Seismic vulnerability assessment of the village of Alzano, in the Salto Valley, as a first and unavoidable step for its revitalization by using local natural resources and advanced technologies

Sabrina Taffarel[a], Francesca da Porto[a], Cesare Silvi[b], Claudio Modena[a]
[a] *Dipartimento di Ingegneria Civile Edile e Ambientale(DICEA), via F. Marzolo 9, 35131 Padova*
[b] *valledelsalto.it and Italian Group for the History of Solar Energy(GSES), via Nemorense 18, 00199 Roma*

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ABSTRACT

Thousands of small villages in Italy seem to be destined to total abandonment. A phenomenon that began with the industrial revolution powered by fossil fuels (coal, oil, gas) and was accentuated in the seismic areas of the Apennine mountains. The village of Alzano, in the Salto Valley (Rieti), with a centuries-old history, is a typical example. Its residents have gone from 90 in 1950 to 7 today, with a few dozen who inhabit second homes. In less than two decades, Alzano could become deserted. The same fate is expected for hundreds of Apennine villages. Government attempts to halt their depopulation will be ineffective unless major seismic safety programs and, in parallel, development projects using local natural resources and advanced technologies are implemented. For Alzano, *DICEA, valledelsalto.it, and GSES* completed a preliminary pilot study on seismic vulnerability of the village. Its results are presented in this paper and its approach is being proposed to be applied to other villages that are extraordinary testaments of life powered exclusively by solar energy until 150 years ago. These villages could be revitalized by turning again to the use of solar energy, in its modern forms.

1. INTRODUCTION

This paper is devoted to small villages[1] in the central Apennine that are likely to become completely uninhabited.

It was inspired while the authors, through different professional experiences, were involved for more than three years in a preliminary pilot study on seismic vulnerability of the entire village of Alzano, in the Salto Valley (Figure 1). Alzano is a village of the municipality of Pescorocchiano in the province of Rieti, less than 100 km from Rome.

Since 2015 the municipality of Pescorocchiano has been included in the *Strategia Nazionale Aree Interne* (Strategy for Inner Areas in Italy)) whose content is summarized in the abstract copied below:

“*The Italian territory is characterised by a polycentric and interdependent system, with towns, rural areas and smaller clusters linked by a solid network of relations, and larger towns and cities, which attract people because of their wealth of public services. Access to services such as education, mobility and healthcare is crucial. The more remote rural areas, historically deprived of many of these services, have gone through a lengthy and steady period of abandonment in favour of urban areas, which has taken a heavy toll in terms of hydro-geological instability, decay and soil consumption. The fall in population has been matched by a decline in personal services. These areas, however, contain much untapped regional, natural and human capital, seen as strategic for the recovery and growth of Italy’s entire system. Intervention targeted at safeguarding, rehabilitating and revitalising inner territorial areas has been deemed necessary, in order to overcome the urban/rural dichotomy and put a new perspective on the concept of service acceptability. These ‘Inner Areas’ are defined as areas being at some considerable distance from centres offering such services, and where there has been a fall in population and a rise in degradation.*

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[1] In the mountains there is the coexistence of various settlements, like a *villaggio* (an open settlement), and a *borgo* (a fortified settlement) (Leggio 2014)

Demographic trends, access to healthcare and adequate education provision are just some of the essential criteria for defining and classifying Inner Areas. These areas currently make up approximately 60% of the Italian territory and are home to round 13.540 million people."

Figure 1. An aerial view of Alzano, a typical Italian Apennine village, whose urban layout and its surroundings remind its past based on the empirical use of solar energy and other natural resources.

The Italian national strategy for Inner Areas aims at *"reversing the depopulation and marginalisation of these areas, hinging on two key economic policy assets: improving personal services and triggering local development projects*" (Barca et al. 2014) (Figure 2).

Figure 2. In green the inner area of the Reatini Mountains, where 26.664 inhabitants live as of 2011, the majority elderly (SviluppoLazio 2017).

Alzano's pilot study on seismic vulnerability assessment has been carried out also within the context illustrated in the above paragraph.

