Enhancing seismic resilience through insurance mechanisms: insights from the Romanian building stock

Îmbunătățirea rezilienței seismice prin mecanisme de asigurare: perspective asupra fondului rezidențial din România

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Abstract. *Seismic risk in Romania is mainly triggered by relatively rare but very severe earthquake events capable of generating significant structural damage and socio-economic losses. While traditional seismic risk mitigation has focused primarily on structural measures, increasing attention is being paid to the concept of seismic resilience, which also includes post-event recovery capacity. This paper discusses the role of insurance mechanisms as a financial component of seismic resilience, with emphasis on the Romanian context. By analysing seismic risk characteristics, expected losses and the current level of insurance coverage, the study highlights the existing protection gap and the limitations of current approaches. The paper argues for integrated strategies combining structural risk reduction and financial risk transfer to enhance seismic resilience.*

Key words: *seismic risk, seismic resilience, insurance, earthquake losses*

Rezumat. *Riscul seismic din România generat în principal de producera unor cutremure relativ rare, dar foarte severe, cu potențial ridicat de pierderi structurale și socio-economice. În mod tradițional, reducerea riscului seismic a fost abordată în principal prin măsuri structurale, însă conceptul de reziliență seismică implică și capacitatea de recuperare după producerea evenimentului. Lucrarea analizează rolul asigurărilor ca instrument financiar în creșterea rezilienței seismice, cu accent pe contextul românesc. Pe baza analizei riscului seismic, a pierderilor potențiale și a nivelului actual de asigurare, este evidențiat decalajul existent între pierderile așteptate și capacitatea de compensare. Sunt subliniate necesitatea unor strategii integrate care să coreleze reducerea vulnerabilității structurale cu mecanismele financiare de transfer al riscului.*

Cuvinte cheie: *risc seismic, reziliență seismică, asigurări, pierderi seismice*

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Introduction

Seismic risk represents one of the major natural hazards affecting the built environment in Romania. The characteristics of the Vrancea seismic source, combined with the vulnerability of a large part of the existing building stock, lead to the potential for significant structural damage and severe socio-economic consequences during major earthquakes. Past events, most notably the 1977 Vrancea earthquake, have clearly demonstrated the extent of human, material and economic losses that may result from strong ground shaking [1].

Traditionally, seismic risk mitigation in civil engineering has focused primarily on structural measures, such as seismic design provisions for new buildings and strengthening or retrofitting interventions for existing structures. While these measures are essential for reducing physical damage and loss of life, they do not fully address the broader consequences of earthquakes. Even when structural performance is improved, significant economic losses may still occur, and the recovery process after a major seismic event can be long and costly.

In recent years, the concept of seismic resilience has gained increasing attention [2]. Seismic resilience extends beyond structural safety and refers to the ability of the built environment and society to absorb seismic shocks, limit disruptions, and recover within a reasonable time after a damaging earthquake. From this perspective, resilience depends not only on the physical performance of buildings, but also on the availability of financial mechanisms that support post-earthquake recovery.

Insurance systems represent an important financial tool in this context. By transferring part of the seismic risk from individual property owners to a collective pool, insurance mechanisms can help transform rare but potentially catastrophic losses into manageable annual costs [3] [4]. In this way, insurance can contribute to reducing the financial burden on both affected populations and public authorities following a major earthquake, supporting faster and more effective reconstruction [5] [6].

Despite the high seismic risk, the current level of seismic insurance coverage in Romania remains limited. The existing compulsory insurance system provides only partial protection and is characterized by relatively low penetration rates and modest coverage limits when compared to the potential scale of seismic losses. This situation highlights a significant gap between expected earthquake-induced losses and the financial capacity available for recovery.

The objective of this paper is to discuss the role of insurance mechanisms as a component of seismic resilience, with a particular focus on the Romanian context. The study presents a qualitative analysis of seismic risk, expected losses and current insurance coverage, emphasizing the limitations of existing approaches and the need for integrated strategies that combine structural risk reduction with appropriate financial instruments. By doing so, the paper aims to contribute to a broader understanding of seismic resilience in civil engineering practice and policy-making.

2. Seismic risk and the existing building stock in Romania

Romania is exposed to a significant seismic risk, primarily associated with the intermediate-depth seismic source in the Vrancea region [7] [8]. This source is characterized by the ability to generate strong earthquakes with large affected areas, producing significant ground motions amplitudes over extensive parts of the country. As a result, seismic events in Romania have the potential to cause widespread structural damage and economic losses.

