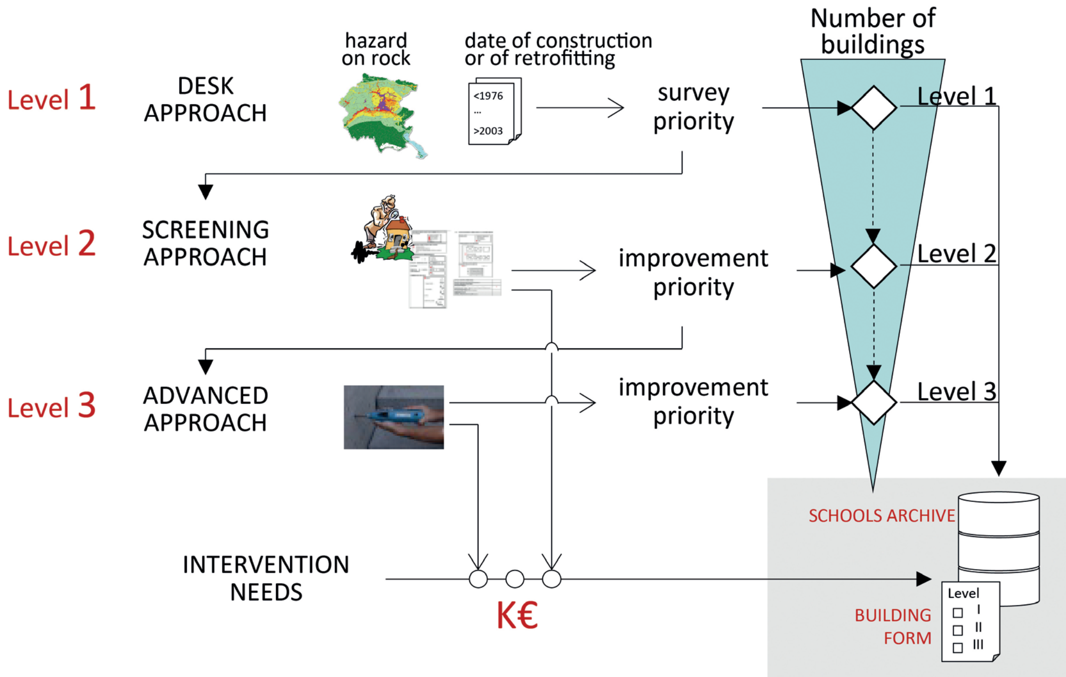


Fig. 3 – The three levels of the ASSESS project: all schools are evaluated at Level 1 (desk analysis), 10% of them at Level 2 (expeditious analysis), and 1% at Level 3 (detailed analysis).

4.1. The Level 1 analysis

The Level 1 analysis is based on documentary data used to define the ground motion at the site as well as to characterize the building vulnerability.

At Level 1, an "Index of Damageability" (I_D) was estimated for each of the 1,022 schools, on the basis of the information available in the database built as part of the ASSESS project and also containing the data of the Italian national census of school buildings (MIUR, 1996). I_D is defined using the macroseismic method [already adopted in the European Risk-UE project (Spence and Le Brun, 2006)], which allows us to make a prediction of the average expected damage, expressed in terms of the European macroseismic scale EMS98 (Grünthal, 1998). In particular, according to the building features and the local hazard where it is located, the use of a statistical formula proposed by Lagomarsino and Giovinazzi (2006) allowed us to estimate the level of average expected damage.

Furthermore, a geological-technical map with related explanatory notes was prepared for an area of 0.25 km^2 (a square with a 500-m side with the building placed in its centre) to characterize each site where school buildings are located. In this area, the geological, geomorphological, and hydrogeological characteristics were represented together with the main lithological-technical units, defined by taking into account the geotechnical and geomechanical behaviour of the material characterizing the first few superficial metres (loose deposits and rock) and the structural elements according to the type of movement (stratification, faults, folds, and overthrusts). All these aspects, in fact, can contribute to define potential causes of seismic

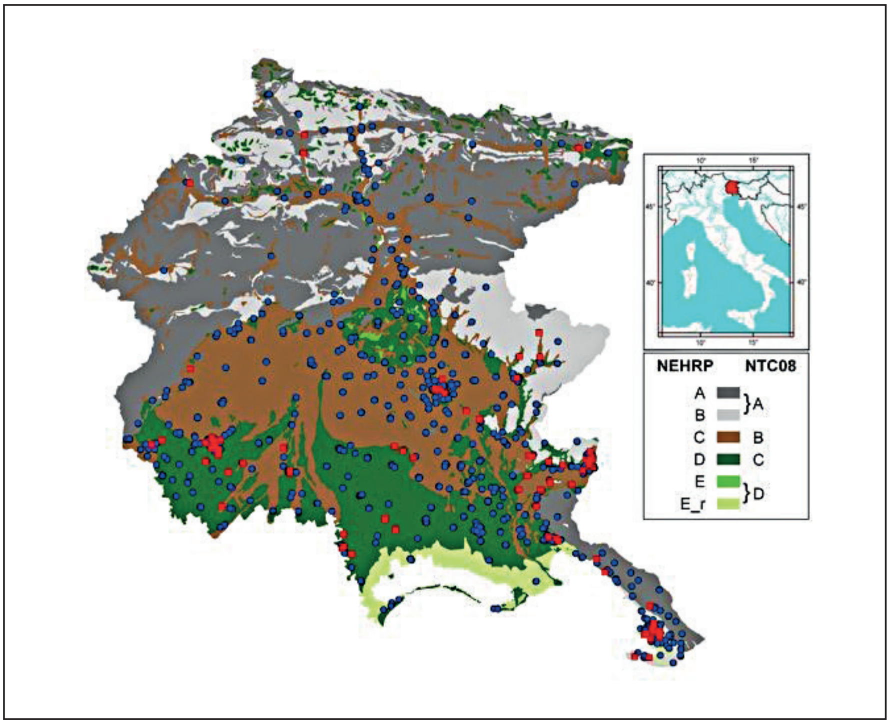


Fig. 4 – Geographical distribution of the schools studied: the blue dots represent the location of the school buildings analysed at Level 1, the red squares that of the school buildings analysed at Level 2. The colours in the legend identify the soil type according to the U.S. NEHRP seismic provisions (BSSC, 2004) and the Italian seismic law NTC-2008 (Ministro delle Infrastrutture, 2008).

