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Seismic risk assessment of precast industrial buildings in Italy by the GEOSAFE platform

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Abstract

Precast industrial buildings play a fundamental economic role due to the production and commercial activities they house. However, due to their structural characteristics and functional importance, they are vulnerable to significant economic losses in the event of an earthquake. In this context, insurance companies are crucial for the financial coverage of earthquake-related losses, and they need to rely on a reliable seismic risk assessment tool. This study focuses on the application of a method to assess the seismic risk of precast buildings using GEOSAFE, a service developed by ANIA Safe. The main objective is to demonstrate the potential of GEOSAFE as a tool for rapid seismic risk assessment of precast industrial buildings. Different scenarios were considered, including both “as-built” and “retrofitted” conditions for existing precast industrial buildings. The risk assessment covers both structural and non-structural components as well as industrial equipment. The results are presented in the form of damage probabilities for each component type, along with graphical outputs generated via the GEOSAFE platform.

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1. Introduction

Precast buildings are an important part of the Italian industrial sector, as they play an essential role in industrial production and commercial activities. Thousands of such structures were built in Italy in the second half of the 20th century, often before the introduction of comprehensive seismic design regulations. The widespread adoption of precast systems was mainly driven by the numerous advantages they offer compared to cast-in-place concrete structures, in particular better control of material quality and shorter construction time. These buildings usually consist of single-story structures. Assessing their seismic vulnerability is crucial to ensure business continuity and protect economic investments. Despite the simplicity of their structural design, which usually consists of prefabricated RC columns, beams and roof elements, precast buildings have complex seismic behavior. Severe earthquakes that have struck Italy in recent decades, such as the L'Aquila event in 2009 and the Emilia event in 2012, have caused widespread damage to precast buildings and revealed their inherent vulnerability [Toniolo et al. (2012); Belleri et al. (2016); Belleri (2017); Dal Lago et al. (2018)]. A pronounced susceptibility to various failure mechanisms has been observed, especially in older buildings where poor structural details and inadequate connections are common [Eteme Minkada et al. (2021); Labò et al. (2022)]. It is important to note that the observed damage affected not only older structures but also some newer constructions. Given the potential losses and economic consequences associated with seismic damage to precast industrial buildings, the need for efficient risk assessment methods has become increasingly urgent. In recent years, researchers have made significant efforts to assess the seismic vulnerability and risk of both existing and code-compliant precast buildings [Casotto et al. (2015); Magliulo et al. (2018); Iervolino et al. (2018); Iervolino et al. (2019); Bosio et al. (2022); Iervolino et al. (2022)]. However, conventional methods for seismic risk assessment are usually resource-intensive and require detailed modeling and specialized engineering knowledge. Such methods are not readily adopted by stakeholders such as insurance companies who require simple, reliable and scalable tools to assess seismic risk for large building portfolios.

To address this challenge, GEOSAFE, a digital platform developed by ANIA Safe, provides an automated and streamlined seismic risk assessment framework tailored to the insurance industry. It enables users to estimate the expected risk for both structural and non-structural components, including industrial assets, based on a limited number of key input parameters. This study illustrates the applicability and efficiency of the GEOSAFE industrial risk tool using a case study of a typical industrial building from the 1970s. The analysis considers two construction sites (Modena and L'Aquila) and two structural states: as-built and retrofit.

2. Seismic vulnerability and code evolution for precast buildings

Previous earthquakes in Italy have shown that precast industrial buildings are very vulnerable, often leading to partial or complete collapse. A notable reference is the seismic sequence that occurred in the Emilia-Romagna region in 2012. These earthquakes affected a large and economically vital area, whose productive system generated an added value of 19.6 billion euro in 2011, equivalent to about 2% of the national added value [Dipartimento della Protezione Civile (2012)]. Field investigations and subsequent research [Belleri et al. (2015); Brunesi et al. (2015); Belleri et al. (2016); Belleri (2017); Belleri et al. (2017); Belleri et al. (2018); Lago et al. (2018); Torquati et al. (2018); Ercolino et al. (2018); Bosio et al. (2020); Savoia et al. (2017); Bressanelli et al. (2021)] identified the most common collapse mechanisms in precast buildings. Global collapses were often due to the inadequate seismic response of the connections between precast elements. Local collapses included loss of roof elements, failure of RC fork connections with subsequent out-of-plane collapse of supported beams, failure of perimeter elements (e.g., masonry infill or cladding panels), and plastic flexural failure at column bases leading to overturning. To understand these deficiencies, a broader look at the evolution of seismic design codes is needed. As shown in Figure 1, prior to 2003, Italy had a limited number of seismic zones, with certain areas categorized as seismically safe and many others not. The regulations were usually issued by special decrees after major earthquakes and applied only to the affected regions. A formal seismic zoning system was first introduced in 1926 [Regio Decreto 3 aprile n. 705 (1926)] and established seismic categories. For example, the provinces of Calabria and Messina were classified as Category 1 (high seismic risk), while cities such as Ancona, Perugia, Siena and Grosseto, which have been affected by earthquakes in recent times, were assigned to Category 2, which indicates a lower seismic risk. Based on this classification, different building regulations applied depending on the zone. This inconsistent legal framework contributed to many buildings being

