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Eccomas Proceedia COMPDYN (2025) 4066-4084

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COMPDYN 2025
10th ECCOMAS Thematic Conference on
Computational Methods in Structural Dynamics and Earthquake Engineering
M. Papadrakakis, M. Fragiadakis (eds.)
Rhodes Island, Greece, 15-18 June 2025

ENRICH PROJECT: ENHANCING THE RESILIENCE OF ITALIAN HEALTHCARE AND HOSPITAL FACILITIES

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Abstract

Nonstructural elements have gained significant attention in the field of structural and earthquake engineering, as it was proven their critical seismic response and their major influence on seismic risk and losses. In the last two decades, several studies investigated the seismic response of nonstructural elements, implementing observational, experimental, theoretical, and numerical investigations, and this significantly expanded literature knowledge and design/assessment methods. The next challenges in the field involve moving beyond individual structural or seismic evaluations to embrace more holistic and comprehensive approaches that integrate multiple aspects of assessment and improvement. This includes considering the

Peer-review under responsibility of the organizing committee of COMPDYN 2025.
doi: 10.7712/120125.12715.25 76

interplay between structural and nonstructural elements, operational functionality, and systemic resilience.

The present study summarizes the research innovations carried out in the framework of the ENRICH project, a national relevance Italian project (PRIN) aiming at assessing and enhancing the resilience of healthcare facilities, with a focus on both seismic risk and functional adaptivity, directly accounting for nonstructural elements and organizational aspects. Launched in 2022 and concluded in 2025, ENRICH involved five research units, including University of Naples Federico II, University of Salento, University of Sannio, National Institute of Geophysics and Volcanology (INGV), and Construction Technologies Institute (ITC) of National Research Council (CNR). The project takes a multi-criteria approach, combining various methods: field data collection in hospitals, non-destructive in situ tests, laboratory experiments, analytical and numerical simulations, statistical analyses, data management and the development of BIM tools and communication strategies. Theoretical, experimental, numerical, and observational methods were implemented in the project in order to assess seismic vulnerability/risk, flexibility associated with pilot healthcare facilities, aiming at estimating a simplified but meaningful measure of resilience. Communication strategies were also developed to raise stakeholder awareness and enhance systemic healthcare resilience. ENRICH findings demonstrate significant contributions to both research and practical applications, benefiting public safety and the economy while laying the groundwork for future research funding. The outcomes are expected to have broad applicability across regions, with their implementation likely to deliver substantial social and economic benefits in Italy and internationally.

Keywords: ENRICH project, Hospital, Resilience, Seismic, Nonstructural Element, Seismic Risk.

1 INTRODUCTION

Hospitals and healthcare facilities are the backbone of societies, but their ability to fully function during and after seismic events is often compromised by vulnerabilities in nonstructural elements, which include elements that are not part of the structural system such medical equipment, utility networks, and architectural elements that [1]. These elements are crucial for daily operations of hospitals and healthcare facilities [2]. Recognizing this challenge, a multi-institutional research project launched in 2022 aims to enhance the resilience of Italian healthcare infrastructure by improving both seismic performance and functional adaptability.

Project PRIN 2020 ENRICH (www.enrichproject.it) tries to answer the following question: How can hospitals continue to operate safely in the face of seismic hazards and emergencies? In addition to an extensive assessment related to seismic response and functional adaptivity, the project aimed to develop innovative methods and practical solutions, from new technological advancements to strategic planning tools, that help professionals and stakeholders to take proactive steps toward risk mitigation.

To tackle this complex challenge, the project integrates multiple research methods into a comprehensive strategy: (a) field inspections of healthcare facilities provide firsthand data on real-world vulnerabilities; (b) experimental testing, both in laboratories and on-site, helps evaluate how nonstructural elements behave under seismic conditions; (c) numerical and analytical simulations allow researchers to predict damage scenarios and optimize design improvements; (d) statistical analyses refine findings, identifying key risk factors and performance trends; (e) implementation of design and maintenance tools ensures that research outcomes translate into practical applications for engineers and facility managers; (f) targeted communication strategies raise awareness among decision-makers, ensuring that resilience measures are understood and widely adopted. This structured approach allows researchers to move beyond theory, ensuring that the knowledge generated leads to tangible improvements in healthcare safety and preparedness.

The significance of this project extends far beyond academia. By focusing on practical applications, it has the potential to transform how hospitals prepare for and respond to seismic events. The benefits account for social impact: a more resilient healthcare system ensures that hospitals remain operational when they are needed most, protecting patients, medical professionals, and emergency responders, and economic impact: preventing damage to critical medical infrastructure reduces recovery costs, minimizes downtime, and safeguards essential healthcare services. Moreover, the strategies developed in this project are not limited to Italy. The methodologies, technologies, and best practices can be adapted to other seismic-prone regions, making this research a potential global reference for hospital resilience.

Led by Prof. G. Magliulo from the University of Naples Federico II, this initiative brings together leading institutions in structural engineering, geophysics, and construction technologies: University of Naples Federico II (UNINA), University of Sannio (UNISANNIO), coordinated by Prof. G. Maddaloni, University of Salento (UNISALENTO), coordinated by Prof. M.A. Aiello, National Institute of Geophysics and Volcanology (INGV), coordinated by Dr. G. Musacchio, and Institute for Construction Technologies (ITC-CNR, National Research Council), coordinated by Eng. A. Bonati. By combining scientific expertise with practical implementation, this project is paving the way for a future where hospitals are better prepared, safer, and more resilient, ensuring that healthcare services remain uninterrupted when they are needed most.

The present paper presents in a synthetic manner the methodological advances and findings of the project, referring to the relevant published works for details.

2 SURVEYS AND IN-SITU TESTS

2.1 Technical surveys in healthcare facilities

In-site surveys were carried out in health facilities in Benevento and Caserta (WP1a- field data acquisition) in order to highlight any deficiencies for the main nonstructural elements and systems. At the same time the importance of the functionality of each component and the extent of the damage that component can cause in the event of leaving service is evaluated. In-site surveys revealed inadequate anchorages of tanks to the concrete plate below (Figure 1a) and the presence of rigid connection between supply methane gas pipe and boiler (Figure 1b), therefore an earthquake could cause a disconnection of the pipes and a release of gas that could give rise to an explosion. Regarding the suspended pipe systems (water, steam, methane gas), surveys revealed that they do not have any kind of bracing but are simply resting on metal bars with a space of about 2 m. Moreover, the pipes that cross the walls and the floors do not have any type of flexible joint but are cemented (Figure 1c), this means that deformations or breakages induced by the earthquake can easily occur.


(a) (b) (c)

Figure 1: Nonstructural elements deficiencies detected during in-situ surveys.

Starting from the results of in-situ surveys and analyzing the literature about the experiences of hospitals during past earthquakes, the most critical nonstructural elements to be analysed have been identified (WP1b- critical case identification). More specifically, it was found that the complexity of nonstructural elements in hospitals and health facilities is due to the presence of extensive networks of mechanical, electrical and piping systems essential for essential functions. These systems are critical services on which the operation of a hospital depends. Furthermore, inside a hospital, partition walls of small thickness used to subdivide interior spaces, as well as partition walls with greater thickness can be found. The latter are often used for fire compartmentalization or in the separation of rooms with increased radiation risk. These walls are sensitive to deformation of the structure and can suffer both in-plane and out-of-plane damage. In addition, the debris from broken walls may clog emergency exits and be particularly dangerous in stairwells and lift shafts. Moreover, often partition walls are used as side support for pipes, electrical cabinets, storage racks or other nonstructural elements therefore their failure can in turn cause damage to pipes or other installations that pass inside.

