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IMPLEMENTING A KNOWLEDGE-BASED SEISMIC RISK ASSESSMENT APPROACH FOR AN EXISTING SCHOOL IN ITALY

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Abstract: *When dealing with seismic risk assessment of existing buildings, the technical complexity arising from limited building knowledge often represents a primary obstacle, potentially leading to high levels of uncertainty. This issue is critically emphasised in large-scale applications, where a statistical characterization of the building stock is typically assumed based on a few building data. Yet, recent research in the literature has pointed out that various types of information on the structure, such as structural details and material mechanical properties, can have significant impacts on the seismic performance assessment. This would suggest that the diagnosis phase could be conducted through an incremental procedure enabling the gradual acquisition of significant information on the seismic performance of the structure, even in scenarios where data collection is limited. Moreover, when coupled with an ad-hoc data collection form, a knowledge-based seismic risk assessment approach could serve as an important step toward achieving a building-to-building characterization of the national building stock. To this end, standardised, adaptive and updatable methodologies and tools for knowledge-based seismic risk assessment of buildings are essential. As part of a wider ReLUIS research project, this paper discusses the ongoing developments in the definition and validation of a multi-knowledge seismic assessment methodology based on the SLaMA (Simple Lateral Mechanism Analysis) method. Particular focus is given to an application of the SLaMA-based procedure to an existing reinforced concrete school located in a high seismic hazard zone in Italy. To simulate a realistic "incremental" diagnosis phase, two different Research Units (RUs) are involved in the investigation: RU-1 and RU-2. Operatively, RU-1, owning relevant building data, progressively shares information with RU-2. Subsequently, RU-2 conducts a knowledge-based seismic risk assessment for each data collection scenario. The results are finally returned to RU-1, which analyses and compares them with the existing documentation. The preliminary results of the ongoing investigation are herein presented and discussed. The SLaMA-based procedure enables the identification of the expected range/domain of capacity curves and seismic risk classes from the first diagnosis phases. This information can support the decision-making in localised in-situ inspections and/or possible retrofitting solutions.*

1. Introduction and motivations

In most of the seismic-prone countries worldwide, the catastrophic impact of recent major earthquakes (both in terms of human-life safety and economic losses) has further highlighted the urgency of a medium-to-long-term plan for seismic risk reduction. Focusing on the Italian scenario, the direct cost related to past earthquakes in the last 50 years has been estimated as almost € 150 billion; the cost estimation becomes even more critical when the effects of indirect economic losses, public debt and long-term interest rates are considered (Pampanin, 2022). Moreover, recent strong earthquakes, such as the 2009 L'Aquila, 2012 Emilia, and 2016 Central Italy sequence have dramatically confirmed the vulnerability of school buildings, which typically play a crucial role in post-earthquake emergency management and whose collapse has a strong socio-economic impact on communities (e.g., Di Ludovico et al., 2019). Therefore, reducing the seismic risk of the national building stock and enhancing the structural/seismic safety of strategic structures and infrastructure has become a crucial objective towards a more resilient community.

As part of this seismic risk analysis, the Detailed Seismic Assessment (DSA) of existing buildings is a crucial component. However, the DSA implementation, along with the subsequent definition of appropriate (i.e., easy-to-apply, cost-effective, and sustainable) retrofitting solutions, hides a high technical complexity (Pampanin, 2017). Among others, limited building knowledge is often deemed a primary obstacle, potentially leading to severe dispersion and high levels of uncertainty in the results. The knowledge level of a building depends on the available materials/documentation and can lead to less or more reliable assessment results depending on the quality and quantity of information collected. This issue is further emphasised in large-scale seismic-risk assessment studies, due to the complexity in the data acquisition of the building stock. State-of-the-art vulnerability assessment guidelines at the international level (e.g., NZSEE, 2017) point out that the first step in the overall seismic assessment process should involve the identification of key vulnerabilities and critical structural weaknesses through an Initial Seismic Assessment (ISA). This task requires the definition of relevant building characteristics, such as geometry, quality of construction materials, and structural details. This information can be typically collected through ad-hoc assessment forms or extrapolated from existing databases or inventories of building typologies. As an example, in Italy, significant research efforts have been carried out to support the digitization of data related to public administration assets (e.g., the Public Energy Living Lab, PELL, platform; Annunziato et al., 2019), as well as to develop enhanced survey forms for disaster risk management (e.g., Blaso et al., 2021). Furthermore, since 2014, the Italian Department of Civil Protection (DPC) in collaboration with the Network of University Laboratories for Earthquake Engineering (ReLUIS) has been working on improving the national risk assessment (Dolce et al. 2021) through the CARTIS project ("Inventory of existing structures and building typologies"; Zuccaro et al. 2023). The latter aims for a typological-structural characterization of residential buildings at the territorial scale. Information on buildings in areas subjected to recent earthquakes is also available from the Da.D.O. (Observed Damage Database) web-GIS platform (Dolce et al., 2019). For school buildings, a database associated with the Regional Registry of School Building (ARES, "Anagrafe Regionale Edilizia Scolastica") has been developed and used in seismic risk analyses at the national scale (e.g., Faravelli et al., 2023).