amplification, especially in the epicentral areas (Grimaz and Malisan, 2014). The sediments were represented as a function of particle size and origin, while the rocks were defined according to their litho-stratigraphic characteristics and discontinuities. The litho-stratigraphic units were divided into rock and soft sediment as a function of the shear wave velocity [> 800 m/s for rock and ≤ 800 m/s for soft sediments, as reported by the Italian seismic code NTC-2008 (Ministro delle Infrastrutture, 2008)]. The geomorphological features (terraces, river embankments, morainic and water table deposits, etc.), hydrological (natural and artificial river network, isopiezometric contours, flooded areas, etc.), and landslides (landslide niches, punctual landslides, areas of accumulation of landslides, debris flow, areas prone to collapse and areas with widespread instability both on rock and soft deposits) were also shown on the map (Biolchi *et al.*, 2011). Additional information, such as a stratigraphic column representing the superficial 30 m of soil, data on landslide hazard and/or flooding, geophysical information on the subsoil, the depth of the water table subdivided into three classes (<10 m, 10-30 m, >30 m), the deep trend of the bedrock, and the geomorphological scenario of the area where the school building is located are also reported on the map. The possibility that liquefaction phenomena could occur was pinpointed in cases of a subsoil characterized by the presence of sand and with depth of the water table less than 15 m. Fourteen scenarios (geomorphotypes) were defined from the geomorphological point of view (Fig. 5) in order to represent the geometric relationships between rock and soft sediments along with the slope or trend of the bedrock. The geomorphotypes were defined for the entire Friuli Venezia Giulia region and were plotted on a

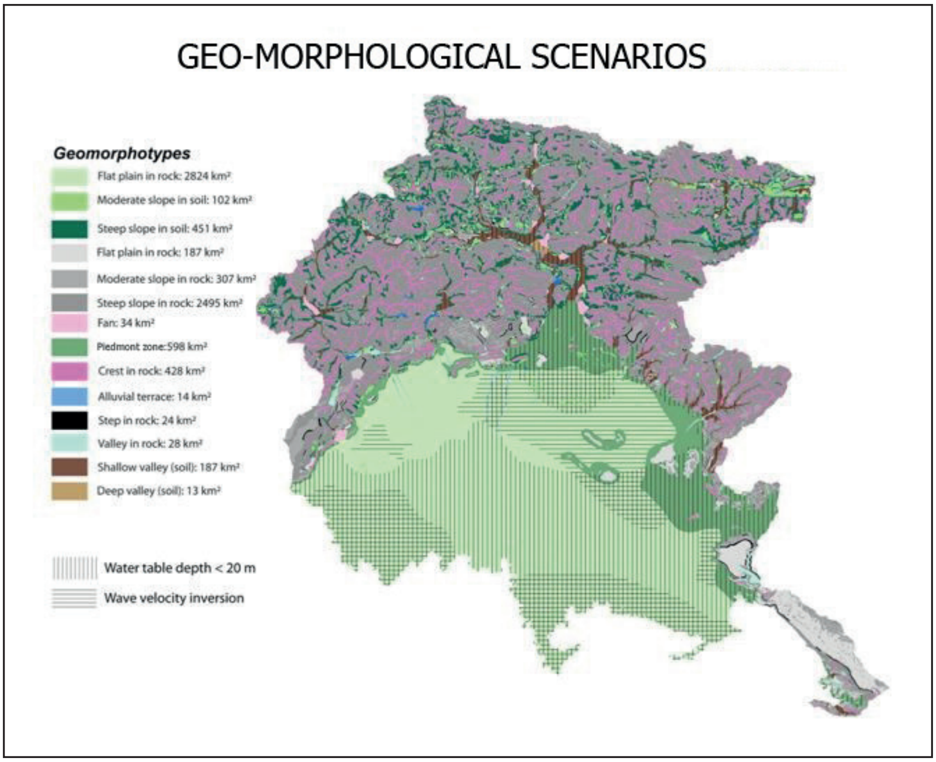


Fig. 5 – Geo-morphological scenarios identified in the Friuli Venezia Giulia region.

map at the scale of 1:150,000. Three classes of slope (<8°, 8°-15°, >15°) were recognized. In addition, the geomorphological characteristics of the superficial and deep valleys (in rock or soft sediments), of the crests, of the alluvial fans, of the piedmont areas (with bedrock at a depth lower than 100 m), of the alluvial terraces (in soft sediments), and of the morphological steps (in rock) were also identified.

In order to define a specific point of reference for the analyses of the subsequent Level 2, 186 seismic design projects of school buildings were acquired and analysed. For these buildings, a first indicator of seismic structural performance was quantified by using the concept of the protection deficit for the shaking. The peak ground acceleration (*PGA*) at the free surface was used as the shaking parameter; the value for each building was taken from the most recent national seismic hazard map (Stucchi *et al.*, 2011) and adopted in the current Italian seismic code NTC-2008 (Ministro delle Infrastrutture, 2008). Furthermore, a specific analysis was developed in order to take into account the variations in the approaches related to the different seismic regulations in the past (Gattesco *et al.*, 2011). Therefore, it was possible to compare the value of the seismic regulation used in the past for the building design with the current seismic design value. The ratio between these two values, called "Index of Congruence" (I_C), was evaluated for each building with an available seismic design documentation (i.e., the 186 identified projects). The value of the index I_C was used as an indicator of potential criticality for the global seismic behaviour of the building (Gattesco *et al.*, 2011): buildings without a value of I_C were considered as "gravity loads only designed buildings", while the buildings with a seismic design were ranked according to the value of their index I_C.