For the above reasons, the utility piping systems and the partition walls are selected as critical case studies to be analysed in detail through in-situ dynamic tests, i.e., modal identification testing (WP1c- in situ experimental tests). An extensive in-situ experimental campaign has been carried out to identify the nonstructural elements' dynamic properties.

The two classes of nonstructural elements have been tested i.e., piping systems with two specimens: a fire-fighting system (Figure 2a) and a heat water piping system (Figure 2b) and partition walls with two specimens: masonry partition wall 15 cm (Figure 3a) and 37 cm thick (Figure 3b).


(a) (b)

Figure 2: Fire-fighting system and (b) heat water piping system tested.


(a) (b)

Figure 3: (a) 15 cm-thick and (b) 37 cm-thick partition walls tested.

2.2 In-situ dynamic identification tests

The dynamic identification has been performed through several ambient vibration tests (AVTs). The adopted procedure included:

- measuring the acceleration time-histories of interest using uniaxial accelerometers during the normal operation of the nonstructural component;
- constructing the PSD plots using the FFT algorithms;
- identifying the natural frequencies of the nonstructural component through well-known OMA (operational modal analysis) techniques including, Frequency Domain Decomposition in the frequency domain [3] and stochastic subspace techniques in the time domain [4].

A detailed description of the in-situ experimental campaign results can be found in [5,6]. A testing program on a full fire protection system was carried out in the laboratory of Civil Engineering (LInC) at the University of Sannio in Benevento (Figure 4). The novelty of the proposed testing system is the capacity of testing the network under pressure thanks to the use of a full-scale pumping system. The proposed test setup and the fire extinguish network allows to reproduce different types of damage to the system such as damage to the pipes and joints under imposed lateral drift, damage to the sprinkler or pipes supports, capabilities of changing the support configuration. Furthermore, the network has been equipped with a health monitoring system capable of detecting variation in the status of the physical network and check the attainment of the alert thresholds. Laboratory tests are ongoing, and results will be available in future publications.

Figure 4: Fire protection piping system under test.

3 EXPERIMENTAL METHODS AND APPLICATIONS

3.1 Shake table testing protocol

Shake table testing represents the optimal method for assessing acceleration-sensitive and acceleration-/displacement-sensitive nonstructural elements [7,8]. A novel shake table protocol is proposed to improve the seismic assessment and qualification of acceleration-sensitive nonstructural elements [9]. The need for this development arises from a critical review of existing protocols, which reveals significant limitations and highlights the necessity for more advanced methodologies.

The proposed protocol is designed to address these gaps by integrating recent advancements in the field and leveraging the research team's expertise. Its most significant contributions lie in the definition of novel required response spectra and the generation of tailored input signals for seismic performance evaluation tests. Equation (4) shows the proposed formulation of the required response spectrum (RRS) used as a reference for the development of the seismic performance evaluation seismic input, which complies with the Italian building code [10,11]. The protocol was implemented in recent literature studies, developed in the framework of ENRICH project, referring to analytical/numerical studies [12] and experimental tests [13].

$$\frac{S_a}{(\alpha S)} = \begin{cases} 4\,(1+z/H) + \dfrac{(1+z/H)}{(f_1 - f_0)}\,(f_a - f_0) & \text{for } f_a < f_1 \\ 5\,(1+z/H) & \text{for } f_1 \le f_a < f_2 \\ \left[\dfrac{5\,(1+z/H)}{1+4\left(1-\dfrac{f_2}{f_a}\right)^2}\right] & \text{for } f_a \ge f_2 \end{cases} \tag{1}$$

In Equation (1), α is the ratio between the design peak ground acceleration on stiff soil for the relevant limit state and acceleration of gravity, S is the soil amplification factor, z is the height of the building point of attachment of component, measured from the foundations, H is the average roof height of the building measured from the foundations, T_a the fundamental period of the component-attachment system, T_1 is the fundamental period of the building, and a, b, and a_p are parameters defined according to the fundamental period of the building [11].

To validate its effectiveness, the protocol is assessed using real floor motions as a reference. The results confirm protocol reliability and robustness while demonstrating clear advantages over existing alternatives. Furthermore, the approach is inherently flexible, allowing for easy adaptation to different case studies and applications.

A specific study [12] was carried out to investigate the seismic reliability of shake table testing protocols for seismic assessment and qualification of acceleration-sensitive nonstructural elements, including the abovementioned protocol (Figure 5). The analysis follows an incremental approach, modeling nonstructural elements as inelastic SDOF systems across a broad frequency range of interest. Real floor motions recorded in instrumented reinforced concrete (RC) buildings serve as a reference. Reliability is assessed by considering multiple damage states (DSs) and various sets of floor motions. Specifically, the seismic capacities associated with real floor motions (from the shake table protocol) are treated as actual-demand (nominal-capacity) measures, and the demand-to-capacity margin is interpreted as the protocol's overestimation of NE capacity.

Based on the estimated protocol reliability, capacity safety factors are determined and depicted in Figure 6. The use of the abovementioned factors allow to implement the investigated protocols, including the protocols developed in the framework of ENRCH project, ensuring the desired level of reliability.

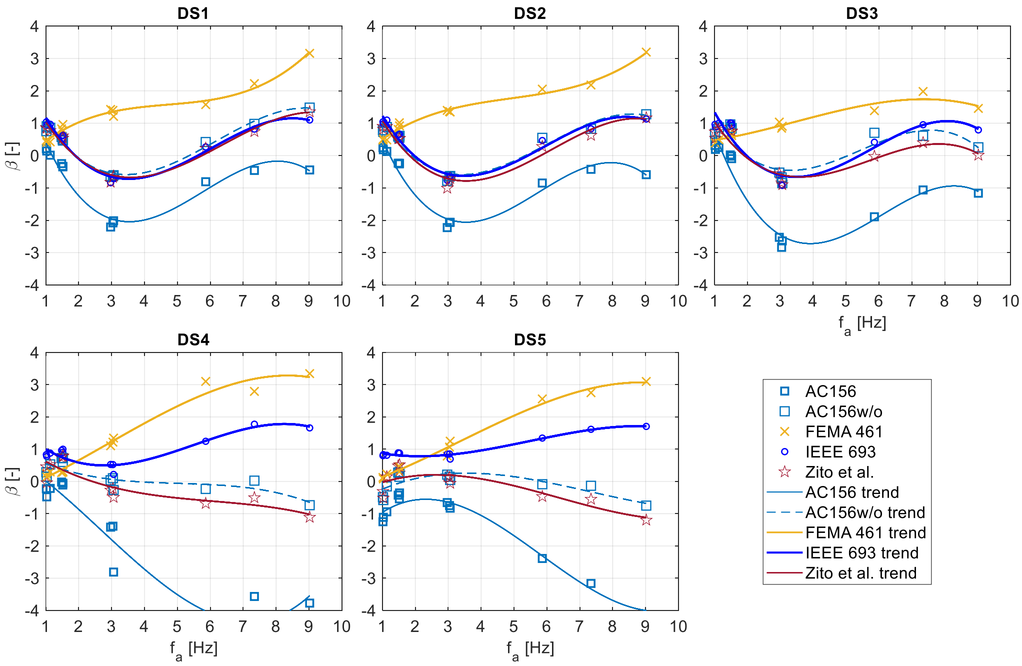


Figure 5: Reliability index (β) corresponding to the minimum β envelope of the investigated FM sets, associated with the elastic frequency of the investigated models (markers) and fitting curves (III-degree polynomial equations), estimated for all protocols and damage states (DSs) [12].