Recent studies in the literature have shown that various building-knowledge uncertainties, such as the lack of documentation/information regarding structural details and/or material mechanical properties, may have a different impact on the seismic performance assessment (e.g., Gentile et al. 2021b). Therefore, the data collection process could be conducted through an "incremental" approach. Moreover, by coupling ad-hoc data collection forms with a fast (yet reliable) assessment procedure, the seismic performance of the structure could be evaluated in a dynamic and updatable way, accounting for uncertainties due to limited data acquisition. Outcomes obtained at each step of such a knowledge-based assessment framework (together with the related dispersion) can support the decision-making in the diagnosis phase, for instance suggesting specific and localised material/details investigations. In this context, and as part of a wider ReLUIS research project, this paper presents and discusses the ongoing activities toward the definition and validation of a knowledge-based seismic risk assessment procedure. The framework involves the analytical-mechanical SLaMA (Simple Lateral Mechanism Analysis) method (NZSEE, 2017; Pampanin 2017). The paper is structured as follows. Firstly, an overview of the investigated SlaMA-based multi-knowledge assessment methodology is given in Section 2. Section 3 presents an application to an existing reinforced concrete (RC) school building, with a particular focus on the research methodology, involving two different Research Units (RUs) to simulate a realistic "incremental" data collection process. Preliminary results are discussed in Section 4 while concluding remarks are finally given in Section 5.

2. Knowledge-based seismic risk assessment framework

Focusing on RC buildings, the proposed multi-knowledge seismic-risk assessment framework is conceptually illustrated in Figure 1. Each step of the methodology is discussed in more detail in this section.

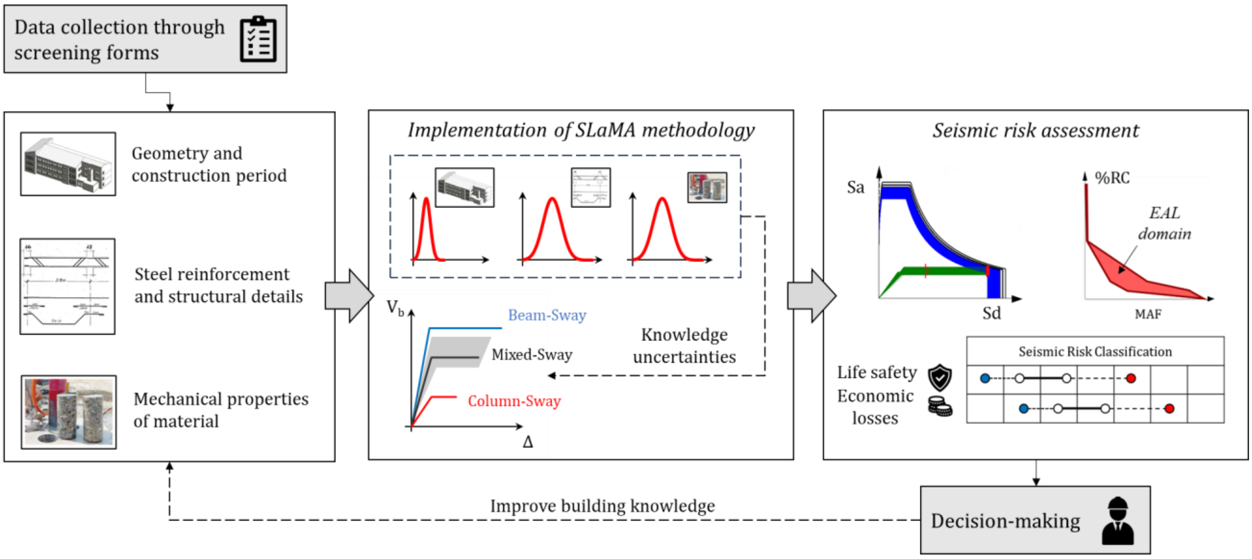


Figure 1. Flowchart of the SlaMA-based multi-knowledge assessment methodology.

The first fundamental step of the framework is the identification and data collection of relevant building information and any critical structural weakness potentially affecting the seismic performance of the structure. Therefore, the proposed knowledge-based method should be coupled with comprehensive vulnerability assessment forms and/or databases. As shown in Figure 1, building knowledge can be grouped into three macro-categories: (i) geometry and construction period; (ii) construction details; and (iii) mechanical properties of materials. These data can be identified by engineers from available documentation, which can include architectural and structural drawings, in-situ testing/inspections, photographic records, and technical reports. The information on the data source and the available documentation should be also collected to account for the reliability of the data and properly consider the related uncertainties.

Data collected in the first phase can be processed and used as input information for an adaptive seismic vulnerability assessment of the structure. If incomplete information/documentation is available, the methodology requires specific assumptions/calculations to account for the uncertainties related to the achieved knowledge level. Typically, these assumptions should be based on codes and guidelines of the construction period as well as on the most relevant research works available in the literature. For instance, a "simulated design" (i.e., re-designing the structure according to the codes and guidelines of the construction period) is typically needed if no information on the steel reinforcement details is available. On the contrary, when no data on the mechanical properties of materials are collected, probabilistic distributions can be selected from the literature (e.g., Verderame et al. 2001). This way, when uncertainties are introduced, parametric configurations - rather than a single configuration - can be defined and analysed.