The impact of seismic actions is strongly influenced by the characteristics of the existing building stock. A large proportion of residential and public buildings in Romania were constructed before the introduction of modern seismic design regulations or according to earlier codes that did not fully account for the current understanding of seismic demand and structural behavior [9] [10]. Consequently, many existing buildings exhibit varying degrees of seismic vulnerability, particularly in urban areas with dense and aging construction.

Historical earthquakes provide clear evidence of this vulnerability. The 1977 Vrancea earthquake remains a reference event, illustrating both the severity of structural damage and the scale of socio-economic consequences. Post-earthquake investigations revealed significant differences in damage levels among buildings with similar apparent characteristics, highlighting the complex interaction between seismic demand, structural systems, construction quality, and detailing practices. These observations underline the difficulty of predicting damage at the level of individual buildings and emphasize the importance of considering seismic risk at a portfolio or regional scale.

The typology of the Romanian building stock further contributes to this complexity. Residential buildings include a wide range of structural systems, such as unreinforced and confined masonry structures, reinforced concrete frames, shear wall systems, and large-panel prefabricated buildings. Each of these typologies exhibits distinct seismic performance characteristics, leading to non-uniform damage patterns during strong ground shaking. Moreover, the spatial distribution of these building types often results in concentrated losses in certain urban zones.

From a risk assessment perspective, seismic risk in Romania results from the interaction between seismic hazard, exposure, and vulnerability. While hazard levels are primarily controlled by the Vrancea source, exposure is determined by the number, type, and value of buildings, as well as by population density. Vulnerability reflects the expected structural response of buildings subjected to seismic loading. Together, these components lead to the possibility of large, infrequent loss events with severe consequences.

Importantly, even when the probability of occurrence of major earthquakes is relatively low on an annual basis, the associated potential losses are extremely high. This characteristic place seismic risk in the category of low-probability, high-consequence events. For such events, conventional approaches based solely on average or expected annual losses are insufficient to capture the full extent of potential damage and disruption. This aspect has direct implications for risk management strategies and for the financial capacity required to support post-earthquake recovery.

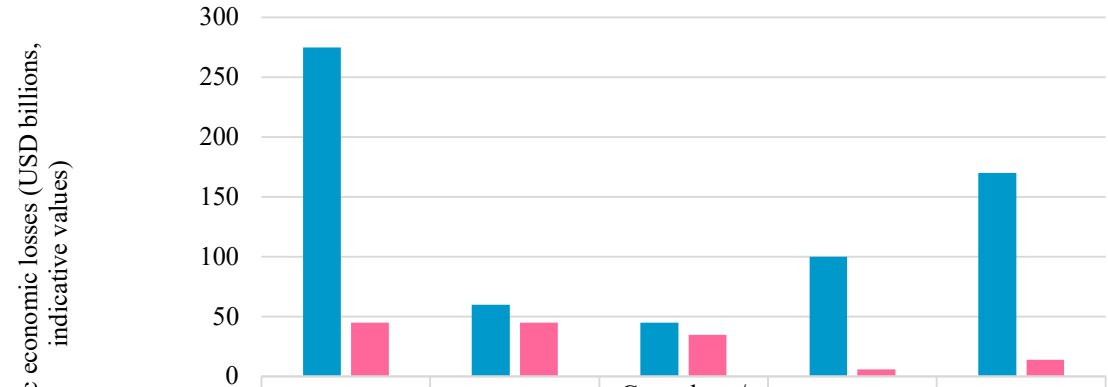
In this context, the seismic risk associated with the existing building stock in Romania represents not only a structural engineering challenge, but also a broader societal and economic issue. Understanding the characteristics of hazard, exposure, and vulnerability is therefore a fundamental step toward developing integrated approaches that address both damage reduction and recovery capacity after major seismic events.

3. Seismic losses and limitations of conventional loss indicators

Seismic losses associated with earthquakes differ significantly from losses caused by other types of natural hazards. Earthquake-induced losses are typically rare, but when they occur, they can be extremely large and highly concentrated in space and time [11]. This characteristic makes seismic risk particularly challenging to assess and manage using conventional indicators.

In engineering practice and risk assessment studies, seismic losses are often expressed using average-based indicators, such as the average annual loss. This metric represents the expected value of losses averaged over a long period of time, accounting for both frequent low-intensity events and rare high-intensity earthquakes. While average annual loss can be useful for comparative analyses or long-term planning, it does not adequately reflect the potential impact of extreme seismic events.