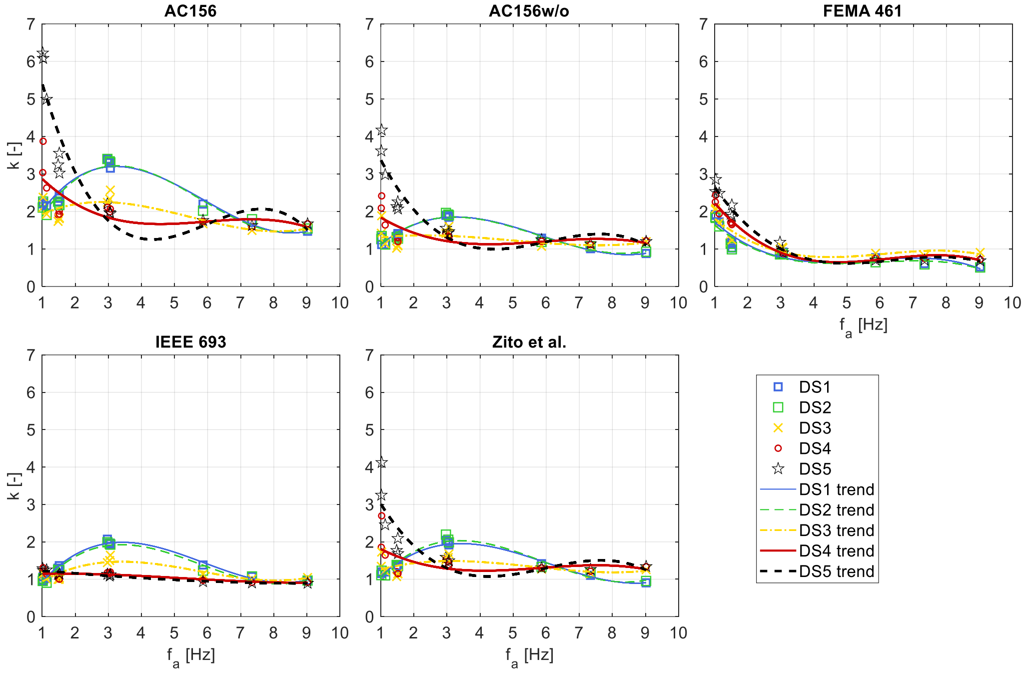


Figure 6: Safety factor (k) corresponding to the maximum k envelope of the investigated FM sets, associated with the elastic frequency of the investigated models (markers) and fitting curves (III-degree polynomial equations), estimated for all damage states (DSs) and protocols [12].

The implementation of the abovementioned protocol in both research and practice has the potential to significantly enhance the seismic qualification of acceleration-sensitive elements. Its widespread adoption could lead to meaningful improvements in public safety and economic resilience.

3.2 Innovative testing procedure and experimental application

An experimental procedure aimed at the assessment of the seismic performances of the selected NCs is proposed.

The experimental procedure consists of:

- out-of-plane (with respect to the component plane) dynamic tests;
- in-plane crescendo tests.

The two kinds of tests have to be applied to each system separately. Then, the seismic as-assessment is pursued trough the identification of two engineering demand parameters (EDP) representative of the behavior under seismic actions of the studied nonstructural component. For the selected NCs the two following EDP are selected:

- the acceleration in the component center of gravity measured during out-of-plane dynamic tests, synthetically indicated as in Equation (2).

$$a_{g,DSi,out} \quad [g] \tag{2}$$

where:

- a_g indicates the maximum acceleration recorded in the centre of gravity of the component.
- DS_i indicates the i-th achieved limit states, with i=1, 2 or 3;
- out represents the out-of-plane direction;
- inter-story drift ratio measured during in-plane crescendo tests, indicated as Equation (3) reports.

$$\Delta_{dmax,DSi,ip} = \frac{D_{max}}{h} \quad [\%] \tag{3}$$

where:

- D_{max} is the difference between top and bottom displacements applied to the specimen;
- h is the height of the tested specimen;
- DS_i indicates the i-th achieved limit states, with i=1, 2 or 3;
- i_p represents the in-plane direction.

In order to be representative of the seismic behavior of the tested elements, these parameters shall be associated with the achievement of defined damage limit states. According to literature, three limit states can be defined: DS1 (minor damage) - implies the need to slightly repair the component, in order to restore its original condition; DS2 (moderate damage) - signifies that the component is damaged and therefore implies the need to partially replace it; DS3 (severe damage) - implies that the level of damage reached is such that the component must be completely replaced or the safety of the occupants is not guaranteed.

Starting from the latter definitions, a specific damage scheme has been drawn up for both internal partition kits [14] and for façade kits [13], in which damages are identified for each kit component and for each assigned damage limit state.

The damage scheme represents the reference for the identification of the damage limit state achievement during the tests. Values of out-of-plane acceleration, recorded in the specimen center of gravity and corresponding to the achievement of each defined damage state will represent the engineering demand parameters for the assessment of the seismic behavior of the specimen in the out-of-plane direction.

In a similar way, values of in-plane drift ratio, corresponding to the achievement of each defined damage state, $\Delta_{dmax,DS1,ip}$, $\Delta_{dmax,DS2,ip}$, $\Delta_{dmax,DS3,ip}$, will be representative of the in-plane seismic behavior of the tested partition.

The applicability of the proposed procedure has been assessed by an experimental campaign conducted on three types of internal partition kits: a glass partition, a glass-wood mixed partition and a wood partition. The main results of such tests are reported in Coppola et al. 2024 [14]. Further experimental tests have been carried out on a ventilated façade system and sandwich panel façade system confirming the suitability of the experimental procedure aiming at the seismic qualification of the selected nonstructural elements [13] and showing the great potentiality of the testing machine used to carry out the tests, shown in Figure 7, located at the Institute for Construction Technologies (ITC) of the National Research Council (CNR) in San Giuliano Milanese (MI).

Another experimental study was partially funded by ENRICH project, and it refers to shake table tests of an innovative cleanroom [15]. Full-scale shake table tests were conducted on the cleanroom following the ICC-ES AC156 protocol [16], with the cleanroom tested under operational conditions (Figure 8). The study evaluated both the dynamic properties and seismic response of the cleanroom. The results demonstrated the cleanroom's exceptional seismic behavior, highlighting that even simple devices can substantially enhance the seismic performance of nonstructural elements. The cleanroom was demonstrated to remain fully operational even under very high seismic intensities, such as peak floor accelerations exceeding those typically observed in regions with high seismic activity (e.g., Italy and Europe). It was also shown that the seismic demand peak floor acceleration (PFA) corresponding to the life safety limit state (LSLS) for a high-seismicity Italian site and strategic buildings was lower than the maximum PFA tested.