Inner area depopulation is part of a well-known phenomenon that does not have geographic boundaries, from Europe to the Americas, from Asia to Africa, and is attributed to various causes, including, of course, earthquakes.

In Europe, Italy holds the undisputed primacy with more than 6,000 abandoned villages according to The National Institute for Statistics (Istat). About 2,800 are likely to disappear in the short term, a problem that affects the entire Italian territory with particular concentration in Central (45%) and Southern (35%) Italy (Pirlone 2016).

The pilot study on seismic vulnerabily assessment of Alzano was inspired in the aftermath of L'Aquila earthquake (2009) and it was started in January 2015, on the occasion of the 100th anniversary of the 1915 Marsica's earthquake. It took almost ten years to start talking about Alzano's seismic safety prevention program as we are doing in this paper.

The impact of earthquakes on the abandonment and the very existence of small rural villages in the Salto Valley, such as Alzano, can be traced for hundreds of years, based on literary sources and archaeological remains from Roman colonization and previous and successive civilizations. Despite being affected by major earthquakes (484, 1315, 1349, 1639, 1703, 1915), with epicentres in the Salto Valley and in the surroundings, Alzano and the area continued to be inhabited throughout the centuries.

It was only with the second Italian industrial revolution powered by fossil fuels, whose use was intensified immediately after World War II, that large scale depopulation occurred.

Alzano's permanent residents have gone from 90 in 1950 to just 7 today, all elderly, and a few dozen who inhabit second homes.. In less than two decades, Alzano could become totally deserted.

This inevitable fate of Alzano is likely to be the same for other villages. In fact, securing seismic safety of entire villages might not avoid abandonment.

In Italian seismic areas, there are villages that continue to be depopulated even after seismic safety measures were implemented at the highest levels.

"Reversing the depopulation and marginalisation" of villages, like Alzano, is an aim of The Italian national strategy for Inner Areas (Sviluppo Lazio 2017), that should be pursued with these considerations in mind:

- Seismic safety prevention programs require long implementation times, in the order of 10-50 years;
- Seismic prevention measures involve interventions on urban layout, architectural structures and building envelopes;

- Sunlight radiation falls on building surfaces and urban spaces on which solar collectors can be installed;
- “Solar electricity generation is one of very few low-carbon energy technologies with the potential to grow to very large scale. As a consequence, massive expansion of global solar generating capacity to multi-terawatt scale is very likely an essential component of a workable strategy to mitigate climate change risk;” (Schmalensee et al. 2015);
- Mitigate climate change risk, while implementing seismic safety prevention programs, could offer additional motivations for modernizing and revitalizing Apennine economies. The two actions must go hand in hand;
- The introduction of advanced technologies, such as electric solar technologies, can contribute to rebuild the link between the use of solar energy and local economies, interrupted when fossil fuels came on stage, as it is further analysed in the following section 3 on past, present and future of solar energy.

2. GEOGRAPHIC, ECONOMIC AND SEISMIC SAFETY PREVENTION CONTEXTS

2.1. Geographic context

Alzano belongs to the inner area of Reatini Mountains in the Rieti province, made up of 29 municipalities, including Pescorocchiano, one of the seven making up the Valle del Salto (or Cicolano, the historical name of this territory).

The valley covers an area of 50,137 hectares with a population of 10,111. The depopulation rate from 2001 to 2011 was 13.12%. Population density per km^2 is equal to 20.16 (Piano di sviluppo Locale, il Cicolano un territorio da scoprire del Gruppo di Azione Locale, 2014/2020).

The Salto Valley is well connected to nearby cities such as Rome, L'Aquila and Avezzano via the A24 and A25 motorways (Pagano et al. 2014).

It has environmental and cultural tourism potential. For example, trekking and local associations are developing the construction of a long distance walking trail, the European Path E1 (Silvi et al. 2014).

In the valley there are about 88 villages, of different sizes, smaller and larger than Alzano, many of them close to complete depopulation.