Major earthquakes generate losses that are far greater than the values suggested by average indicators, as shown in Figure 1 [12].



	Great East Japan Tohoku 2011	Northridge, USA 1994	Canterbury/ Christchurch New Zealand 2010-2011	Great Kanto, Japan 1923	San Francisco 1906
Total Economic Loss	275	60	45	100	170
Insured Loss	45	45	35	6	14

Fig. 1. Comparison between direct economic losses and insured losses for major earthquake events [13].

All values are expressed in USD at 2025 price levels. For historical events (1906 and 1923), insured loss data mainly reflect fire-related claims and are not fully comparable with modern earthquake insurance systems.

A single destructive event may cause economic losses that exceed the cumulative average losses expected over several decades. For decision-makers and stakeholders involved in post-earthquake recovery, it is precisely these extreme scenarios that dominate the real-world consequences, rather than the long-term average behavior of seismic losses.

Another important aspect of seismic losses is their strong dependency on the spatial distribution of damage. Due to the characteristics of seismic wave propagation and the clustering of vulnerable buildings, losses tend to be highly concentrated in specific urban areas. As a result, the financial burden imposed by a major earthquake is not uniformly distributed, but instead affects particular regions and communities disproportionately. This spatial concentration further amplifies the socio-economic impact of seismic events.

From a structural perspective, observed damage patterns also exhibit significant variability, even among buildings with similar structural systems and construction periods. This variability introduces additional uncertainty into loss estimation and complicates predictions at the level of individual buildings. Consequently, loss assessment methods are generally more reliable when applied at the level of building portfolios or regions, rather than single structures.

These characteristics place seismic risk in the category of low-probability, high-consequence events. For such risks, approaches based solely on expected or average losses provide an incomplete picture of the potential damage and disruption. Indicators capable of capturing extreme loss scenarios and tail behavior of loss distributions are therefore essential for effective risk management.

The limitations of conventional loss indicators have important implications for post-earthquake recovery planning. In the absence of sufficient financial preparedness, large seismic losses may overwhelm the capacity of public authorities, households, and private stakeholders to fund reconstruction efforts. This gap between potential losses and available financial resources represents a critical vulnerability in the overall seismic resilience of the built environment.

In this context, seismic loss assessment should not be viewed only as a technical exercise, but as a foundation for identifying appropriate risk transfer and risk financing mechanisms. Understanding the scale and nature of potential seismic losses is a key prerequisite for evaluating the role of insurance systems and other financial instruments in supporting post-earthquake recovery and enhancing seismic resilience.

4. The role of insurance in enhancing seismic resilience

As discussed in the previous sections, seismic risk in Romania is characterized by the potential for large and concentrated losses associated with rare but severe earthquakes. Although structural measures are essential for reducing physical damage and loss of life, they cannot fully mitigate the economic consequences of major events. Therefore, seismic resilience should be understood not only in terms of structural performance, but also in terms of the capacity to finance post-earthquake recovery.

Insurance systems represent an important financial mechanism for managing seismic

losses [14] [15]. From an engineering perspective, insurance enables the transfer of part of the economic consequences of structural damage from individual owners to a collective framework. By pooling risks across many insured assets and over time, insurance helps transform rare, high-impact losses into more predictable financial flows.

The primary contribution of insurance to seismic resilience lies in its role in supporting post-earthquake recovery. Following a damaging event, the availability of financial resources is critical for repair, reconstruction, and restoring functionality [16]. Insurance payouts can facilitate these processes by providing timely funds, reducing reconstruction delays and limiting prolonged social and economic disruption. In this sense, insurance complements structural risk reduction measures rather than replacing them.

Conceptually, the interaction between seismic hazard, building vulnerability, economic losses, and recovery capacity can be described as a sequential process, as illustrated in Figure 2.