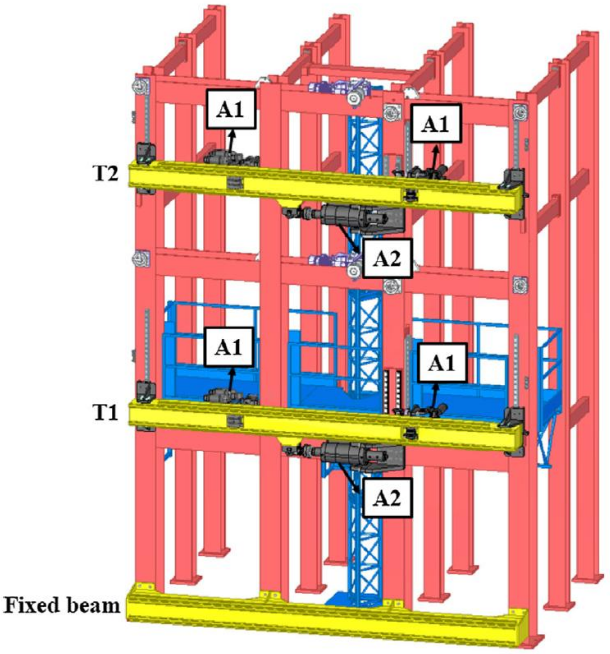


Figure 7: Schematic view of the ITC-CNR test facility [13].

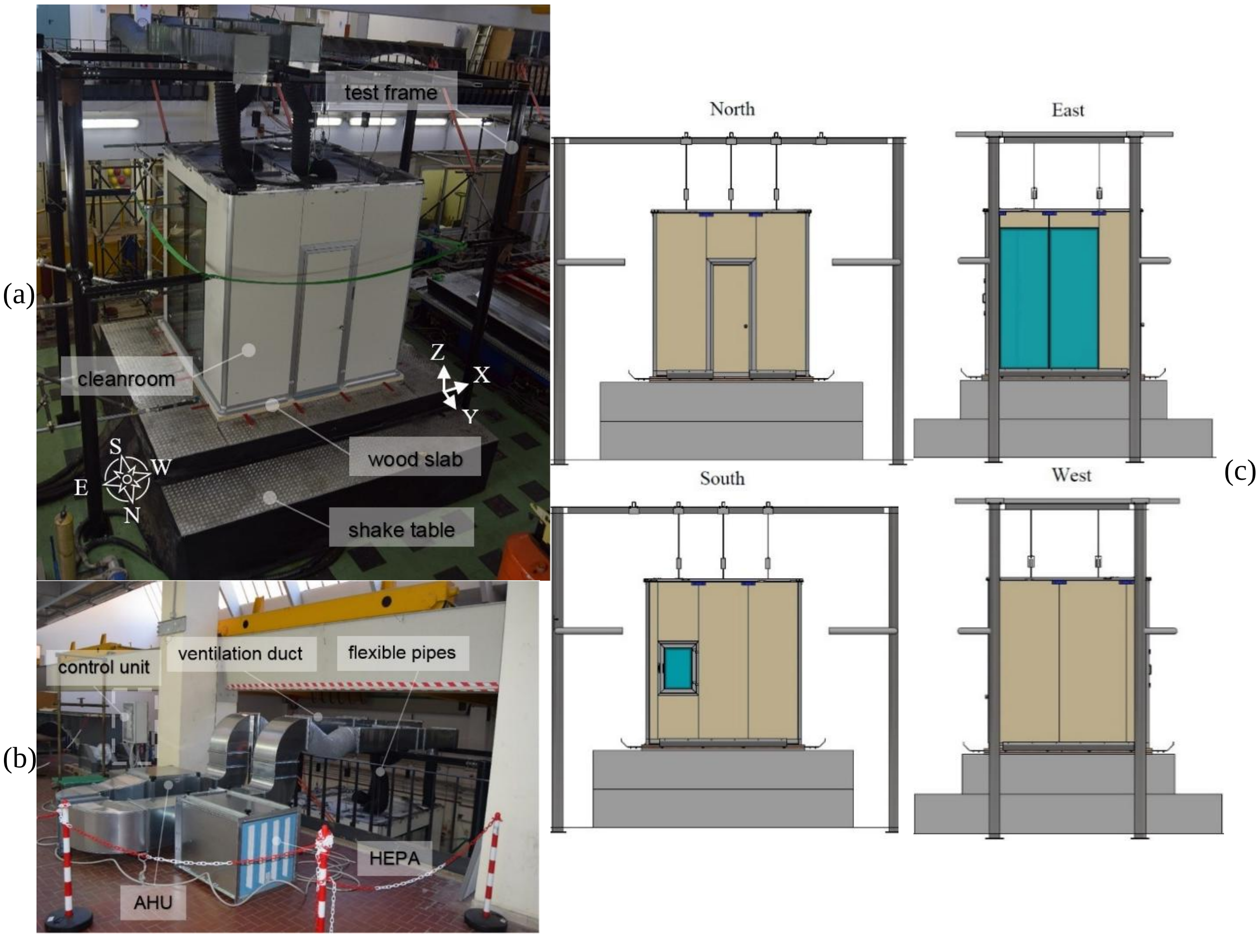


Figure 8: Cleanroom specimen and test setup [15].

4 SEISMIC CAPACITY AND SAFETY ASSESSMENT

4.1 Rocking-dominated elements and inelastic SDOF systems

This study focuses on establishing methodological guidelines and quantifying seismic capacity and safety for nonstructural elements. By evaluating the seismic response of rocking blocks (RBs) and inelastic SDOF systems, it seeks to advance knowledge in this area and address existing research gaps.

A unified and systematic framework is developed, applying consistent methodologies and metrics to both NE categories. This approach avoids case-specific methods and results, enhancing the effectiveness of comparisons and critical evaluations. The study assesses both seismic capacity and safety, integrating past data with newly generated datasets. It provides methodological guidance and establishes quantitative safety metrics.

Nonlinear dynamic analyses and damage assessments are performed, considering both ground and floor motions as input excitations. Additionally, the influence of key geometric and dynamic parameters of nonstructural elements is examined, accounting for their presence in both standard and critical facilities across regions of varying seismicity in Italy.

Seismic capacities were assessed considering fragility curves [17]. As an example, Figure 9 shows the capacity surfaces that account for key parameters associated with dynamic properties of SDOF elements (f_a) and damage severity ($|\Delta_{max}|_{lim}/|\Delta_{max}|_{DS5}$), as discussed in [18], whereas Figure 10 illustrates fragility curves associated with investigated inelastic SDOF systems.