2.2. Typological and urban context

The Cicolano population lives in small villages and rarely in isolated homes in the countryside (Riccardi 1955). This centralized settlement was dictated by the defensive needs of the medieval age, the lack of security in the region due to the flourishing banditry in the 1800s; the mountainous territory and the presence of woods; the fragmentation of agricultural property; the great importance of sheep herding, an activity that is based on forms of collective property and collaboration for goods production. For all these reasons, the majority of the Cicolano villages are located between 600 m and 1000 m asl.

The villages that were not involved in the 1915 post-earthquake reconstruction are generally composed by one or two story terraced houses divided by narrow streets which are usually characterized by steps on steep slopes. Frequently, the streets flow into open spaces (small squares) with a rural church. For these reasons, the villages layout is usually very irregular.

In the two-story historic houses, the lower floor has a rural vocation (barns or tool storage) and the upper one is residential. Generally, two-story buildings built on a slope are characterized by different heights. As a result, the same floor could be at ground level on one side and the first floor on the other. In both in stables and dwellings, rooms are poorly lit and ventilated through very small windows. Sandstone blocks and lime mortar are the most commonly used materials for house construction.

Over the centuries, in Alzano (Figure 3 and Figure 4) various materials were used for building construction such as rough stones; concrete blocks with light concrete aggregate; wood; iron (for beams or tie rods); bricks; concrete and reinforced concrete. Rough stone was mainly used for historic external bearing walls; concrete blocks and light aggregates for new walls. Wood was used for floors, lintels and roofs. Iron was used sporadically for tie rods or chains and often for construction floors. Brick, concrete and reinforced concrete were used for inner floors and roofs.

Figure 3. Typical historic building in Alzano made by sandstone blocks. This building was affected by the earthquakes of 1703 and 1915, whose effects are still apparent today.

Figure 4. Typical terraced houses built in Alzano after the earthquake of 1915.

2.3. Seismic and safety prevention context

The Lazio region, like most of the Italian peninsula, is characterized by significant seismicity predominantly located on the Apennines, while the rest of the territory has a moderate seismicity, albeit quite recurring in the Albani hills area (Figure 5).

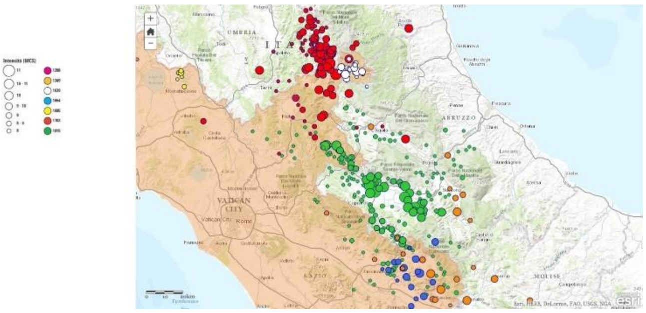


Figure 5. Distribution of the effects of serious damage from major Apennine earthquakes that affected Lazio. At link: http://www.arcgis.com/apps/StorytellingTextLegend/index.html?appid=d0f0abbeeff64c0d98eef2683c592180

The geographic distribution of Lazio earthquakes from 2006 to 2013 confirms historic information which underlines that seismic events are mostly concentrated along the Apennine chain.

The Cicolano was often hit by earthquakes with their epicentres in the surrounding areas, characterized by intense seismicity, such as the neighboring basins of L'Aquila and Fucino. Some examples of recent earthquakes in the area include (at link: https://emidius.mi.ingv.it): January 21, 1892 (epicentre in Pescorocchiano, also felt in L’Aquila, Avezzano and Subiaco, causing severe damage to villages; M_w=4.51±0.34); August 2, 1893 (epicentre in Gargano, causing minor damage, M_w=5.36±0.22); June 27, 1898 (epicentre in Rieti, M_w=5.49±0.12); July 23, 1930 (epicentre in Irpinia, M_w=6.62±0.09).