constructed without adequate earthquake protection measures. An important turning point was the OPCM Decree No. 3274 (2003), which introduced a comprehensive classification of the entire national territory into four seismic zones. From this point onwards, earthquake-resistant construction became mandatory for all new buildings, a development that has been reinforced by updates to national building codes such as NTC08 (2008) and NTC18 (2018). It is important to note that buildings constructed prior to the 1980s, particularly those of prefabricated construction, typically used simple friction-based connections for the structural elements [Belleri and Labò (2021); Belleri et al. (2014); Angiolilli et al. (2022)], with little or no detailing to meet seismic requirements. Many of these buildings were constructed in regions that were not yet classified as earthquake-prone at the time, which increased their vulnerability. In summary, the 2012 Emilia earthquakes provided important lessons to the scientific and engineering community by highlighting both the delayed development of seismic regulations and the deficiencies in the structural performance of existing precast industrial buildings.

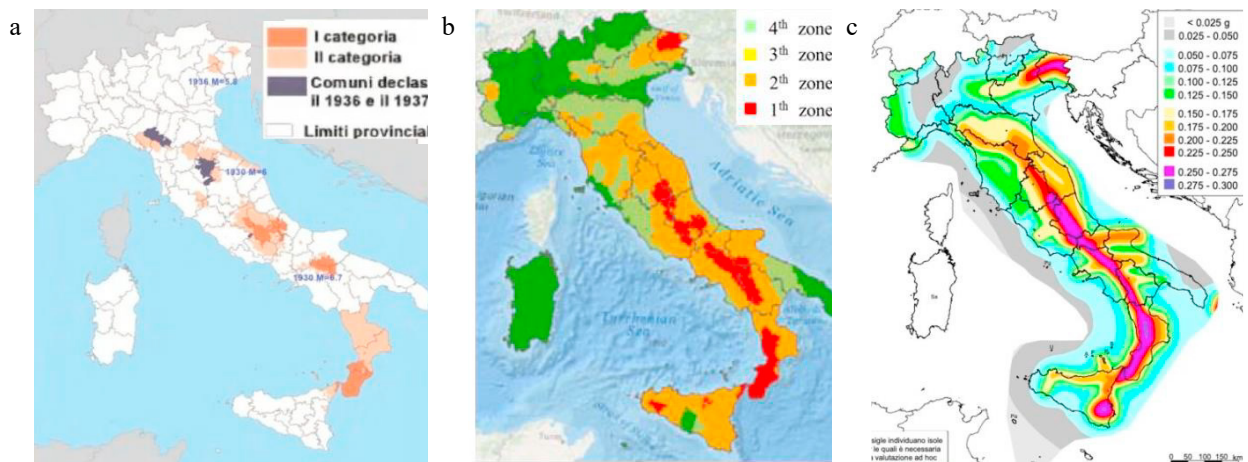


Fig. 1. Seismic classification map of Italy in: (1937), (b) 2003, (c) 2005.

3. GEOSAFE platform and seismic risk assessment

This section briefly introduces the GEOSAFE platform and focuses on demonstrating its core capability to provide a first level seismic risk assessments using a limited number of input parameters related to the building and site.