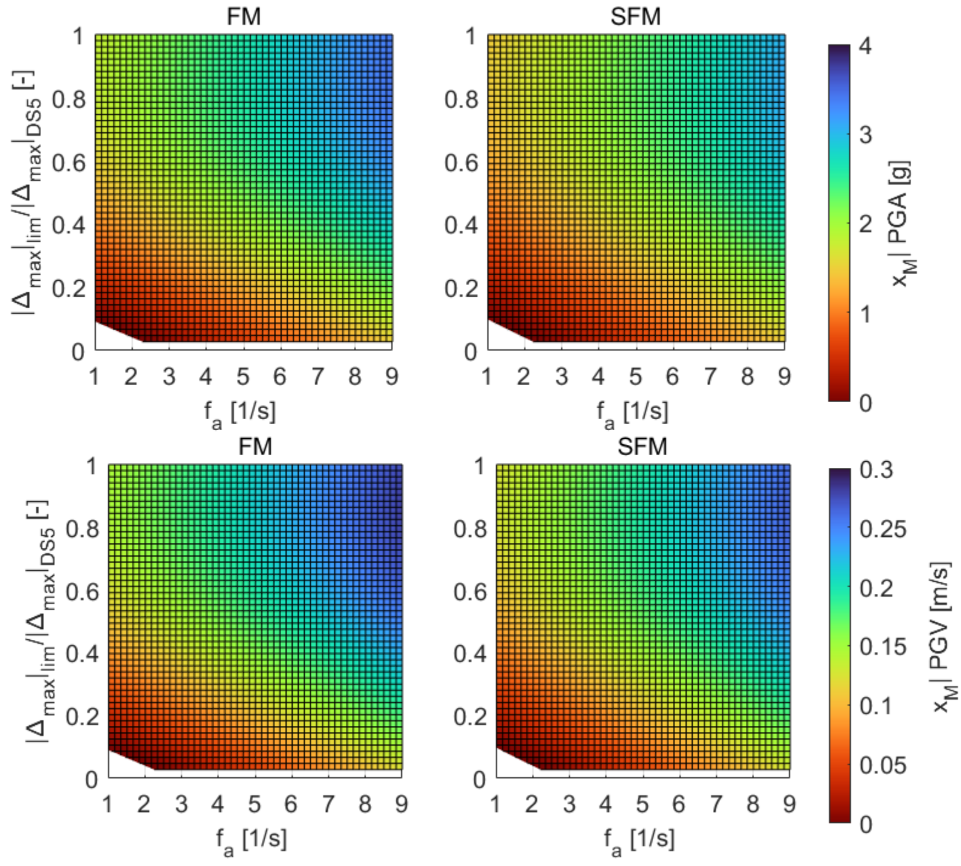


Figure 9: 2D view capacity surfaces (fragility medians (x_M)) associated with SDOF (SDOF) systems, expressed in terms of peak ground acceleration (PGA) and peak ground velocity (PGV), as a function of limit dimensionless displacement $|\Delta_{max}|_{lim}/|\Delta_{max}|_{DS5}$ and SDOF frequency (f_a), considering floor motion (FM) and strong floor motion (SFM) sets [18].

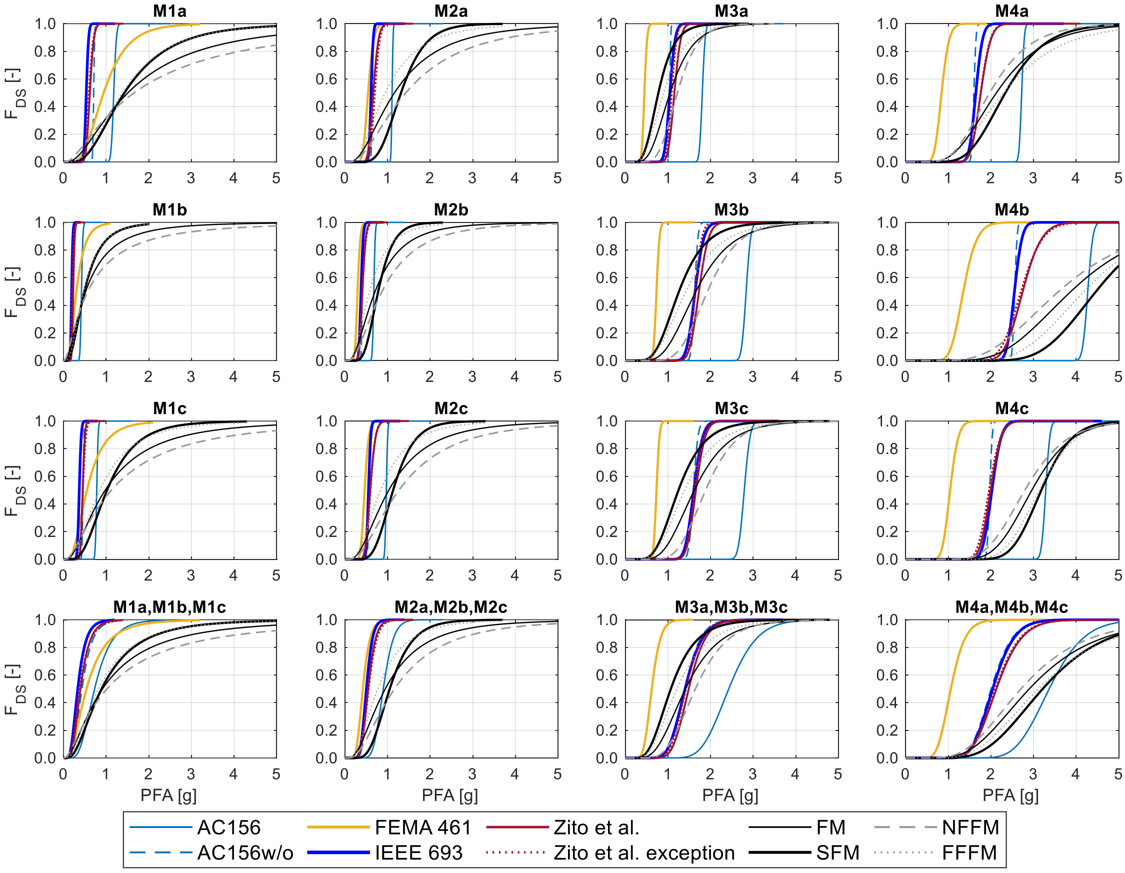


Figure 10: Fragility (FDS) as a function of peak floor acceleration (PFA) evaluated considering DS2, associated with all loading history sets, corresponding to single models and grouped range models [19].

Figure 11 and Figure 12 show the results of the seismic safety assessment associated with rigid blocks and SDOF elements, respectively, referring to high-seismicity L'Aquila site in Italy. To support practical applications, graphical and tabular tools were developed to identify potentially critical conditions for RBs and SDOF elements, allowing for a rapid estimation of seismic safety factors. These tools offer an effective means for assessing the vulnerability of acceleration-sensitive elements, particularly in cases where parameter variations and uncertainty sources play a significant role. The findings suggest that the proposed criteria can serve as a valuable reference for the design and assessment of such elements, offering a structured approach to account for uncertainties while ensuring consistency across different case studies.

4.2 Piping networks

Blasi et al. [20] conducted non-linear time-history (NLTHA) analyses aimed at evaluating the seismic performance of medical gas and fire-fighting piping system layouts. Two networks' configurations were defined for each piping system considered, featuring regular and irregular geometry, respectively. In the numerical models of the piping systems (Figure 13), the non-linear response under cyclic loads of piping restraints and pipe joints was simulated to detect failure modes. The NLTH analyses were carried out using a set of 20 tri-directional (X-Y-Z) floor motions generated from a cascading analysis conducted in a previous work [21] (Figure 13). The results of the analyses allowed the evaluation of the influence of the layout geometry and the vertical component of the floor acceleration on the seismic damage to pipe joints and piping restraints. Furthermore, fragility functions of each configuration analysed were provided.