Seismic analysis is then performed through the simplified analytical-mechanical SLaMA method. This procedure allows for a rapid estimation of the seismic performance of the structure, in terms of both force-displacement capacity curve and expected plastic failure mechanism, and without the need for any software-based numerical simulation (Pampanin, 2017; Figure 2). Despite the intrinsic simplicity of the method, SLaMA provides satisfactory results as also demonstrated by various analytical vs. numerical comparisons (e.g., Del Vecchio et al., 2017, 2018; Bianchi et al., 2019; Gentile et al., 2021a; Pedone et al., 2023). Thus, it is deemed an effective tool for applications involving different levels of building knowledge. Clearly, when parametric configurations are analysed due to limited building knowledge, the results of the method are in the form of the expected range/domain of possible capacity curves rather than a single force-displacement curve.

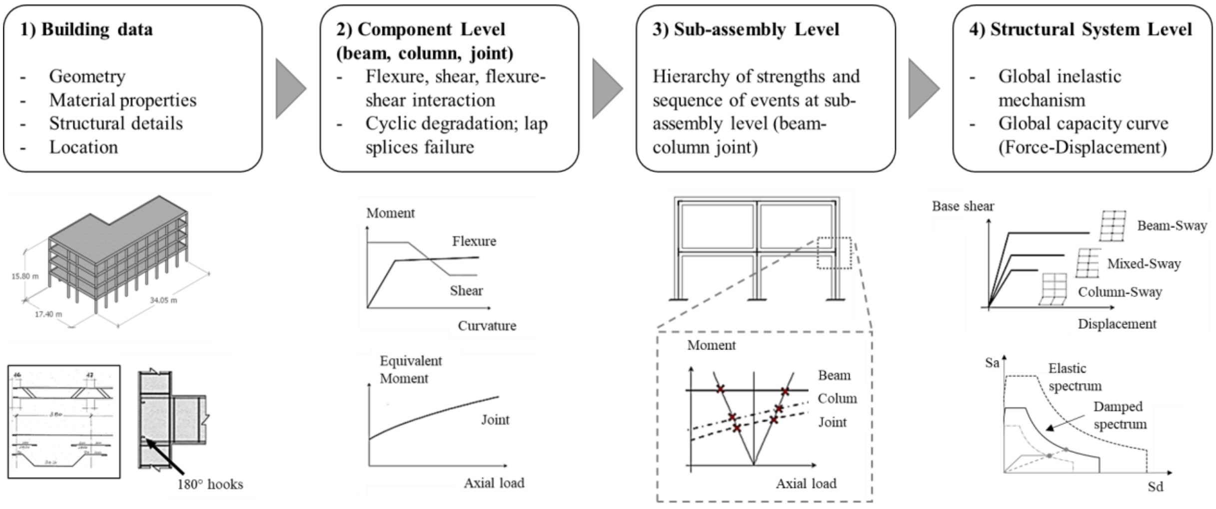


Figure 2. Flowchart of the analytical-mechanical SlaMA methodology (modified after Pampanin, 2017).

Results of the SlaMA method are then used to perform safety evaluation and economic-loss assessment. These analyses can be carried out according to the code-compliant spectrum-based approach described in the Italian “Guidelines for the Seismic Risk Classification of Constructions” (DM 65, 2017; Cosenza et al., 2018). This document defines the technical rules to access financial incentives when implementing seismic retrofitting interventions on private buildings (the so-called “Sismabonus”). Operatively, the capacity/demand ratios at different limit states are evaluated in the Acceleration-Displacement Response Spectrum (ADRS) domain (e.g., by applying the Capacity Spectrum Method, CSM, proposed by the ATC40, 1996). The capacity/demand ratio at the Life-Safety Limit State (LSLS) defines the Safety Index, IS-V (analogous to the %New Building Standard, %NBS, adopted in the NZSEE, 2017). Moreover, the document describes a simplified procedure to evaluate the Expected Annual Loss (EAL). This procedure consists of a simplified implementation of the performance-based earthquake engineering (PBEE) framework introduced by the Pacific Earthquake Engineering Research Center (PEER) (Cornell and Krawinkler, 2000), tailored and modified for applications in the common practice in the Italian context. In this method, a direct loss (expressed as a percentage of Reconstruction Cost, %RC) is associated with each limit state. This damage-to-loss model has been calibrated on the comprehensive database of the cost of repair and reconstruction after the 2009 L’Aquila earthquake (the so-called “White Book”, Dolce et al., 2009; Di Ludovico et al., 2017a, b). By assessing the seismic performance of the structure in terms of Mean Annual Frequency (MAF or λ = 1/Tr, where Tr is the return period) at each limit state, a λ–%RC curve can be thus evaluated. The EAL index is defined as the area underneath this λ–RC curve. The IS-V and EAL indexes are finally used to evaluate the seismic risk class of the structure. Specifically, different classes are associated with both indexes (i.e., from “A+” to “F” for IS-V, from “A+” to “G” for EAL, where A+ identifies the highest performance). The seismic risk class of the structure is defined as the lower class between class IS-V and class EAL. When building uncertainties are involved, the method is applied considering each parametric configuration. Therefore, ranges/domains of expected values are obtained for both IS-V and EAL indexes.

Results in the form of range/domains for both life safety and economic losses are finally used to support the decision-making process. This task clearly depends on the typology of the application as well as on the requirements of the end-users/stakeholders. For instance, when dealing with a detailed assessment of a single structure, the framework can support the data acquisition process by suggesting localised in-situ inspection or material testing to reduce uncertainties dynamically and adaptively (dashed line in Figure 1). Differently, a preliminary evaluation of the expected seismic performance of the structure (even affected by uncertainties) can provide important information for large-scale applications, supporting, for instance, the distribution of funds among the regions for a national seismic risk prevention plan.