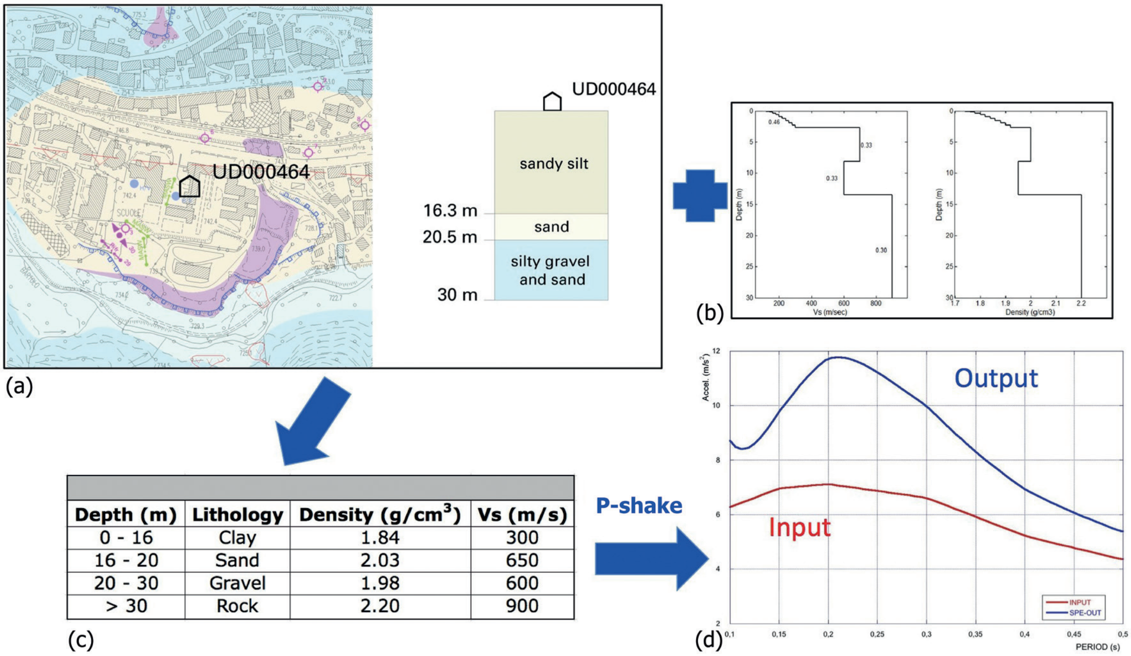


Fig. 6 – In the analysis at Level 2, the velocity profile of the seismic waves (b) characteristic of each site where the school building is located (a) was calibrated on all available or collected geological, geophysical, and geotechnical data (c) in order to compute the local amplification by 1D modelling (d).

4.2. The Level 2 analysis

The school buildings analysed at Level 2 were identified considering the constructions with higher I_D and without seismic design (Level 1) and in a way to be representative of the global regional situation from the point of view of building vulnerability and geological site conditions. The shaking was calculated by 1D modelling on the basis of velocity profiles available or estimated on the basis of the geological and geophysical surveys done. The vulnerability was evaluated by integrating the existing information derived from the Italian national census of school buildings and the building plan with visual inspections and expeditious instrumental measurements.

The ground motion at the site was estimated using the scheme of seismic hazard calculation previously applied for the revision of the regional seismic zonation. The only modification consists of a tightening of the geographical grid of computation so as to obtain a more detailed view of the expected shaking. In addition, as the calculation was addressed to a class of relevant buildings, namely school buildings, the uniform hazard response spectra on rock were calculated for the return period of 712 years, as prescribed by the Italian seismic code NTC-2008 (Ministro delle Infrastrutture, 2008). The stratigraphic profiles for the sites where the selected schools are located were determined from all of the available information (i.e., mechanical and geophysical surveys, wells, etc.). This information was then integrated with geophysical measurements made specifically for this study [MASW and ambient noise; Grimaz *et al*. (2011b)] in order to better define the velocity profiles (Fig. 6). In particular, the HVSR technique was applied to map the natural frequencies of the investigated sites. This technique also allowed us to assess the effects of geomorphology on the seismic response and, then, drove the choice between applying a 1D or 2D modelling. Overall, we analysed 144 sites, mainly located in the Friuli plain, and for them we calculated the specific uniform hazard response spectrum on rock. This spectrum was used as input in 1D seismic modelling, and the related uniform hazard response spectrum at the free surface was obtained.

The analysis of the buildings at the Level 2 was based on the VISUS method (Grimaz *et al.*, 2011a; Grimaz and Malisan, 2016) specifically adapted to schools. The method is based on a quick visual inspection that allows the identification of weaknesses and potential critical effects in the seismic behaviour of the building. VISUS deals with the problem in terms of seismic safety, considering site, global structural, local structural, non structural, and functional issues. The global seismic performance of a building was evaluated using simplified methods of calculation developed by Gattesco *et al.* (2012a) for masonry and Gattesco *et al.* (2012b) for reinforced concrete (RC) buildings. The methods were calibrated on the results of the evaluations performed at the Level 3 analysis, considering the specific seismic action at the site. At the local level, specific components (such as walls, roofs, floors, etc.) were examined. In addition, the vulnerability of non-structural elements (such as ceilings, bookcases, chimneys, etc.) was estimated as well as that of the egress system (for example, functional criticality in the evacuation of the building). The application of the VISUS method permitted the identification of the critical scenarios and the expression of an overall judgment using specific logical evaluation grids.