3.1. GEOSAFE platform overview

GEOSAFE is an innovative service developed by ANIA Safe to support companies in various phases of risk assessment and business process management. Among the latest innovations of the GEOSAFE platform is the “industrial seismic risk” (“rischio sismico industriale” in Italian) tool, developed for the seismic risk assessment of single-storey precast industrial buildings, including structural elements, non-structural components and industrial equipment. It is important to emphasize that the procedure implemented in this tool was developed as part of a research project carried out at the University of Bergamo for ANIA Safe and that herein only its application is addressed. In short, the approach integrates both quantitative and qualitative assessments by combining fragility curves with a taxonomy-based classification system to estimate seismic demand states. Thanks to its user-friendly interface and advanced features, the tool streamlines the seismic risk analysis process and produces final reports that can be easily interpreted by operators without structural engineering expertise. Users interact with the platform by entering key building data (Figure 2), which allows the tool to define seismic inputs and perform the risk analysis. Among the required information, three minimum inputs are mandatory (indicated by an * in the user interface): the location of the building, the year of construction and the building height. The location is selected via a pointer on an interactive map; the year of construction is selected from a drop-down menu with three options: before 1984, between 1984 and

2003 and after 2003; and the building height is entered as a numerical value. In addition to these parameters, the tool allows the input of additional information such as previous retrofit measures, the distinction between local and global measures, the presence of structural irregularities, the type of external closure, and the presence or absence of an overhead crane.

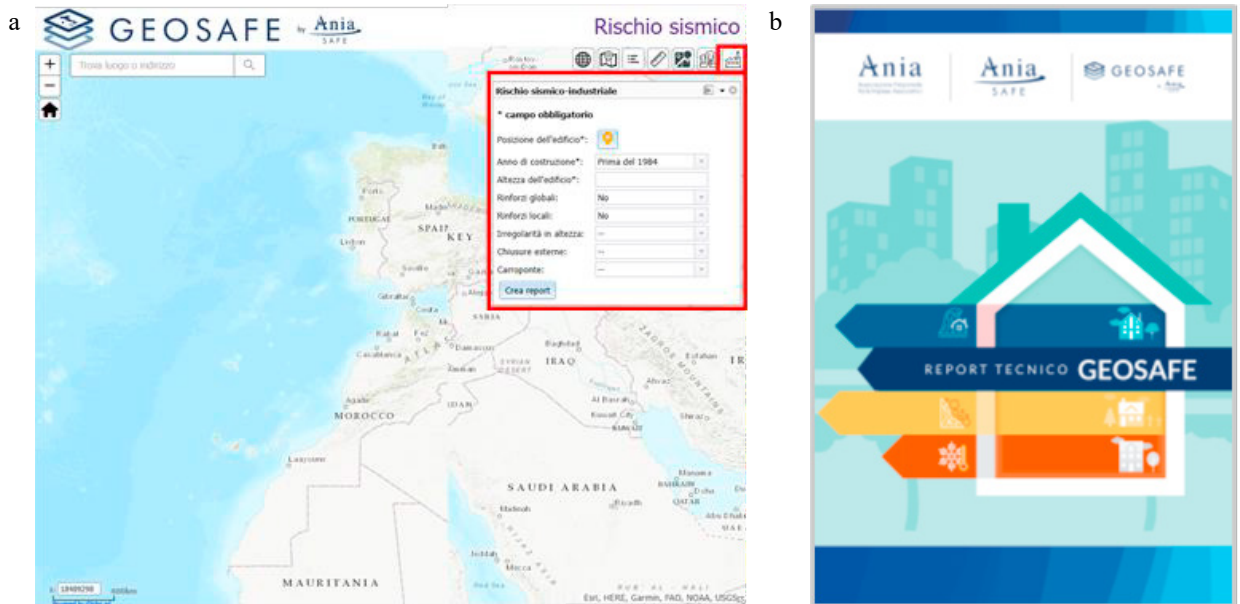


Fig. 2. (a) Interface of the seismic risk tool highlighting the required information (* indicates mandatory fields); (b) cover page of the final report.

Once all the data has been entered, the operator starts the analysis, and the platform generates a report with the results of the seismic risk assessment. The first section contains a comprehensive summary with site coordinates, year of construction, building height and other relevant details. The following sections indicate the risk levels for each category of building components (structural, non-structural and contents).

The results are displayed using an intuitive color-coded system that simplifies reading and interpretation (as shown in Fig. 3). It is worth noting that the tool divides the risk for each element into five ascending levels, from L1 to L5, and includes a minimum level, L0, which represents a risk below the minimum assessable threshold.