Illustrative applications of the SLaMA-based multi-knowledge assessment framework for an RC school can be found in Pedone et al. (2022a, b). It is worth mentioning that the methodology can also be implemented by adopting a probabilistic-based approach (as discussed in Pedone et al., 2023). The latter involves the definition of fragility and vulnerability relationships through state-of-the-art pushover-based procedures (e.g., Vamvatsikos and Cornell, 2006; Bianchi et al., 2019; Nettis et al., 2021).

3. Research methodology

3.1. Incremental data collection and adaptive multi-knowledge assessment

To further validate the proposed SLaMA-based multi-knowledge assessment framework, it is deemed necessary to properly account for an "incremental" diagnosis phase, i.e. different (and subsequent) scenarios of data collection. It is worth highlighting that past investigations on this topic have simulated alternative data acquisition (knowledge) scenarios from a case-study structure whose complete building knowledge was available (Pedone et al., 2022a,b, 2003). The purpose of the cited studies was indeed to prove the feasibility of the framework. Yet, having a complete understanding of the building and its expected behaviour can clearly affect calculations/assumptions needed in the lowest knowledge scenarios, potentially leading to a bias in the results. Therefore, to simulate a more realistic "incremental" diagnosis phase (i.e. reproducing practitioner analysis procedure in the vulnerability assessment of an existing building), a new methodology framework is defined in this investigation. The latter involves two different RUs, referred to as RU-1 and RU-2, respectively. Figure 3 conceptually shows the research methodology framework. Each step is discussed in more detail below.

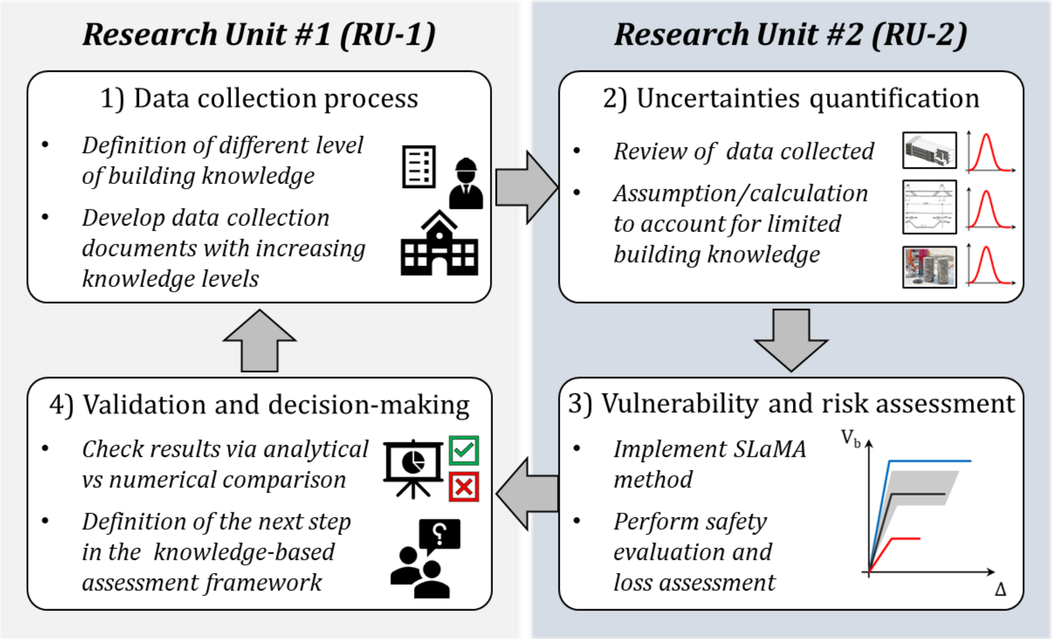


Figure 3. Conceptual illustration of the research methodology framework.

In practice, the initial step involves RU-1 selecting a case-study building from databases developed in previous research works (*step 1*). For the selected case study, complete building knowledge is available, typically involving historical design documentation with architectural and structural drawings, tests on material samplings, in-situ inspection and photographic survey. Nevertheless, to implement the methodology, RU-1 defines alternative data acquisition (knowledge) levels, to simulate an incremental diagnosis phase. Information is progressively shared with RU-2. For each building knowledge level (i.e., data collection scenario), RU-2 implements the knowledge-based seismic risk assessment. As previously discussed, this requires the quantification of knowledge uncertainties and assumptions/calculations to account for limited data collection (*step 2*). Then, seismic response analysis is carried out by implementing the SLaMA method and seismic risk assessment is performed following the approach described in the Italian "Sismabonus" guidelines (DM 65, 2017) (*step 3)*. This allows for the identification of the expected range/domain of both capacity curves and seismic risk classes for the considered knowledge scenario. The outcomes of the procedure are then returned to RU-1 (*step 4*). The latter compares the results of the method with the available documentation and with the results of a more refined numerical simulation considering complete building knowledge. To this end, a 3-dimensional (3-D) lumped plasticity model is implemented in the structural software SAP2000 (CSI, 2019).