In addition to the visual inspection, an instrumental assessment of the dynamic behaviour of the buildings through measurements of ambient noise was also performed (Grimaz *et al.*, 2011b, 2013). This expeditious measurement enabled the identification of the fundamental frequencies of the buildings and their tendency to induce torsional effects during the shaking. The comparison with the fundamental frequency of the site allowed us to recognize the presence of a potential effect of double resonance in the case of earthquakes.

4.3. The Level 3 analysis

The Level 3 analyses concerned only aspects relating to the vulnerability, in order to verify whether the results obtained with the simplified methods used in the Level 2 analysis were in line with the most detailed structural analyses of seismic safety. This comparison, in particular, revealed that the outcomes of Level 2 are proper estimators of the Level 3 judgments.

Specifically, at Level 3, the analyses on the building structural response were conducted by applying numerical codes based on the finite element method. The input data concerning materials and detailing of the structure are coherent with the level of knowledge "LC1" of the NTC-2008 (Ministro delle Infrastrutture, 2008).

4.4. Presentation of outcomes

The ASSESS project sought a proper presentation of the outcomes of the analyses, so that public administrators can directly use them as support elements in decision-making. The graphical indicators proposed by Grimaz and Malisan (2016) were adopted, inasmuch as they are directly applicable to decision-making in strategic planning aimed at reducing the seismic risk.

4.4.1. The Structural Performance Class

Regarding the global structural response of the building, the index I_C and a related series

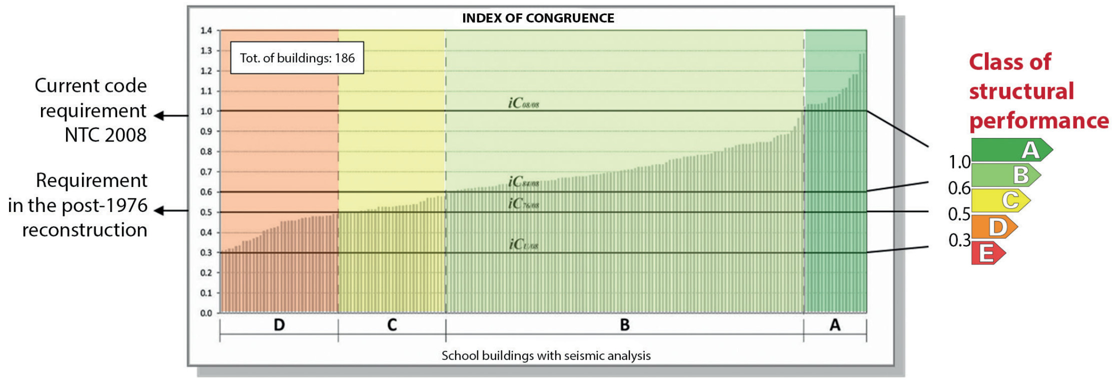


Fig. 7 – Method for the assignment of the SPC to a building.

of "Structural Performance Classes" (SPCs) were evaluated. The index I_C was calculated as the ratio between the estimated resistance of the structure (capacity) and the design resistance (demand), required by the Italian building code NTC-2008 (Ministro delle Infrastrutture, 2008). Both values are expressed in terms of acceleration. The capacity value was estimated either by considering the seismic design value (when available), or by applying the simplified method of calculation. I_C was defined assuming conservative hypothesis: indeed, the actual capacity of the building should be equal or greater to the seismic design value, and the simplified method of calculation works with intrinsic conservative evaluations [for specific details see Gattesco *et al.* (2011)]. The ratio I_C was, then, used to associate each building with a class of structural performance (Fig. 7). In particular, we identified five classes based on the comparison of the values of I_C with the corresponding ones in the previous seismic codes:

- class A refers to buildings with an I_C larger than, or equal to, 1.0, i.e., with a capacity greater than, or equal to, the required demand in the current Italian building code NTC-2008 (Ministro delle Infrastrutture, 2008);
- class B includes buildings with an I_C between 0.6 and 1.0 (it usually refers to buildings seismically designed after 1984);
- class C is characterized by I_C values between 0.5 and 0.6 (the buildings of this class can be compared, in terms of seismic performance, to those built after the 1976 earthquake in Friuli);
- class D collects buildings with an I_C between 0.3 and 0.5;
- class E is defined as buildings with an I_C lower than 0.3 [this means that the buildings in this category have a capacity of less than 30% of the demand required by the current technical standards NTC-2008 (Ministro delle Infrastrutture, 2008)].

The SPCs are represented, graphically, in a manner analogous to energy efficiency classes. During the project, this form of representation facilitated the communication with administrators, making the recognition of the situations and the identification of intervention priorities simple and similar to other sectors.

4.4.2. The Intervention Requirement Rose

The SPC is not the only important indicator if you want to consider the overall issues of seismic safety. It is required, in fact, to judge all aspects that can contribute to or cause casualties or injuries. Following the VISUS method, five main issues (site, global structural,