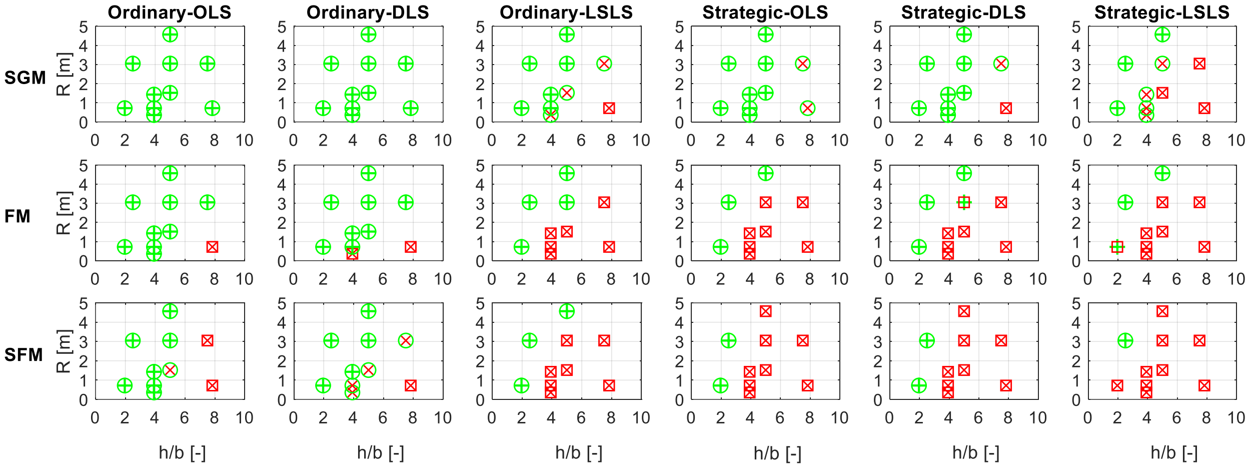


Figure 11: Seismic safety assessment results for rigid blocks (RBs), considering dimensionless peak ground acceleration (PGA*) and dimensionless peak ground velocity (PGV*), for ordinary and critical buildings, and operativity limit state, (OLS), damage limitation limit state (DLS), and life safety limit state (LSLS), considering L’Aquila site [18].

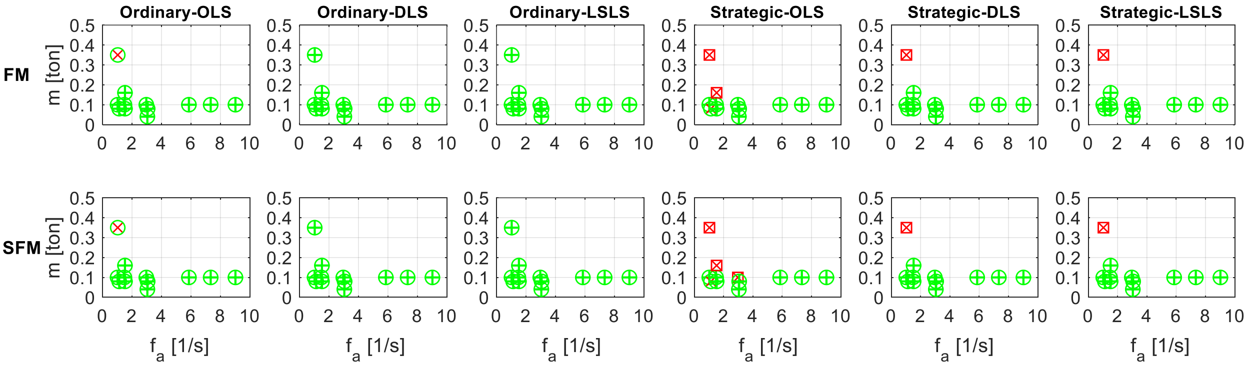


Figure 12: Seismic safety assessment results for SDOF (SDOF) systems considering peak ground acceleration (PGA) and peak ground velocity (PGV), for ordinary and critical buildings, and operativity limit state, (OLS), damage limitation limit state (DLS), and life safety limit state (LSLS), considering L’Aquila [18].

The obtained outcome (Figure 13) evidenced the great influence of the network geometry on the maximum damage to pipe joints, which may be related to variation of local modes participating ratios and modal shape. On the other hand, negligible effect of the vertical component of the floor acceleration on the results was obtained for most of the cases, although the peculiarity of the piping systems examined encouraged further investigations.

The network geometry had a low influence on the maximum damage to seismic restraints damage, which, on the other hand, was mainly influenced by the mass of the main line of the piping system (i.e. the number and diameter of pipes in the main line).

Fragility functions evidenced the low seismic vulnerability of light piping systems (e.g. with copper medical gas distribution pipes). On the other hand, both pipe material and type of conveyed fluid severely affect peak floor acceleration and, consequently, load demand on suspended piping restraints.

Rodriguez et al. [22] investigated the impact of gravity load trapezes in seismically designed suspended piping systems on their seismic performance. Two distinct suspended piping configurations using channel trapezes, installed in four different reinforced concrete moment-resisting frames, were analyzed under two scenarios: i) ignoring the lateral stiffness of the gravity load trapezes, and ii) assuming an elastic-perfectly plastic behavior for the gravity load trapezes, in line with the material and section properties specified by the manufacturer's technical specifications. The main objective of the study was to evaluate the common assumption of neglecting the contribution of the gravity load trapezes on the overall seismic performance of suspended piping systems.

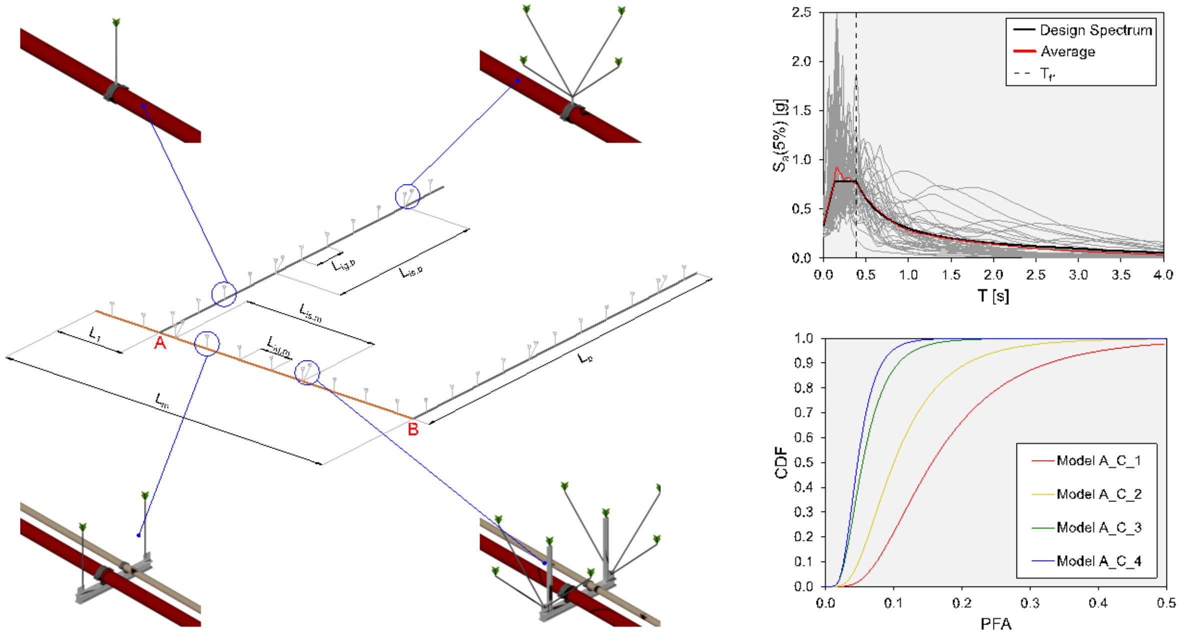


Figure 13: Model layout, seismic input spectra, and fragility curves [20].