The earthquake that had the greatest impact on the Cicolano in modern times was the one in the Marsica area, on January 13, 1915, which hit the whole of Italy and caused 30,519 victims. This earthquake hit Cicolano with an intensity of VII-VIII on the Mercalli scale. It caused the collapse of churches, historic palaces and ordinary buildings. More than 100 victims were recorded in the Salto Valley.

In Figure 6 is a 1908 photo of a historic palace in Torre di Taglio, a village less than one kilometer from Alzano, that was severely damaged by the 1915 Marsica earthquake. The remains of the palace were removed only after World War II to make room for a new construction.

Figure 6. Vulpiani’s palace in Torre di Taglio in 1908 (Picture from the Zuccari archive).

The Marsica earthquake was preceded in 1908 by the earthquake of Messina, Sicily, which caused between 90,000 and 120,000 victims. It was the largest national catastrophe ever experienced in Italy.

In the aftermath of the Messina and Marsica catastrophic events, Venceslao Amici, an engineer and parliamentary representative of Cittaducale, to which Pescorocchiano belonged at the time, raised the issue of seismic safety prevention in Parliament. In March 1915 Amici presented a plan regarding safety prevention measures to the Italian Parliament. His work was soon after completely overlooked and resurfaced only recently during the 100th anniversary of the Marsica earthquake of 1915, held in Avezzano in 2015 (Pizzaroni 2017).

While the 2009 L'Aquila earthquake caused 309 victims and widespread damage to the immediate area, there were no victims in the Salto Valley and more limited damage. Twelve churches, some schools and dozens of private homes were declared unfit for use. Cracks, some more evident than others, were caused on dozens of buildings, in particular older ones, including repaired cracks produced by previous earthquakes. The most serious consequence was the creation of a widespread unease among the population, with fear of earthquakes leading many families to sleep outside their homes for several months. It took more than four years after 2009 to recover a sense of security, which, however, precipitated again, to the lowest levels, after the Amatrice earthquake of August 24, 2016 and the following seismic crisis.

The abandonment of the villages of Salto Valley is now more evident than ever. Images on television of villages, similar to their own, reduced to piles of rubble, made people aware as never before of local seismic risks. Fossil fuels gave them a possibility that did not exist in the past, to abandon the area and move elsewhere.

3. USE OF SOLAR ENERGY: PAST, PRESENT, FUTURE

3.1. Solar energy

By solar energy, we mean the energy contained in the direct and diffuse light radiated every day from the Sun to Earth as well as its indirect energy forms of air and water currents, powered by Sun’s heat, and of forests and other forms of biomass resulting from photosynthesis.

We propose to distinguish the sources of energy on Earth in two groups:

- *Energy from sun’s light*;
- *Energy stored underground* (coal, oil, natural gas, nuclear fuels, and the internal heat of the Earth).

Figure 7 provides a comparison regarding the types and quantities of energy sources on Earth.

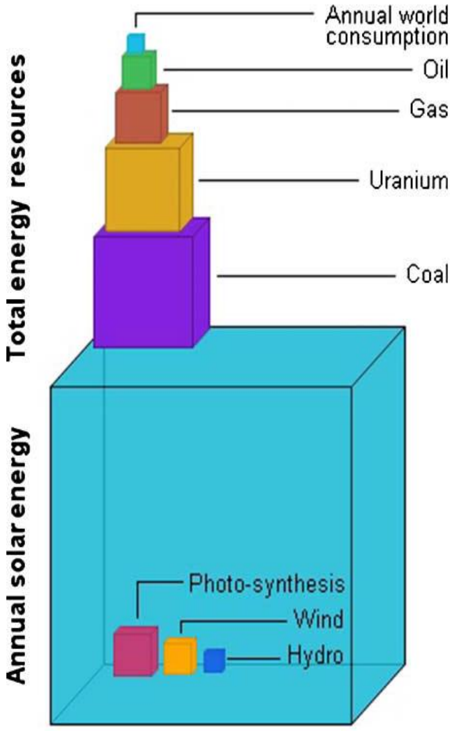


Figure 7. Order of magnitude of energy sources on Earth (Lomborg 2001)

The direct and renewable solar energy is the largest source of energy on earth.