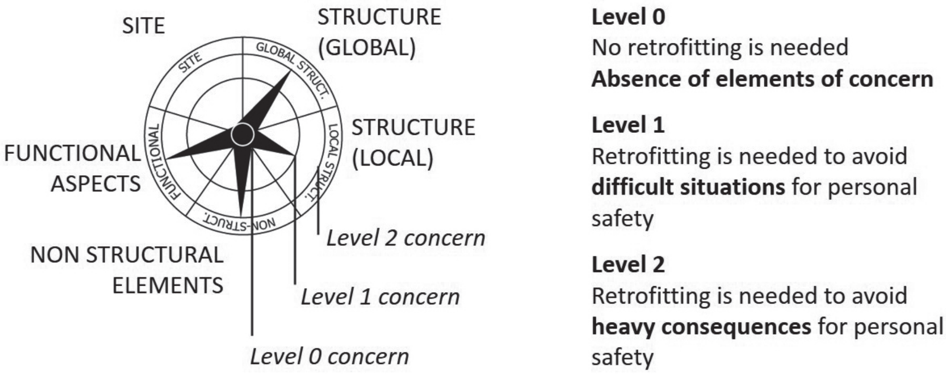


Fig. 8 – The Intervention Requirement Rose.

local structural, non-structural, and functional) have been investigated in order to check all the critical states. The site analysis evaluates if the location is unsuitable due to unstable conditions, namely: flood areas, areas with the presence of cavities in the soil, areas characterized by the presence of faults, areas with potential liquefaction, areas affected by potential landslides. The presence of any of these conditions implies the need to assess whether it is advisable to intervene on the building, or if it is preferable to move the building to a stable location. The global and local structural characterization focuses the attention on the values of the seismic resistance of the building and its parts (such as walls, roof, floors, etc.). The evaluation of the non-structural elements (e.g., ceilings, chimneys, bookcases, etc.) involves the potential problems related to the presence of non-structural elements that can collapse or, in general, can cause damage to the occupants. Finally, an assessment of the egress system was also provided (functional criticalities), because the ability to leave the building quickly is also a key aspect in the evaluation of seismic safety. In particular, for each investigated issue (site effects, global and local structural response, non-structural response, and functional response), the potential weaknesses were identified and classified into three levels of severity, namely: Level 0 - absent or negligible elements of concern; Level 1 - potentially difficult situations for personal safety; Level 2 - potentially heavy consequences for personal safety. These degrees of severity are represented in a summary graph called the "Intervention Requirement Rose" (IRR) (Fig. 8). From a communication point of view, this representation presents immediate advantages: each needle of the rose is tied to an aspect related to the seismic safety, the presence of one or more needles implies the existence of potential problems in the building, while a rose without needles means that the goal of personal safety has been reached. The length of the needle indicates if the potential element of concern could imply heavy consequences (long needle) or difficult situations (short needle) for personal safety.

4.4.3. The Safety Stars

The summary judgment on the conditions of seismic safety is finally expressed by assigning the "Safety Stars" (SSs) (Fig. 9) as proposed by the VISUS method. The basic concept of the SSs is the same one used in other fields, where a judgment of overall quality/performance is required (such as in the case of hotels, cars, software applications, etc.). Once the various evaluations are done, each star is awarded only if the building meets certain requirements.

Fig. 9 – The Safety Stars.

Specifically, in the ASSESS project the following award criteria were adopted:

- no star assigned: if the site is unsuitable (Level 2 concern for site);
- 1st star assigned: if the site is suitable (absence of Level 2 concern for site);
- 2nd star assigned: if the SPC is at least D;
- 3rd star assigned: if the SPC is at least C and there is an absence of Level 2 concern for local structural, non-structural, and functional issues;
- 4th star assigned: if the SPC is at least B and there is an absence of non-structural deficiencies;
- 5th star assigned: if there are not functional deficiencies.

4.4.4. The school safety individual and collective reports

The data collected and the results of the analyses were summarized in individual reports, specifically designed and divided into three main sections (Fig. 10). The first section presents an overview of the school building with the most important identification data (including geographical location and photos of the building). The second section summarizes the data about the site where the building is located; in particular, it illustrates the level of seismic hazard, the geological framework, any site unsuitability, and expected site effects. The third section summarizes the structural information (structural design, materials used, and their resistance), along with any structural, non-structural, and functional criticality and indicates the relative suggested interventions. Finally, a collective report summarizes the graphic indicators: SPC, IRR, SSs, and expected cost for interventions (Fig. 11).

The ASSESS atlas of the school buildings was prepared as a compendium of the performed evaluations. The data contained in it (maps, statistical evaluations, building forms, list of analyzed buildings showing the respective summary graphic indicators, estimates of the costs of intervention) provide the essential elements on which the planning of strategies for seismic risk reduction at the local level should be based.