A cascading analysis approach was implemented to estimate the seismic demand that the selected suspended piping layouts would experience in the various supporting structures.

Using the results from NLTHAs, lognormal fragility curves were independently derived for the transverse and longitudinal sway-braced trapezes, as well as the piping joints of the suspended piping archetypes, employing a multiple-stripe approach. A comparison of the resulting fragility curves revealed that accounting for the contribution of the hangers in the numerical modeling of the suspended piping archetypes significantly enhanced their seismic performance across all considered limit states. This suggests that overlooking the role of the hangers in the seismic design and analysis of suspended piping systems might be a conservative approach. Moreover, the derived fragility curves indicated that leakage through the piping joints was the primary limit state influencing the overall performance of the suspended piping archetypes, which aligns with field observations following recent seismic events. The findings from this research highlight the importance of performing component tests on suspended piping hangers to obtain reliable performance data, which can be used to calibrate more accurate numerical models.

5 PERCEPTION AND COMMUNICATION STRATEGIES

One of the main objectives of Work Package 4, led by Istituto Nazionale di Geofisica e Vulcanologia, is the development and implementation of communication strategies to increase stakeholder awareness and enhance the resilience of hospital healthcare facilities. The project seeks to provide useful tools and information to help hospital staff and decision-makers adopt effective mitigation measures to reduce seismic risk.

To achieve these objectives, two pilot sites were selected in areas with different seismicity levels: Lecce and Caserta. These sites were chosen to analyze the behavior of healthcare structures under varying seismic risk conditions and to develop specific adaptation strategies.

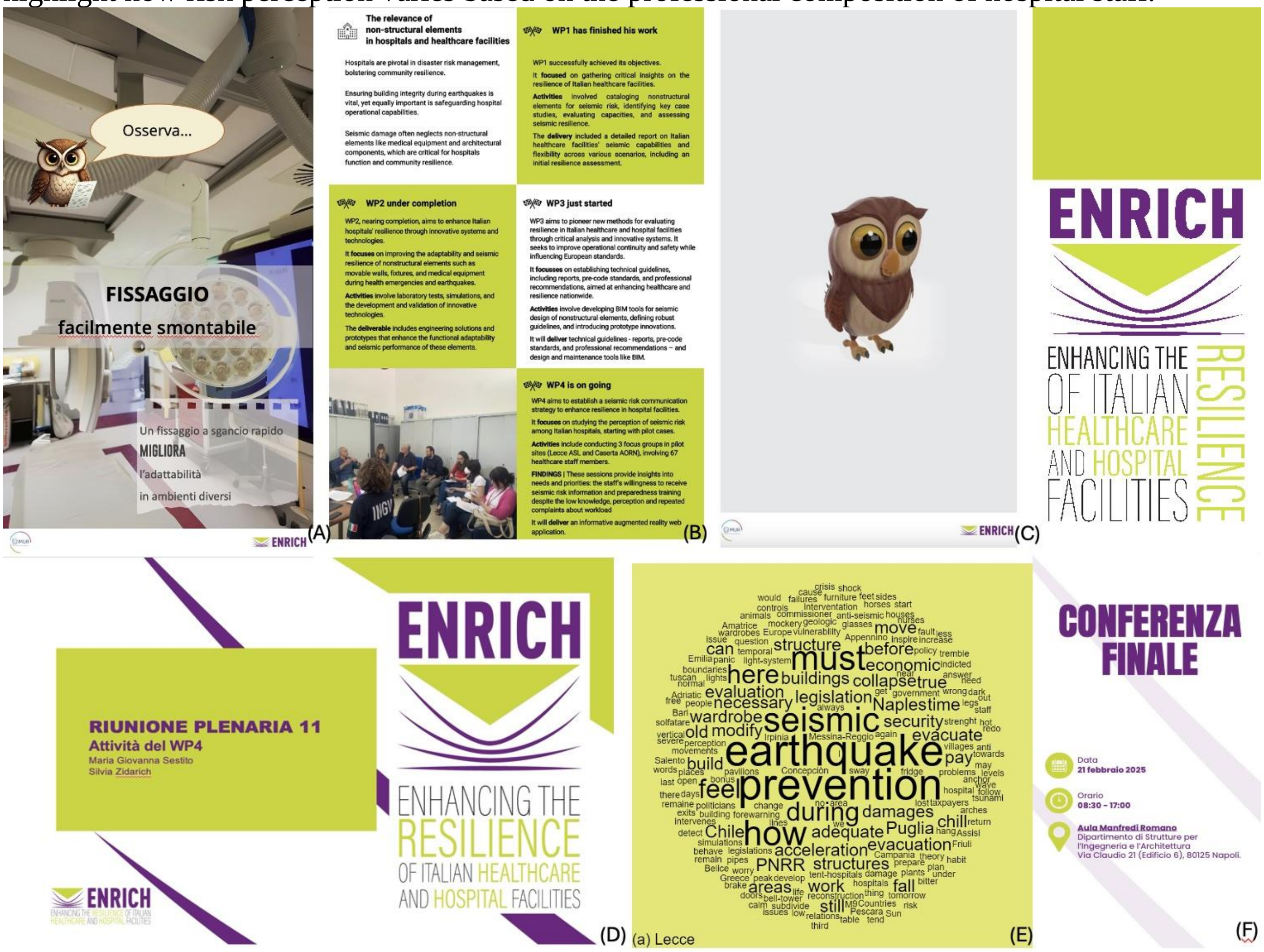
To analyze the perception of seismic risk and the level of preparedness among healthcare personnel, social research methods such as questionnaires and focus groups were used. These methods allowed for the collection of both qualitative and quantitative data, providing a clearer understanding of the needs and critical issues within the hospital system. The results were published in several scientific papers [23–25]. Additionally, risk communication and informative materials were created to communicate the findings effectively, including:

- An informative brochure for the stakeholder meeting in Caserta;
- posters and totems for the final meeting in Naples;
- A brochure prepared for the 18th World Conference on Earthquake Engineering (WCEE);
- A video prepared for the 18th World Conference on Earthquake Engineering (WCEE);
- Postcards summarizing key safety recommendations;
- Regular newsletters updating stakeholders on project developments;
- Plenary meetings held periodically to discuss progress;
- Focus groups conducted in Lecce and Caserta to engage healthcare professionals directly.

The focus group discussions were analyzed using an inductive approach, manually segmenting transcripts into communicative units and categorizing them post-analysis (Figure 14 and Figure 15). This process provided valuable insights into how different hospital staff groups perceive seismic risk.