3.2. Case study and results

The reference building considered herein is a representative example of a typical existing industrial building with a rectangular floor plan and construction details that reflect the design criteria commonly used in Italy in the 1970s. The building has an overall height of 6.50m and has brick infill panels as external cladding. An overhead crane is also present in the facility. To evaluate the impact of the seismic hazard and the effectiveness of the retrofitting strategies, the building was analyzed under two different site conditions: building located in Modena and in L'Aquila, which represent two different seismic zones in Italy. According to the current seismic classification, Modena falls in Zone II, where the expected peak ground acceleration (PGA) is between 0.15g and 0.25g, while L'Aquila belongs to Zone I, with PGA values between 0.25g and 0.35g. Two structural configurations were considered for each site:

- As-built condition: representing the original design with no seismic upgrading, typical of pre-1984 construction.
- Retrofitted condition: involving local strengthening interventions in the roof system.

The results of the risk assessment are shown in Figure 3, using the graphical representation defined by the GEOSAFE tool and previously described in Section 3.1. In order to represent both the as-built and retrofitted configurations in the same matrices, empty circles are used for the as-built condition and filled circles for the retrofitted condition, indicating the level of risk for each building component. In both sites Modena (Figure 3a) and L'Aquila (Figure 3b), the roof system has the highest seismic risk level (L5) in the as-built condition. This risk is significantly reduced after local retrofitting measures and drops to L0 in Modena and L2 in L'Aquila. This behavior is in line with the known vulnerability of typical pre-1980s industrial buildings, where the roof elements are usually connected by simple friction joints. The columns have a low risk level (L0) at both locations in their current state. After retrofitting, their risk level in L'Aquila rises to L2, while it remains unchanged in Modena. This result must be interpreted in the context of the global response of the building. In the actual state, a premature failure of the roof prevents the correct transfer of lateral loads to the columns, masking their real vulnerability. Once the roof system is strengthened, the seismic forces are effectively transferred to the vertical elements, leading to a more realistic assessment of their seismic demand. It is important to emphasize that the same retrofitting strategy, when applied in two different seismic zones, leads to similar absolute improvements, but its relative effectiveness is more pronounced in Modena, where seismic vulnerability is lower. In L'Aquila, despite the improvement, the columns still show a residual risk of L2 in the retrofitted state. For the non-structural elements (such as masonry infills, windows, drywalls and internal doors), the overall risk values remain unchanged between the as-built and retrofitted scenarios. In Modena, masonry infills, and windows are assigned to risk level L1, while drywall and interior doors are assigned to risk level L2. In L'Aquila, all non-structural elements are assigned to risk level L2. It is important to note that for certain components, such as drywall and interior doors, L2 is the only possible risk level, which means that they are no longer functional once this level is reached.

The contents, including the industrial equipment, differ only minimally between the two scenarios. In both Modena and L'Aquila, the overhead crane and the electric elevator remain at risk level L3 throughout. The hydraulic elevator is classified as L0 in Modena and L3 in L'Aquila, while the refrigerator changes from L0 to L2. An exception can be observed in Modena, where the storage racks show a significant improvement and move from risk level L3 to L0 after retrofitting. This once again underlines the effectiveness of local retrofitting measures, especially in regions with moderate seismic risk, and demonstrates the sensitivity of the GEOSAFE tool in capturing risk differences between components and locations. Overall, the results emphasize the importance of a component-based approach to seismic risk assessment. The analysis shown herein considers the individual risk of each component without considering a collapse hierarchy. This assumption allows a clear comparison of the expected performance of structural, non-structural and content elements, although it does not take into account possible interaction effects. The issue of collapse hierarchy in precast buildings, especially between structural and non-structural components, is addressed in Bosio et al. (2020).