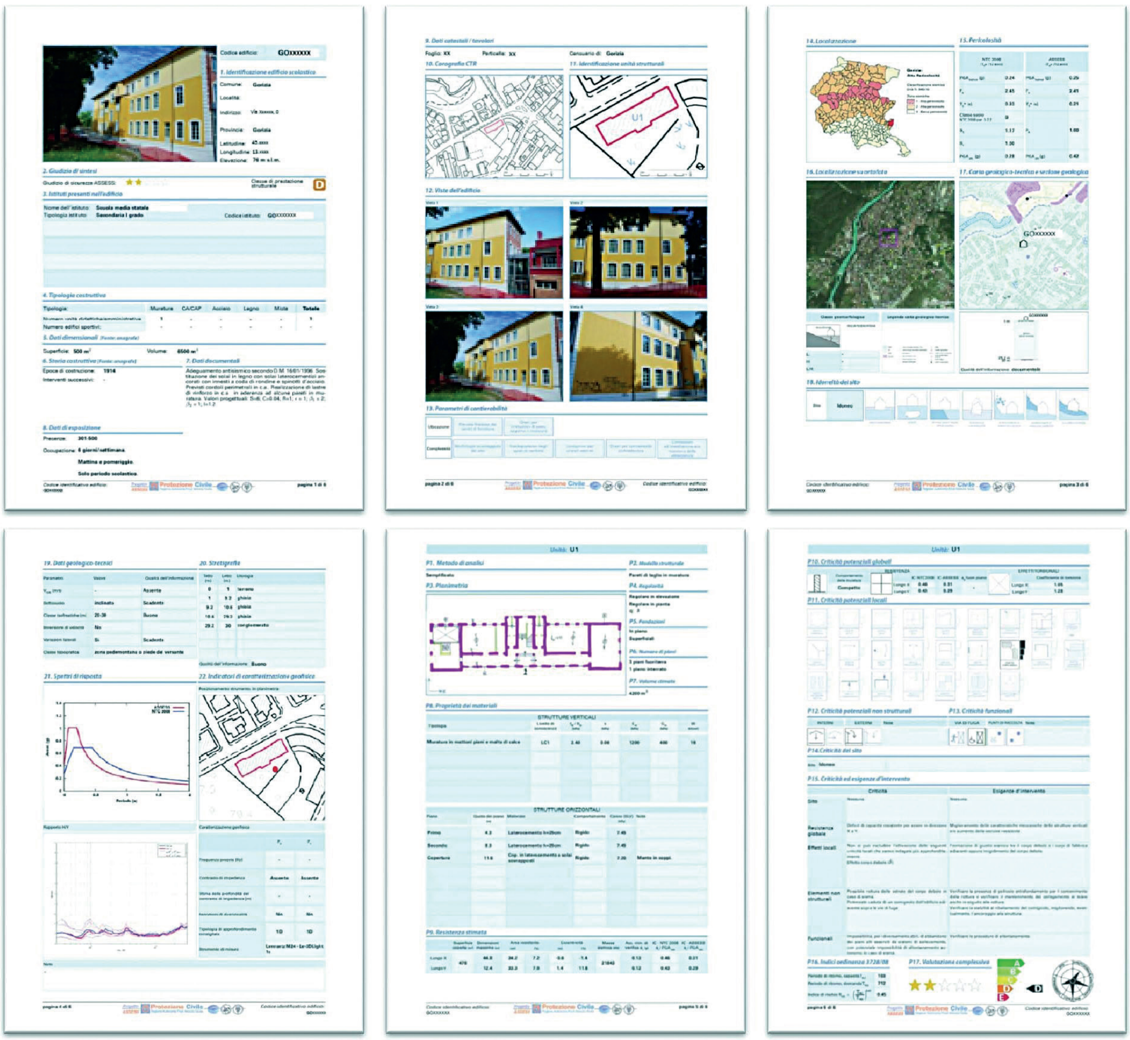


Fig. 10 – Example of individual report presenting the seismic characterization of a school building analysed as part of the ASSESS project.

5. Main results and final remarks

The ASSESS project analysed 1,022 schools in the Friuli Venezia Giulia region at Level 1, with respect to the topographic, geological, and seismic context and to each building's structural characteristics. This analysis identified the buildings for which the Level 2 analysis was suggested. More than 10% of all school buildings (144 to be precise) were involved in this more detailed analysis, consisting of geological, geophysical, and engineering surveys. The set of buildings analysed at Level 2 consisted of 50% masonry buildings, 31% RC frame buildings, 11% RC frames with RC shear walls, and small percentages of other types (Fig. 12a). Seventy-two percent of the buildings have one or two floors, 26% have three or four floors, while only 2% of school buildings have more than four floors (Fig. 12b). Overall, the Level 2 analyses concerned 950,000 m^3 of volume of school buildings. The results of the analyses also show (Figs. 12c and 12d), in particular, the importance of considering the site

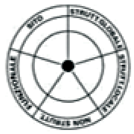
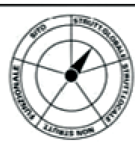
School ID	School typology	Structural performance class	Intervention requirement rose	ASSESS safety stars	Costs (K€)
GO 000 XXX	Preschool	A		★★★★★	0
GO 000 XXX	Preschool	A		★★★☆☆	Technical verification
GO 000 XXX	Primary school	B		★★☆☆☆	47÷63
GO 000 XXX	Secondary school	D		★★☆☆☆	1.380÷1.870
GO 000 XXX	High school	E		★☆☆☆☆	2.300÷3.150
PN 000 XXX	Primary school	D		★★☆☆☆	920÷1.250

Fig. 11 – Extract from the collective report: indices used in the ASSESS project to characterize the seismic behaviour of an analysed school building: SPC, IRR, SSs. A rough estimate of costs for the required interventions is also reported.

criticalities. In fact, 9% of the studied buildings were found to have such problems. This fact emphasizes the need to apply a holistic approach that considers all aspects related to safety and not only building vulnerability. Furthermore, the outcomes of the assessment show that the schools constructed or retrofitted after the 1976 Friuli earthquake according to the reconstruction codes show a widespread occurrence of a SPC C and assignments of 3 stars as a global judgment. Less positive evaluations were found mainly in areas not seismically classified before 2003 (the southern Friuli plain), especially for R.C. or masonry buildings that have not undergone a seismic retrofit. Furthermore, the zones with the worst results were identified in the areas around the River Isonzo and along the western Friuli foothills. The results obtained provide an overall view of the territory and suggest different priority ranks of intervention according to the criteria to be followed for the interventions themselves (source of funding, area of intervention, risk level, type of intervention, etc.).