3.2. History of solar energy

It often happens that we think of solar energy as belonging to our modern world. However, it powered everything on Earth until 150-200 years ago.

In order to distinguish the use of solar energy in the past, its present day use and its future prospects, we propose to distinguish two solar ages:

- *Primitive or ancient solar age*, from antiquity until 200 years ago, essentially based on empirical solutions;
- *Present and future solar age*, which has just begun, based on the knowledge and methods acquired from the scientific and technological revolutions of the last 500 years, primarily on the understanding of the composition of light and how Sun’s light can be manipulated to produce modern forms of energy: steam, electricity, and fuels.

A lesson from the study of the history of using solar energy in the past is that man has built, upon the experience of centuries, systems able to offer living conditions based entirely on the use of solar energy in its direct and indirect forms. These systems, still existing up to 100-150 years ago, are testaments of the primitive or ancient solar age, including the many villages of the Apennine such as Alzano (Figure 1).

The introduction and diffusion of fossil and nuclear fuels derailed the solar energy civilizations developed over millennia, which were built on the basis of centuries old inventions that are still valuable in our lives today. We can learn about the use of renewable solar energy in the primitive or ancient age from history and archaeology. For example, the remains of a Roman hypocaust used to heat villas can be seen at the ancient Roman city of Alba Fucens, just a few kilometres away from the southern boundary of the Salto Valley (Figure 8).

Similar systems of underfloor heating used in houses today were inspired by hypocausts of the past. This is just one of many examples of the use of solar energy in the past that inspired modern day systems.

Figure 8. Hikers visiting the archaeological site of the ancient Alba Fucens on Nov. 2016, while walking on the Roman remains of an hypocaust heated by firewood. Alba Fucens was destroyed by an earthquake dating from 484 to 508 BC, which affected also the Salto Valley and Rome.

The biggest challenge for Alzano today is to return to using a solar energy system, but in a modern way. With renewable energy and seismic safety measures, villages and small towns on the Apennine can be revitalized and at the same time offer an alternative to overcrowded cities, providing a more sustainable way of life (Figure 9).

Figure 9. Building roof orientation to the south offers the possibility to use it for the installation of photovoltaic panels.

4. SEISMIC VULNERABILITY ANALYSIS OF ALZANO ORDINARY BUILDINGS

The redevelopment and revitalization of Alzano village cannot be carried out if buildings making up the area are not safe in the case of natural disasters, from earthquakes to landslides.

As mentioned in 2.3, the Salto Valley was affected by numerous seismic events over the last centuries; the seismic events of 2009 (L’Aquila) and 2016 (Amatrice and adjacent areas) affected the entire territory, causing damage to buildings in Alzano as described in 2.3.

The study herein proposed focuses on the seismic vulnerability assessment of ordinary buildings composing the village of Alzano. The study was launched in 2015. Onsite surveys were carried out before the 2016 Amatrice seismic sequence.

The village has 61 structural units (SU) composing 11 aggregate buildings.

58% of SU are intended for residential use, which highlights the vocation of the village. The onsite surveys have been essential in obtaining a comprehensive understanding of typological and constructive aspects of the village, which are fundamental in order to define the building dynamic behaviour. Building surveys, mainly from the outside, aim at collecting data through rapid survey forms, including information about geometric and typological features, vulnerability and the level of damages.

4.1 Recurring construction typologies in the historical centre

Collected data have been statistically analysed in order to define the most common construction features. Starting from these results, the main representative structural elements are taken into consideration for the typologies definition. In particular, vertical elements, horizontal elements and roofs are considered, as they significantly influence building structural behaviour and, at the same time, are the most surveyed data.

Typologies are then identified considering the possible combination between floors, walls and roof types. Figure 10 shows the map representing the 11 typologies, through a colour scale, included in the analysed area. They are characterized by stone, brick or concrete masonry, each one presented alone or in combination with the others in the same typology. Roofs and floors are classified considering their weight (light – till 2.0 kN/m^2, medium – 2.0/4.0 kN/m^2- or heavy – 4.0/6.0 kN/m^2) and their stiffness (rigid or deformable), and matched with the corresponding vertical elements.