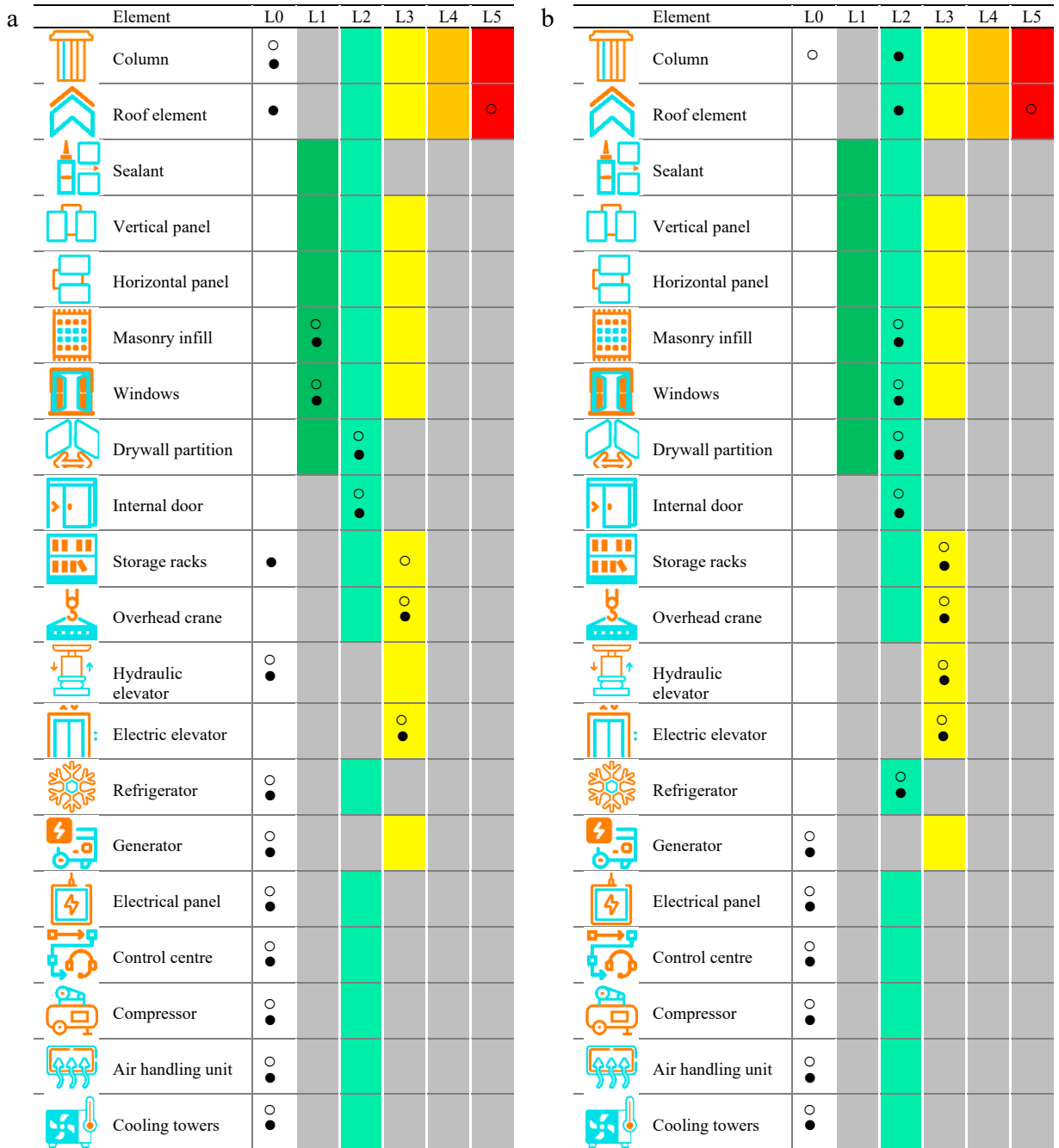


Fig. 3. Seismic risk levels for Emilia (a) and L'Aquila (b) site. Note: the empty circles refer to the as-is condition, while the filled ones refer to the retrofitted condition.

4. Conclusions

This paper presents an application of the seismic risk assessment tool integrated in the GEOSAFE platform, focusing on prefabricated industrial buildings. The tool was shown to provide a practical and efficient solution for seismic vulnerability assessment using a limited number of key input parameters related to building characteristics and site conditions. Using the case study of a typical 1970s industrial building exposed to various seismic hazard levels and retrofit scenarios, the application demonstrated the tool's ability to effectively distinguish risk levels for structural, non-structural and content components. The results emphasized the pronounced vulnerability of as-built roof systems and highlighted how targeted local retrofits can significantly mitigate these risks, particularly in regions of moderate seismic exposure. It is crucial that users carefully interpret the results of the tool and recognize the dependencies between the different elements (structural, non-structural and content) in relation to the occurrence of damage. For example, a low risk to the contents is unlikely if the roof is expected to collapse, as such an event would likely cause significant damage to the interior. Understanding and considering these interrelationships between elements is critical to accurately assessing the overall risk of the building.

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