For the sake of brevity, a detailed description of the numerical model is not herein provided since this paper only presents and discusses the first preliminary results of the investigation. Yet, a description of the adopted modelling approach can be found Frescadore et al. (2015). Finally, RU-1 shares with RU-2 the next data acquisition scenario, which involves more information to reduce the knowledge uncertainties. This procedure is repeated until a complete building knowledge is achieved.

More details on the selected case-study structure, the simulated data acquisition levels, and the numerical model implemented for the validation are given in the following paragraphs.

3.2. Description of the case-study school building

The selected case-study structure is a 4-storey RC school building located in Sulmona, Province of L'Aquila, Italy ("B" soil type; Peak Ground Acceleration PGA = 0.329g). This case study is part of a large data collection on buildings carried out after the 2009 L'Aquila earthquake (Di Ludovico et al., 2023). Figure 4 shows the satellite view and a photo of the buildings. The school is composed of 6 structural units, separated by structural joints. In this investigation, only the structural unit highlighted in Figure 4 by dashed lines is investigated.

(a) (b)

Figure 4. Case-study school building: (a) satellite view (Google Earth) and (b) a photo of the building (note: the analysed structural unit is highlighted in yellow).

For the selected case study, complete building knowledge is available, including historical design documentation, architectural and structural drawings, tests on material samplings, in-situ inspection, technical reports and photographic survey. Nevertheless, at the first stage of this investigation (whose preliminary results are discussed in this paper) only basic (very limited) documentation is shared by RU-1 to RU-2. Conceptually, this first step of the diagnosis phases is deemed representative of a preliminary data collection carried out through a desktop study. Thus, available data only concerns the construction period and some general information on the global building geometry. In line with the spirit of the research methodology, only the information given in this first (basic) data collection scenario is herein discussed. Specifically, the construction period is between the late 1960s and early 1970s. The total height of the structure is 15.5m, while the plan dimensions are 10.6m x 28.0m. The structural system is characterised by moment-resisting 8-bay frames in the longitudinal direction and moment-resisting 2-bay frames in the transversal direction. Bay lengths are almost constant for the longitudinal frame while, for the transversal frame, one bay's length is about double the length of the other. No other information is given for this knowledge level.

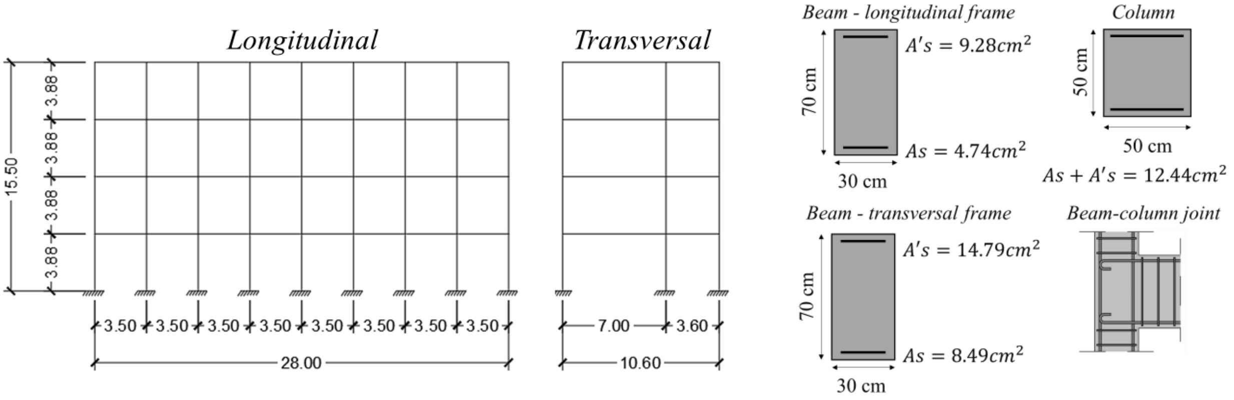
To implement the study, RU-1 has already defined alternative data acquisition scenarios, from basic (previously discussed) to complete building knowledge. According to the adopted methodology, documentation/information will be progressively shared with RU-2.

4. Preliminary results

This section presents and discusses the preliminary results of the investigation, with a specific focus on the first very poor building knowledge level. As described above, this knowledge level only involves information on the construction period and some building global dimensions, thus assumptions/calculations are needed to implement the SLaMA-based assessment procedure and severe uncertainties in the results are expected. More details on the performed analyses are given in the following subsections.

4.1. Assumed building geometry and structural details

To implement the knowledge-based assessment framework, the first step consists of the definition of the building geometry and the identification of the lateral-load resisting systems. Due to the limited information provided in the adopted knowledge scenario, assumptions are needed. Therefore, in line with the construction practice of the period, the span direction of floors is assumed along the longitudinal frame shown in Figure 5a. Moreover, bay lengths and interstorey heights are defined based on the limited available information and shown in Figure 5a for transversal and longitudinal frames.



(a) (b)

Figure 5. Assumed building geometry: (a) longitudinal and transversal frames; (b) geometrical details of RC members.