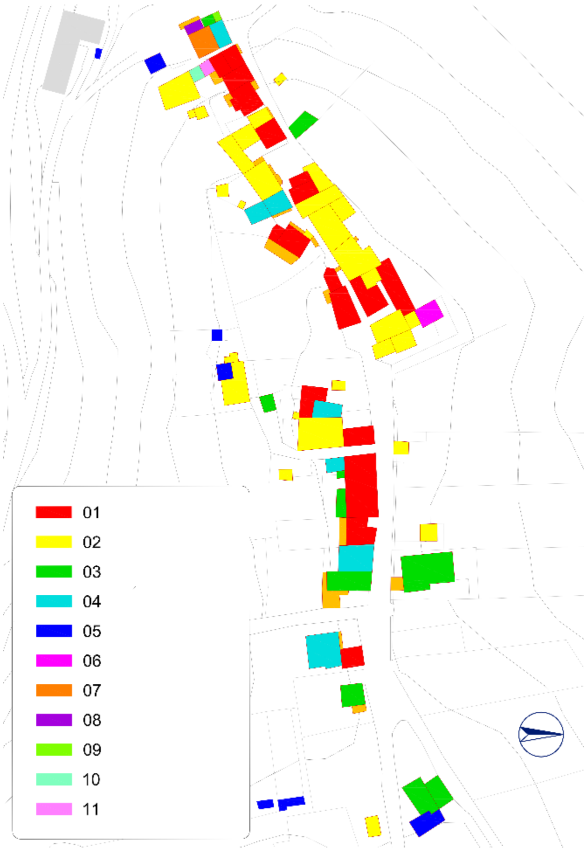


Figure 10. Typological identification of Alzano SU

4.2 The analysis of local mechanisms of collapse to assess the seismic vulnerability of the village

The seismic behaviour of existing masonry aggregate buildings is clearly understandable only in a few cases, because of their complexity and heterogeneous dynamics. Italian codes (NTC 2008) and (Circolare 617/2009) explain that the seismic vulnerability assessment of existing aggregate buildings should be analysed through both an analysis of the most representative local mechanisms of collapse (C8.7.1.1) and a simplified global analysis (C8A.3). This paper describes the vulnerability results obtained by implementing the kinematic analysis of the most representative out of plane local mechanisms of collapse for each typology in Alzano.

Considering the scale of analysis, the study aims at defining a typological vulnerability classification. The main purpose of a study at a territorial scale is the definition of a preliminary vulnerability assessment for the analysed structures; more detailed analyses can then be conducted, reaching appropriate levels of knowledge, on structures that will be more vulnerable at the forefront (DPCM 2011).

However, the main goal is the protection of human life; in this context, the first mode mechanisms are the most dangerous, as their activation should cause the partial or total destruction of buildings, where falling construction material could injure people. Moreover, rubble can prevent the transit of people and rescue vehicles during the post-emergency phases: the knowledge of the most dangerous areas can help local municipality offices define emergency plans and escape routes.

Fragility curves are suited for the graphic representation of these results, providing estimates of the exceedance probability of predefined levels of damage related to the Peak Ground Acceleration (PGA) levels. Obviously, the ultimate goal of the analysis is to provide intuitive, rapid and functional tools allowing technicians, professionals, municipalities and public authorities to define vulnerability assessments/priority lists for buildings typologies, starting from the knowledge of a few known data/parameters.

The definition of typological classifications is fundamental. It allows a preliminary analysis of each building starting from its classification in a predefined typology. Including non-surveyed buildings within the identified typologies allows for extending the vulnerability assessment to other areas not directly involved in the survey procedures.

Obviously, the seismic vulnerability assessment must be accompanied by observations of a professional technician on the possible activation of the analysed local mechanisms of collapse for each SU. The level of analysis adopted for this study requires that building propensity to local out of plane damage could be defined for each typology: it will then be necessary to assess the real possibility of the mechanism activation, based both on boundary conditions and more detailed information about structures (eg connection effectiveness), case by case.