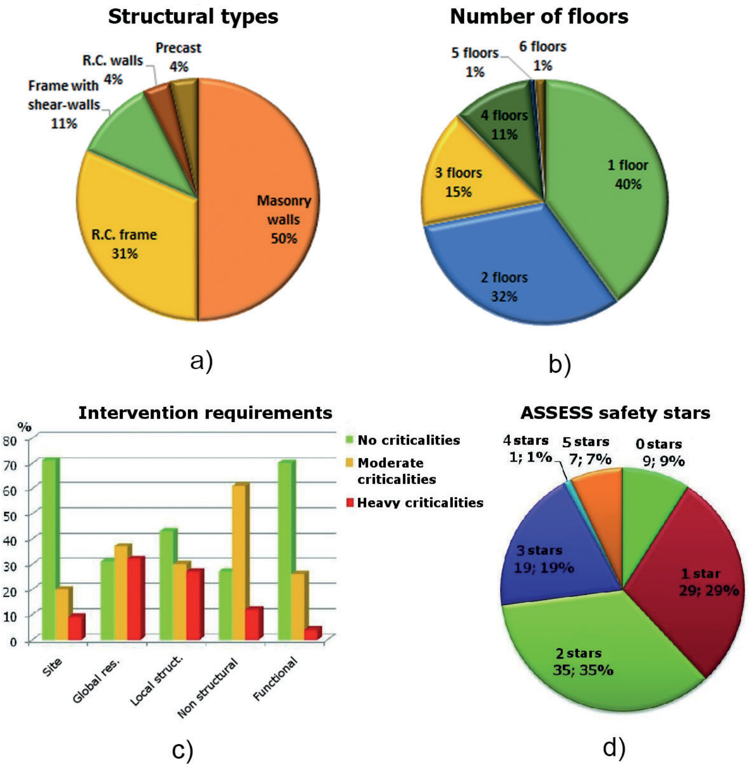


Fig. 12 - Summary of results obtained for the 144 school buildings analysed at Level 2 as part of the ASSESS project: a) distribution of required interventions and b) assignment of the SSs.

In such a way, a rough estimate of the financial resources necessary for their implementation was identified as well.

The comparison of the outcomes of the different levels of analysis permits to observe that there is good consistency in the judgments among the levels of analysis. Nevertheless, some discrepancies were identified between the indicators of priority of Level 1 and those of Level 2, when the data of the Italian National census used in Level 1 were not consistent with reality. As an example, in some cases the information of the census was not up-to-date and several schools (identified as high-priority by the Level 1 assessments) underwent interventions after the data of the Italian national census survey. In the multi-level approach, the presence of errors or inaccuracies at Level 1 could influence the prioritization list. This means that Level 2 evaluations should be extended to the entire set of buildings. Nevertheless, Level 1 outcomes proved to be useful for addressing the in-depth analyses.

The results obtained and the experience gained during the ASSESS project allow the authors to make some concluding remarks.

The first remark concerns the methodology developed and adopted. The ASSESS project has emphasized the importance of a holistic, interdisciplinary, and multi-level approach in handling a lot of diverse information, which is necessary for defining seismic risk reduction priorities. The point of view of seismic safety, intended as an evaluation of the consequences on people, is fundamental and strategic, especially if the object of investigation is a type of building with great social importance.

The second remark concerns the communication and operational management of the seismic problem. The ASSESS project has proven the importance of considering not only the scientific correctness and reliability of the results obtained, but also the manner of communicating them to the end users, public administrators. The definition of appropriate graphic indicators for summarizing the results can play a decisive role because they can also become a communicative element. The set of summary indicators was designed to permit the establishment of lists of prioritized interventions defined according to different political and administrative criteria (consider, for example, the case in which the funds are aimed at specific interventions, such as for non-structural elements, or relate to specific geographical areas, or depend on the type of owners).

It is important to note, moreover, that the indicators should take into account all the elements that contribute to the definition of seismic risk: the five needles of the IRR and the criteria for the award of the SSs allow one to consider all aspects, and also to evaluate the necessary interventions. This methodology, therefore, allows one to address in an optimal way the available resources as part of a strategy aimed at mitigating the seismic risk on a regional scale.

Finally, stressing once again that this project is a prototype study for seismic risk reduction, it is the authors' belief that the ASSESS methodology and the above described tools for decision-making support lend themselves to be applied, with appropriate adjustments, to other structures, such as important community buildings and critical facilities (Grimaz and Slejko, 2014), and even to ordinary buildings.

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REFERENCES

Biolchi S., Zini L., Leita P., Malisan P.; 2011; *Mapping the geomorphological scenarios of the Friuli Venezia Giulia Region (NE Italy): a tool for the evaluation of the local seismic amplification*. Il Quaternario, **24**, 79-80.

BSSC (Building Seismic Safety Council); 2004: *NEHRP recommended provisions for seismic regulations for new buildings and other structures (FEMA 450). Part 1: Provisions, 2003 edition*. BSSC, Washington D.C., 356 pp.

Calvi G.M., Pinho R., Magenes G., Bommer J.J., Restrepo-Vélez L.F. and Crowley H.; 2006: *Development of seismic vulnerability assessment methodologies over the past 30 years*. Journal of Earthquake Technology, **43**, 75-104.

Carulli G.B., Codermatz R., Cucchi F., Peruzza L., Pettenati F., Rebez A., Sirovich L. and Slejko D.; 2002: *A site-dependent seismic hazard map for the Friuli - Venezia Giulia region (NE Italy)*. In: 12th European Conference on Earthquake Engineering, Elsevier Science Ltd, Oxford, CD-Rom paper 860.

Carulli G.B., Riuscetti M. and Slejko D.; 2003: *La carta del rischio sismico*. Rassegna Tecnica del Friuli Venezia Giulia, **54** (2), 17-22.

FEMA 154; 2002: *Rapid visual screening of buildings for potential seismic hazard. A handbook. 2nd edition*. Earthquake hazard reduction series, **41**, 164 pp.

Gattesco N., Franceschinis R., Zorzini F., Grimaz S., Barazza F., Leita P. and Malisan P.; 2011: *Soglie di priorità per l'adeguamento sismico di edifici scolastici costruiti o ristrutturati prima dell'entrata in vigore delle NTC 2008*. In: Proceedings of the XIV Convegno ANIDIS – L'Ingegneria sismica in Italia, Paper n. 918, ISBN 978-88-7522-040-2, CD-Rom.