Differently, a "simulated design" according to the construction practice of the time is performed to evaluate steel reinforcement details in the structural members. The simulated design is developed considering the prescriptions from "Regio Decreto" RD 2229 (1939), which is the reference building code for pre-1970s buildings in Italy, and according to technical guidelines available in that period (e.g., Santarella 1957; Pagano, 1963). Moreover, as the building site (i.e., Sulmona, AQ) has been classified as a seismic zone since the early 1900s, seismic loads are also taken into account in the simulated design phase. Specifically, according to the old construction practice (Law 1684, 1962), seismic loads are defined by equivalent lateral forces with a uniform distribution along the height of the building and intensity equal to 0.1W, where W is the story mass. Moment and shear distribution on the structural members due to the seismic load are evaluated according to the simplified method described in Tasligedik et al. (2018). As a conservative hypothesis, the lowest quality of materials allowed by RD 2229 (1939) is assumed for the calculation. Moreover, the minimum-by-code amount of reinforcement and the weakest construction details are adopted in this investigation. The results of the simulated design in terms of the geometrical details of RC members are shown in Figure 5d. Transversal reinforcement is Φ6/15 (i.e., 6-mm-diameter stirrups at 15 cm) for both beams and columns. For the beam-columns joint, it is assumed that no stirrups are provided and that beam longitudinal bars are anchored with end hooks (i.e., the worst structural details as described in Pampanin et al., 2002). It is worth mentioning that, at this stage, simplified hypotheses derive from the limited building knowledge. More specifically, a square section is assumed for columns and no section reduction along height is assumed. Although these assumptions may be unrealistic, they allow for rapid estimation of the expected seismic capacity of the structure in a simplified way. Yet, building geometry can be easily defined through simple in-situ surveys; thus, it is highly recommended as the first step to improve building knowledge.

4.2. Results of the SlaMA method

Seismic capacity assessment is performed through the SLaMA method and following the prescription of the NTC (2018). This simplified procedure allows for the identification of the "hierarchy of strength" at the beam-column subassembly level, as well as the expected plastic mechanism and the global capacity curve of the structure. The analysis is implemented for frames in both longitudinal (X) and transversal (Y) directions. Material mechanical properties are assumed consistently with those selected for the simulated design and according to the relevant research work in the literature. Specifically, concrete compressive strength is $f_c' =$

$15.7 MPa$, while steel yielding and ultimate strength are respectively $f_y = 325.4 MPa$ and $f_u = 467.1\ MPa$ (Verderame et al., 2001). The Young's modulus of steel is $E_s = 210.0\ GPa$.

Results of the SlaMA methods are herein discussed. For the sake of brevity, Figure 6 shows the observed plastic mechanism for only the transversal 2-bay frame. It can be noted that the expected plastic mechanism is a so-called "mixed-sway" mechanism, mainly involving column and joint failures. This is mainly due to a lack of "capacity-design" principles, as expected for pre-1970s buildings in Italy. Figure 6 also shows an example of the hierarchy of strength for a beam-column-joint subassembly.

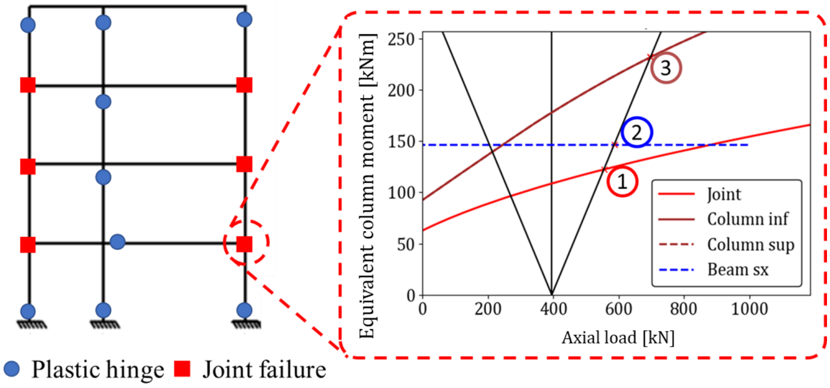
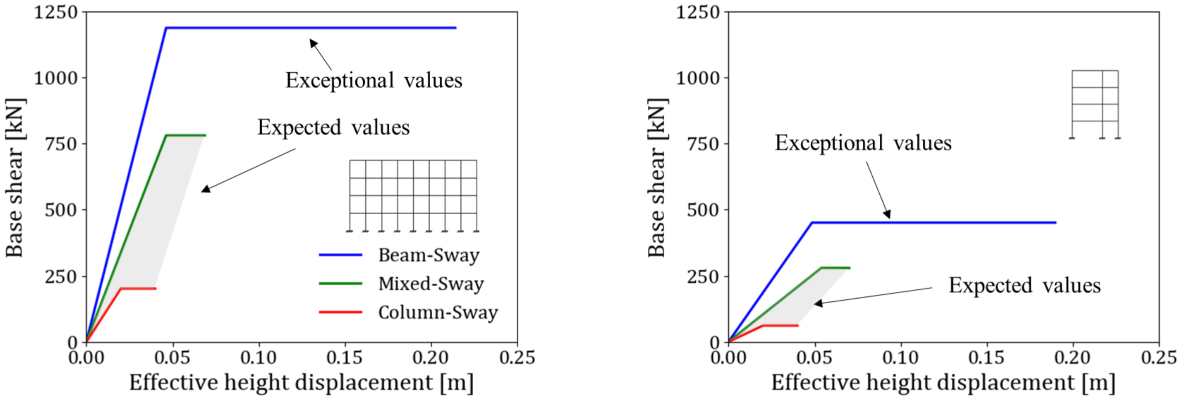


Figure 6. Expected plastic mechanisms for the transversal frame and example of "hierarchy of strength" at the subassembly level.