4.3 Main results: fragility curves and vulnerability maps

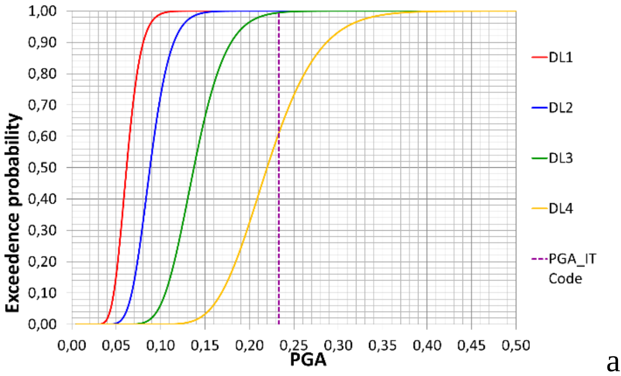
Fragility curves (Shinozuka et al. 2000) for each typology are defined, taking into consideration the most activatable local mechanisms of collapse.

Figure 11 shows the fragility curves related to the local mechanisms of collapse of both whole façades and upper floor, and the vertical bending of the upper floor for the most representative/recurring typology.

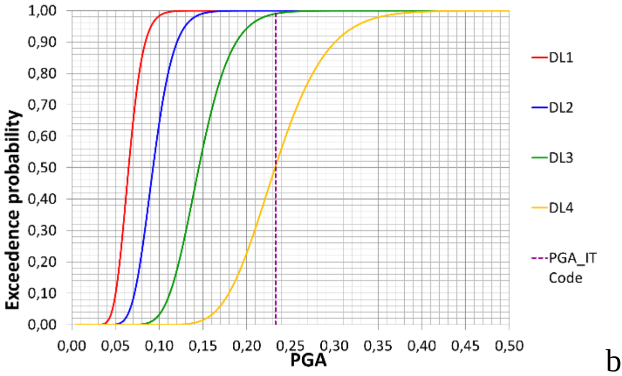
The abovementioned typology is characterized by the following main features:

- two-story buildings;
- rough stones bearing walls;
- flexible wooden floors (2,0 kN/m^2);

light and flexible wooden roofs.



a)



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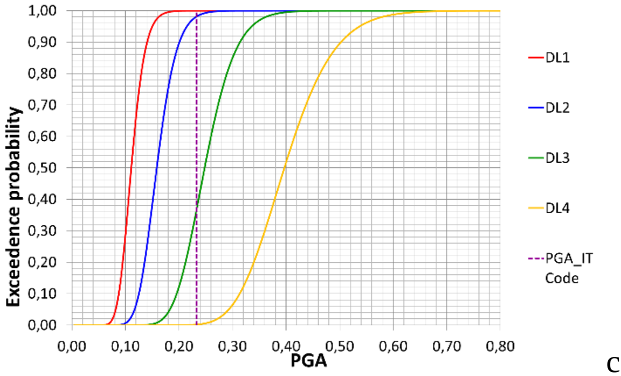

c)

Figure 11. Fragility curves of the most representative building typology in Alzano: simple overturning of the whole façade (a); overturning of walls of the upper floor (b); vertical bending of walls of the upper floor (c)

Considering the PGA level (PGA=0.233g) and the soil conditions (soil category B and topographic category T3) defined by the National code (NTC 2008), in the case of simple overturning mechanism, the exceedance probability for minor to severe damage (from DL1 to DL3) is very high (80-100%), while for very severe damage (DL4) the percentage decreases in a range between 60 and 80%. For upper floor overturning, the same percentages results for minor to severe damage, while the very severe damage is medium (40-60%). As expected, the vertical bending is confirmed as the less vulnerable mechanism, with very high damage percentages for minor to moderate damage, low (20-40%) for severe damage and very low (0-20%) for very severe damage. Obtained assessments are then adopted to create vulnerability maps, in which each range of exceedance probability is represented by using a colour scale. Specifically, the map represented in Figure 12 shows the severe damage (DL3) exceedance probability related to the whole façade overturing mechanism for a PGA=0.233g.