Gattesco N., Franceschinis R. and Zorzini F.; 2012a: *A strategy for the seismic vulnerability assess of heritage architecture*. In: 15th World Conference on Earthquake Engineering, Lisbon 2012, <http://www.nicee.org/wcee/search15.php>.

Gattesco N., Franceschinis R. and Zorzini F.; 2012b: *Analytical simplified procedure for the evaluation of the RC buildings*. In: 15th World Conference on Earthquake Engineering, Lisbon 2012,<http://www.nicee.org/wcee/search15.php>.

Grant D.N., Bommer J.J., Pinho R., Calvi G.M., Goretti A. and Meroni F.; 2007: *A prioritization scheme for seismic intervention in school buildings in Italy.* Earthquake Spectra, **23**, 291-314.

Grimaz S.; 2009: *Seismic site effects estimation from Probit analysis of the data of the 1976 Friuli earthquake (NE Italy)*. Boll. Geof. Teor. Appl., **50**, 319-337.

Grimaz S. and Malisan P.; 2014: *Near field domain effects and their consideration in the international and Italian seismic codes.* Boll. Geof. Teor. Appl., **55**, 717-738.

Grimaz S. and Malisan P.; 2016. *VISUS: a pragmatic expert-based methodology for the seismic safety triage of school facilities*. Boll. Geof. Teor. Appl**., 57**, 91-110.

Grimaz S. and Slejko D.; 2014: *Seismic hazard for critical facilities*. Boll. Geof. Teor. Appl., **55**, 3-16, doi: 10.4430/bgta0124.

Grimaz S., Slejko D., Cucchi F., Barazza F., Garcia J. Leita P., Malisan P., Rebez A., Santulin M., Zini L.; 2010: *A holistic approach in the definition of priority interventions list for seismic risk reduction of strategic buildings at a territorial level*. In: Proceedings 14th European Conference of Earthquake Engineering, Ohrid, Macedonia, August 30 – September 3, 2010, CD-Rom.

Grimaz S., Barazza F., Malisan P., Moretti A.; 2011a: *Riconoscimento delle evidenze di criticità comportamentale degli edifici in caso di terremoto attraverso ispezioni visive*. *Il metodo VISUS*. In: Proceedings of the XIV Convegno ANIDIS – L'Ingegneria sismica in Italia, Paper n. 918, ISBN 978-88-7522-040-2, CD-Rom.

Grimaz S., Malisan P. and Barazza F.; 2011b: *Ambient-noise measurements for seismic risk mitigation of school buildings*. Environmental Semeiotics, **4**, 55-62.

Grimaz S., Slejko D., Cucchi F. e Gruppo di Lavoro ASSESS; 2012: *Il progetto ASSESS (Analisi degli scenari sismici degli edifici scolastici per la definizione delle priorità di intervento per la riduzione del rischio sismico): un esempio di stima del rischio sismico esportabile ad altre realtà nazionali*. Geoitalia, **39**, 27-35.

Grimaz S., Malisan P., Barazza F. and Carniel R.; 2013: *Rapid instrumental check of vulnerability parameters on bridges for seismic risk mitigation purposes***.** Boll. Geof. Teor. Appl., **54**, 205-215.

Grünthal G. (ed); 1998: *European Macroseismic Scale 1998.* Cahiers du Centre Europeen de Geodynamique et de Seismologie, **15**, Centre Europeen de Geodynamique et de Seismologie, Luxembourg, 99 pp.

Lagomarsino S. and Giovinazzi S.; 2006: *Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings*. Bull. Earthquake Eng., **4**, 415-443.

Ministro delle Infrastrutture; 2008: *Decreto 14/01/2008 - Norme Tecniche per le Costruzioni*. Ministero delle Infrastrutture, Roma, 438 pp.

MIUR (Ministero dell'Istruzione, dell'Università e della Ricerca); 1996: *Anagrafe dell'edilizia scolastica*. Legge 11/01/1996, n.23, art.7.

Mouroux R. and Le Brun B.; 2006: *Presentation of RISK-UE project*. Bull. Earthquake Eng., **4**, 323-339.

Rebez A., Carulli G.B., Codermatz R., Cucchi F., Peruzza L. and Slejko D.; 2001: *Soil type dependent spectral seismic hazard in Friuli - Venezia Giulia (NE Italy)*. Boll. Geof. Teor. Appl., **42**, 121-138.

Sanò T. and Pugliese A.; 1991: *PSHAKE, Analisi probabilistica della propagazione delle onde sismiche*. RT/DISP/91/03, ENEA, Roma, 30 pp.

Slejko D., Carulli G.B., Riuscetti M., Cucchi F., Grimaz S., Rebez A., Accaino F., Affatato A., Biolchi S., Nieto D., Puntel E., Sanò T., Santulin M., Tinivella U., Zini L.; 2011: *Soil characterization and seismic hazard maps for the Friuli Venezia Giulia region (NE Italy)*. Boll. Geof. Teor. Appl., **52**, 59-104.

Slejko D., Grimaz S., Cucchi F. and the ASSES Working Group; 2012: *Seismic risk of schools at a regional scale: the ASSESS project*. In: SISMOS 2012, por una gestión estratégica de riesgos de desasters, Ediciones UO, Santiago de Cuba, ISBN 978-959-207-449-1, CD-Rom, paper C1.Slejko.It.pdf.

Spence R. and Le Brun B. (eds); 2006: *Preface*. Bull. Earthquake Eng., **4**, 319-463.

Stucchi M., Meletti C., Montaldo V., Crowley H., Calvi G.M. and Boschi E.; 2011: *Seismic hazard assessment (2003–2009) for the Italian building code*. Bull. Seism. Soc. Am., **101**, 1885–1911, doi: 10.1785/0120100130.

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