Results in terms of force-displacement pushover curves for both the longitudinal and transversal frames are shown in Figure 7, together with their upper and lower bound, represented respectively by the beam-sway mechanism (i.e., plastic hinges in all the beams and the base columns) and the column-sway (i.e., soft-storey mechanism). As expected, the structure is characterised by limited displacement ductility capacity, mainly due to joint failures. Moreover, the longitudinal frame shows a higher strength and stiffness capacity than the transversal one. Yet, when considering the global force-displacement capacity curve – obtained by summing the contribution of each frame working in the same seismic direction – strength capacity is quite similar in both directions. Figure 7 also indicates the expected range of capacity curves as well as exceptional (less probable) values. As in Pedone et al. (2022b), due to the high uncertainties affecting this data collection scenario, the range of possible capacity values is assumed to be limited by the column-sway and mixed-sway capacity curves. On the contrary, the beam-sway capacity curve is considered an exceptional result.

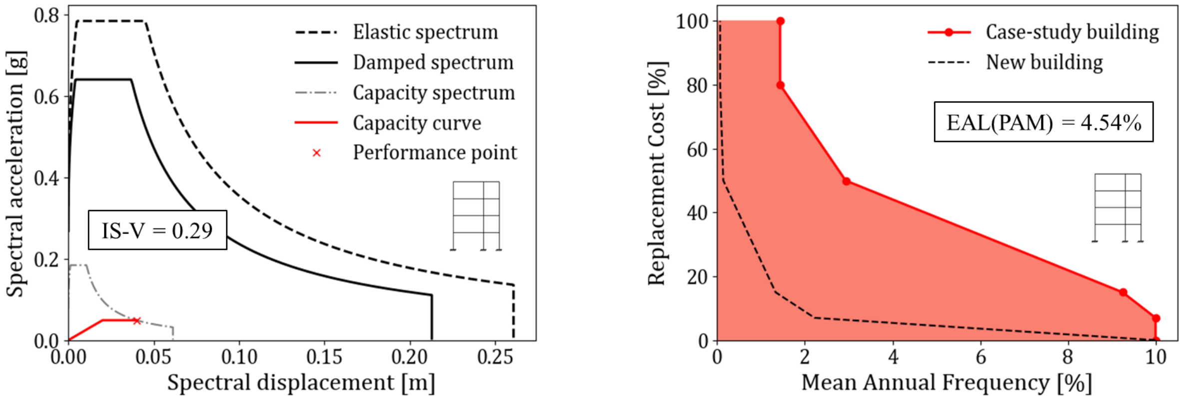


(a) (b)

Figure 7. Analytical force-displacement capacity curves for (a) the longitudinal and (b) transversal frames.

4.3. Safety evaluation and loss assessment

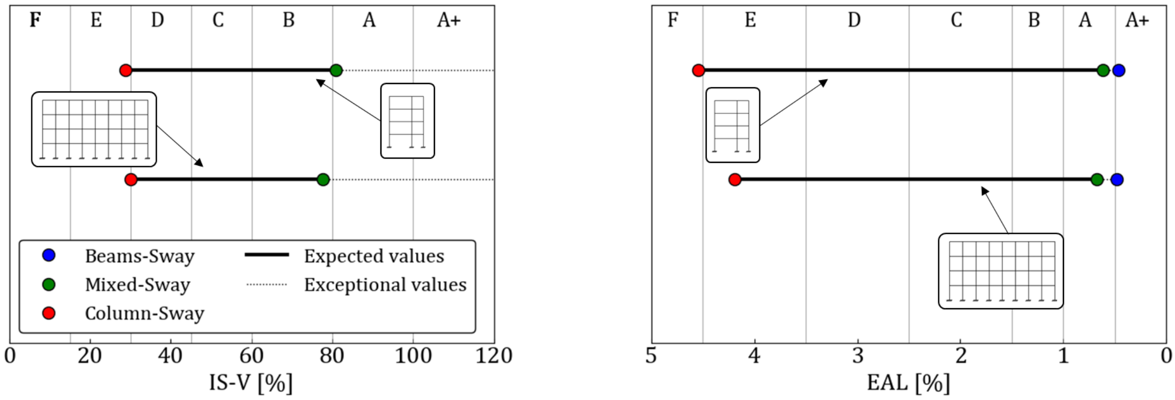
Finally, capacity curves of both the longitudinal and the transversal directions are used to perform safety evaluation and loss assessment. To this end, the capacity/demand ratio for different limit states is evaluated in the ADRS domain by applying the capacity spectrum method, according to the provision of NTC (2018) and Circolare (2019). The safety index (IS-V) and the expected annual loss (EAL, or PAM, “Perdita Annua Media”, in Italian) are evaluated according to the simplified procedure described in the Italian “Sismabonus” guidelines (DM 65, 2017, Cosenza et al., 2018). The IS-V and EAL index are also computed for the beam-sway and column-sway curves for each direction. As an example, Figure 8 shows the results of safety evaluation (IS-V index) and loss assessment (EAL index) for the transversal frame for the column-sway curve (lower expected value). It can be noted that, when considering a soft-storey (column-sway) mechanism, the structure shows a very poor seismic performance in terms of both safety and economic losses.