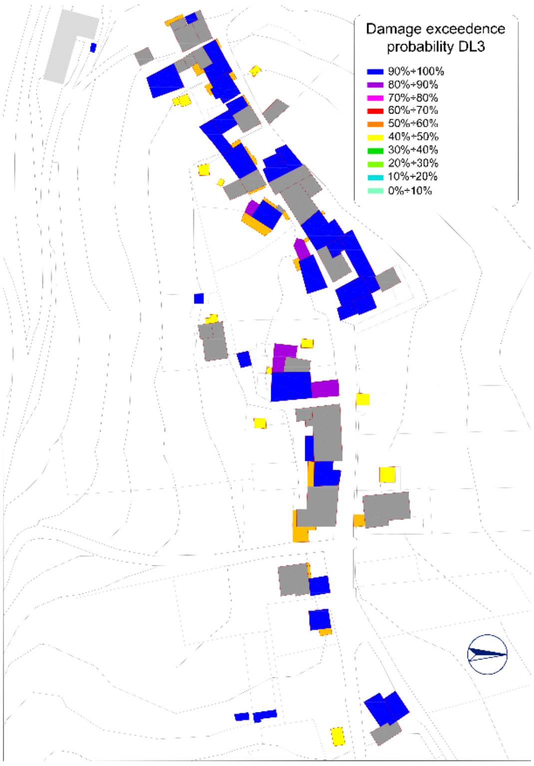

Figure 12. Vulnerability map of whole facade overturning in Alzano (DL3=Damage Level 3, PGA=0,233g). The exceedance probability is typological, as it refers to the most representing building typologies of the village. There is no information about vulnerability for grey coloured buildings

These maps becomes an intuitive tool for technicians of both central and local offices who can use them to immediately define the vulnerability priority list. Results can then be used as an instrument to identify areas or buildings typologies in Alzano that are more inclined to suffer severe damage following a seismic event of a given intensity. At the same time, the definition of more damageable buildings stocks helps in identifying escape routes and safe areas which could be used during the emergency phases. More importantly, the vulnerability assessment makes the plans of development and reconstruction effective by putting the emphasis on the concept of structures and people safety.

5. CONCLUSION

Prevention and mitigation of seismic risk, as proposed and hoped for by Venceslao Amici in his speech at the Italian Parliament of 1915, did not gain adequate consideration in 100 years after.

This paper has been devoted to seismic safety prevention programs of villages of central Apennine by illustrating the preliminary results of the pilot study *"Seismic vulnerability assessment of the small village of Alzano,"* by *DICEA, valledelsalto.it* and *GSES,* started in 2015. The study is the first step in setting up a requalification plan for Alzano, which, just as other small villages in central Italy, has been affected historically by Earthquakes.

The participation in the study of professionals from different backgrounds has stimulated reflections regarding various topics indirectly connected to seismicity, from villages' depopulation to their revitalization.

Regarding depopulation this paper's conclusion is that the cause was primarily the industrial revolution powered by fossil fuels , which interrupted the millennial link between the sole use of renewable solar energy and local rural economies.

Revitalizing Apennine villages today means that we should reconstruct that link in a modern way.

And this reconstruction must go hand in hand with seismic safety prevention initiatives.

From the seismic safety point of view, the study aims at the analysis of the most representative local mechanisms of collapse by adopting a deterministic approach on a typological basis. The seismic vulnerability assessment is carried on at a territorial scale, giving preliminary results about the vulnerability of the main typologies composing the village. All typologies show the activation of the analysed out of plane local mechanisms for the PGA value defined by the National Code. Considering the acceleration levels registered for historic earthquakes the vulnerability levels decreases. However, the vulnerability of the analysed historical typologies is evident, highlighting the need for more detailed studies on individual structures with the aim of defining the specific vulnerability level of each single building.

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