Figure 14: Events organized by WP4, in particular: (a) First focus group Caserta, (b) Meeting at the "Sant'Anna e San Sebastiano" healthcare company, (c) First focus group Lecce, (d) Final meeting in Naples.

Findings indicate that in Lecce, discussions primarily revolved around administrative, legal, scientific, political, and economic aspects, along with personal experiences. Conversely, in Caserta, while scientific and regulatory topics were similarly significant, there was a stronger emphasis on healthcare-specific concerns, a theme largely absent in Lecce. These differences highlight how risk perception varies based on the professional composition of hospital staff.



The relevance of non-structural elements in hospitals and healthcare facilities

Hospitals are pivotal in disaster risk management, bolstering community resilience.

Ensuring building integrity during earthquakes is vital, yet equally important is safeguarding hospital operational capabilities.

Seismic damage often neglects non-structural elements like medical equipment and architectural components, which are critical for hospitals function and community resilience.

WP1 has finished his work

WP1 successfully achieved its objectives.

It **focused** on gathering critical insights on the resilience of Italian healthcare facilities.

Activities involved cataloging nonstructural elements for seismic risk, identifying key case studies, evaluating capacities, and assessing seismic resilience.

The **delivery** included a detailed report on Italian healthcare facilities' seismic capabilities and flexibility across various scenarios, including an initial resilience assessment.

WP2 under completion

WP2, nearing completion, aims to enhance Italian hospitals' resilience through innovative systems and technologies.

It **focuses** on improving the adaptability and seismic resilience of nonstructural elements such as movable walls, fixtures, and medical equipment during health emergencies and earthquakes.

Activities involve laboratory tests, simulations, and the development and validation of innovative technologies.

The **deliverable** includes engineering solutions and prototypes that enhance the functional adaptability and seismic performance of these elements.

WP3 just started

WP3 aims to pioneer new methods for evaluating resilience in Italian healthcare and hospital facilities through critical analysis and innovative systems. It seeks to improve operational continuity and safety while influencing European standards.

It **focusses** on establishing technical guidelines, including reports, pre-code standards, and professional recommendations, aimed at enhancing healthcare and resilience nationwide.

Activities involve developing BIM tools for seismic design of nonstructural elements, defining robust guidelines, and introducing prototype innovations.

It will **deliver** technical guidelines - reports, pre-code standards, and professional recommendations – and design and maintenance tools like BIM.

WP4 is on going

WP4 aims to establish a seismic risk communication strategy to enhance resilience in hospital facilities.

It **focuses** on studying the perception of seismic risk among Italian hospitals, starting with pilot cases.

Activities include conducting 3 focus groups in pilot sites (Lecce ASL and Caserta AORN), involving 67 healthcare staff members.

FINDINGS | These sessions provide insights into needs and priorities: the staff's willingness to receive seismic risk information and preparedness training despite the low knowledge, perception and repeated complaints about workload

It will **deliver** an informative augmented reality web application.

RIUNIONE PLENARIA 11
Attività del WP4
Maria Giovanna Sestito
Silvia Zidarich

ENRICH
ENHANCING THE RESILIENCE OF ITALIAN HEALTHCARE AND HOSPITAL FACILITIES

CONFERENZA FINALE

Data
21 febbraio 2025

Orario
08:30 - 17:00

Aula Manfredi Romano
Dipartimento di Strutture per l'Ingegneria e l'Architettura
Via Claudio 21 (Edificio 6), 80125 Napoli.

Figure 15: Materials produced by WP4, in particular: (a) App video screen, (b) Newsletter, (c) "doctor Gu" interactive figure in the app videos, (d) Powerpoint plenary meetings, (e) Wordcloud, (f) Totem.

A further analysis focused on recurring key topics, identifying major themes for each site. In Lecce, discussions frequently addressed the economic consequences of earthquakes, the financial implications of preventive measures, the importance of regulations, and the underestimation of seismic risk in their region. In Caserta, common themes included skepticism about the staff's role during emergencies, the lack of behavioral models to follow, risk from a professional perspective, and patient safety.

Despite these site-specific variations, some topics emerged consistently across all groups, including:

- Awareness of the importance of prevention;
- The need for targeted training;
- The underestimation of seismic risk related to Nonstructural Elements;
- The excessive workload burden on hospital staff;

Insights from these focus groups played a crucial role in designing the project's web app and video content. The choice was made to develop a web app integrated with Augmented Reality (AR) elements, designed to engage users more actively and promote experiential learning. A web app was preferred over a traditional app because it is not dependent on device updates, making it accessible to a broader audience, regardless of device type or users' computer skills.

The functionality of the ENRICH web AR app is straightforward and effective: the user scans a QR code placed physically next to the Nonstructural Elements (NSE) of interest, which activates an AR avatar providing basic information on the two key aspects of seismic resilience explored in the ENRICH project: seismic capacity and seismic adaptability. Following this, the user is redirected to a video content, which can be selected from two options: one for healthcare personnel and the other for technical staff, with the aim of improving the seismic resilience of the specific NSE. In the video, however, the introductory explanation, common to both videos, emphasized the importance of NSE resilience for hospital functionality, addressing the low awareness of this issue revealed in the discussions. Additionally, the video for healthcare personnel included detailed explanations of the rationale behind each recommended action. For instance, after demonstrating the need to check whether an MRI machine's base was isolated from the floor, a simple, engaging explanation followed, illustrating how such isolation reduces seismic acceleration effects. This approach catered to the participants' curiosity and simultaneously demonstrated the practical impact of individual actions, countering skepticism about their role in emergency preparedness.

Furthermore, the videos were tailored to specific professional roles: for healthcare staff, the focus was on raising awareness and enhancing self-efficacy, while for technical personnel, the goal was to provide the groundwork for further technical analysis and implementation.

WP4 of the ENRICH project has demonstrated the importance of targeted communication strategies in increasing awareness and preparedness among hospital stakeholders. Through case study analysis, the use of social research methods, and the implementation of innovative digital tools, the project has provided key insights into mitigating nonstructural seismic risk. The success of the final meeting highlighted a strong interest in hospital resilience, underscoring the need for continued collaboration between researchers, healthcare professionals, and policymakers. Future efforts will focus on optimizing and disseminating the developed strategies to ensure a lasting impact and effective implementation of seismic safety measures in Italian healthcare facilities.

6 CONCLUSIONS

PRIN 2020 ENRICH project represents a significant step toward enhancing the seismic resilience of hospitals and healthcare facilities, addressing a critical yet often overlooked vulnerability: the impact of nonstructural elements on operational continuity. By integrating field inspections, experimental testing, numerical simulations, statistical analyses, and strategic planning tools, the project provides a comprehensive framework for improving both the seismic performance and functional adaptability of healthcare infrastructure.

The outcomes of this research extend beyond academic contributions, offering tangible solutions for engineers, facility managers, and decision-makers. The methodologies developed enable more accurate risk assessments, inform targeted mitigation strategies, and support the implementation of effective design and maintenance practices. Ultimately, the adoption of these advancements will help ensure that hospitals remain fully operational during and after seismic events, minimizing disruptions to patient care and emergency response.

ACKNOWLEDGEMENT

The paper was funded by the Italian Ministry of University and Research (MUR) in the framework of PRIN 2020 project (YKY7W4) titled "ENRICH project: ENhancing the Resilience of Italian healthCare and Hospital facilities".

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