(a) (b)

Figure 8. (a) Capacity/demand comparison in the ADRS domain for the life-safety limit state and (b) EAL (or PAM) curve for the transversal frame.

Finally, expected and exceptional values obtained for IS-V and EAL indexes are shown in Figure 9 for both the longitudinal and transversal directions. Concerning the longitudinal direction, the expected IS-V values are between 0.30 (class “D$_{\text{IS-V}}$”) and 0.78 (class “B$_{\text{IS-V}}$”), which are the results for the column-sway and the mixed-sway, respectively (Figure 9a). For the EAL index, expected values range between 4.19% (class “E$_{\text{EAL}}$”) and 0.67% (class “A$_{\text{EAL}}$”) (Figure 9b). Similar results are also obtained for the transversal direction: expected IS-V values range between 0.29-0.81 (“E$_{\text{IS-V}}$”- “A$_{\text{IS-V}}$”), while EAL is between 4.54-0.61 (“F$_{\text{EAL}}$”- “A$_{\text{EAL}}$”).



(a) (b)

Figure 9. Expected and exceptional (a) IS-V and (b) EAL values for both structural directions.

Clearly, these results are affected by a severe dispersion, thus additional in-situ investigations are highly recommended, at least to better define the building geometry. Nevertheless, the outcomes presented in this section are still deemed useful to support the decision-making process on more detailed inspection. For instance, since the SLaMA analysis has pointed out possible external joint failures, more detailed inspections focused on these structural components can be recommended. Moreover, in a complementary, these outcomes may suggest future retrofit interventions to resolve this (expected) critical structural weakness. To this end, beam-sway results (exceptional values) may provide valuable information on the effectiveness of retrofit strategies/solutions aiming to re-establish a correct hierarchy of strength at the subassembly level. For this knowledge level, beam-sway results lead to IS-V ≥120% (“A+$_{\text{IS-V}}$”) and EAL ≤ 0.5% (“A+$_{\text{EAL}}$”).

4.4. Decision-making and future steps of the knowledge-based assessment

According to the framework shown in Figure 3, the results previously discussed are returned to RU-1, which compares them with the available documentation and more refined numerical simulations. Yet, in line with the spirit of this research, the results of this comparison/validation are not herein discussed since they can affect calculations/assumptions needed in the next knowledge scenarios.

Concerning the decision-making process, the severe result dispersions observed for this first (very poor) data collection clearly suggest improving the building knowledge to gain a better understanding of the building’s seismic performance. Thus, it has been decided that the next data collection scenario will involve a more detailed description of the structural skeleton, including information on the frame geometry (for both structural direction) and the cross-section dimensions of beams and columns. In practical applications, this information can be obtained through fast in-situ surveys and/or architectural drawings, if available. This enables the definition of the building geometry, while a simulated design is still needed to define reinforcement and structural details. Yet, by knowing the building geometry, alternative parametric configurations can be defined by varying the reinforcement and structural details, as well as the material mechanical properties. Therefore, in the next data collection scenario, expected performance values will be evaluated considering the results of alternative parametric configurations, while the column-sway mechanism will be considered a “possible” outcome (as in Pedone et al 2022b). This way, it is expected that the result dispersions will be reduced. Moreover, it will be possible to obtain a more reliable evaluation of the expected failure mechanism at the sub-assembly level.

5. Conclusions

This paper has discussed the ongoing research activities - part of a wider ReLUIS research project - towards the development and validation of a multi-knowledge level seismic assessment procedure. The procedure under investigation employs the analytical-mechanical SLaMA (Simple Lateral Mechanism Analysis) method and allows for an adaptive and updatable seismic risk assessment of buildings even in the case of limited building knowledge scenarios. The paper has provided an overview of the proposed SLaMA-based multi-knowledge assessment procedure. Then, particular focus has been given to the research methodology framework, which involves two different research units (referred to as RU-1 and RU-2) to simulate a more realistic “incremental” diagnosis phase. In line with the spirit of an adaptive and updatable seismic assessment methodology, RU-1 (the owner of relevant building data) progressively shares documentation/information with RU-2. The latter implements a knowledge-based seismic vulnerability and risk assessment considering the collected data and assumptions/calculations whenever necessary to account for limited building knowledge. In the case of limited data collection scenarios, the outcomes of the procedure consist of expected ranges of force-displacement capacity curves of the structures and, consequently, possible, expected, and exceptional values of the life-safety index and expected economic annual losses, in line with code-compliant seismic-risk classification methodologies (i.e., DM 65, 2017; Cosenza et al., 2018). Moreover, the expected local (sub-assembly level) and global (building level) failure mechanisms are also evaluated. These results are thus returned to RU-1, which analyses and compares them with the existing documentation and more refined numerical simulation (considering a complete knowledge scenario). The procedure is repeated until reaching a complete knowledge scenario.

Preliminary results of the investigation, employing a basic data collection scenario, have been finally discussed. The SlaMA-based multi-knowledge methodology allowed for the identification of the range/domain of the expected seismic risk classes (both in terms of safety and economic losses). Even if these outcomes are affected by severe dispersion (due to limited building knowledge), they are still deemed valuable since they can support the decision-making process in large-scale (regional or national) applications and or in more detailed in-situ investigations to improve building knowledge. It is worth mentioning that only preliminary results have been presented in this paper, and research effort is still needed to complete the investigation and, consequently, better validate the knowledge-based procedure under investigation.

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