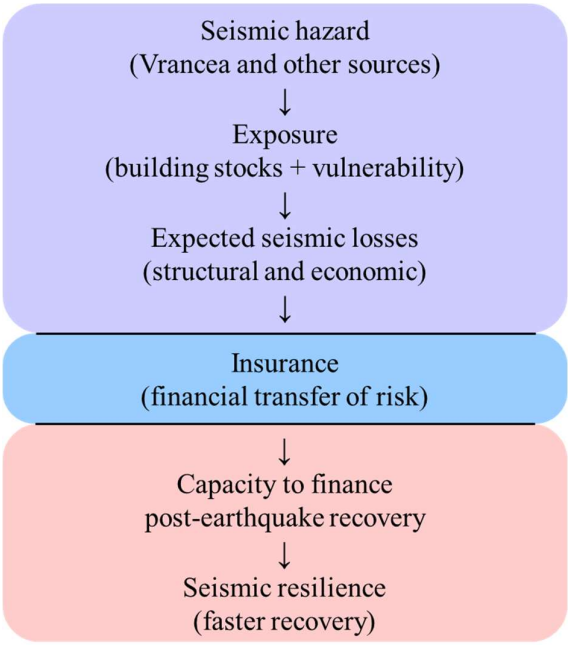


Fig. 2. Conceptual framework linking seismic hazard, losses and insurance within seismic resilience

Seismic hazard acts on the exposed and vulnerable building stock, generating structural and non-structural damage that leads to economic losses. Insurance mechanisms intervene at this stage by transferring part of these losses into financial compensation, which in turn supports post-earthquake recovery and contributes to enhanced seismic resilience. This perspective highlights the integrative role of insurance within the broader framework of seismic risk management.

It is important to note that insurance effectiveness depends on the characteristics of the insured portfolio and on the level of coverage. Low insurance penetration rates and limited coverage caps reduce the ability of insurance systems to significantly influence recovery at a regional or national scale. In such cases, large portions of seismic losses remain uninsured, and the responsibility for recovery falls primarily on affected

individuals and public authorities. This situation may lead to delayed reconstruction and increased long-term socio-economic impacts.

From a risk management standpoint, insurance mechanisms are particularly relevant for low-probability, high-consequence events, such as major earthquakes. Because these events can generate losses that exceed the financial capacity of individual households or local administrations, the absence of adequate risk transfer instruments amplifies overall vulnerability. Insurance, when appropriately designed and widely adopted, can therefore contribute to reducing the protection gap between potential seismic losses and available financial resources.

In summary, insurance represents a key component of seismic resilience by addressing the financial dimension of earthquake risk. When integrated with structural mitigation measures and informed by realistic loss assessments, insurance systems can enhance the capacity of societies to recover more rapidly from major seismic events. Understanding this role is essential for evaluating the current state of seismic risk management and insurance coverage, particularly in high-risk regions such as Romania.

5. Current state of seismic insurance in Romania

Despite the compulsory nature of the insurance scheme, the level of seismic insurance coverage in Romania remains limited, with a national penetration rate of approximately 24% in 2024 [17]. However, the coverage achieved through this system represents only a fraction of the potential losses that may be generated by a major seismic event.

One of the key characteristics of the current insurance framework is the relatively low penetration rate. A significant proportion of residential buildings are not insured against seismic risk, despite the compulsory nature of the scheme. This situation reduces the effectiveness of insurance as a collective risk transfer mechanism and limits its potential contribution to post-earthquake recovery at a national scale.

In addition to low penetration, the level of coverage provided by existing insurance policies is modest when compared to the expected scale of earthquake-induced losses. Coverage limits are fixed and generally insufficient to reflect the actual replacement or repair costs associated with severe structural damage. As a result, even insured buildings may remain partially exposed to significant uninsured losses following a major earthquake.

From a loss perspective, this mismatch leads to a pronounced protection gap between potential seismic losses and the financial resources available through insurance mechanisms [18]. Large-scale seismic events may generate losses that far exceed the capacity of the insurance system to provide compensation. In such scenarios, a substantial part of the financial burden associated with reconstruction is transferred to affected households and public authorities.

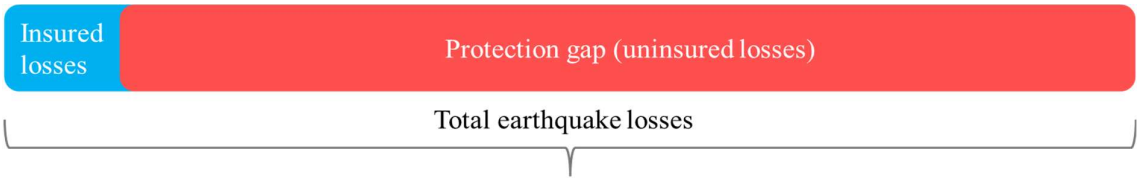


Fig. 3. Conceptual illustration of the seismic insurance protection gap in Romania

The figure highlights the limited share of losses currently covered by insurance and the resulting protection gap, which may have significant implications for post-earthquake recovery.

Another important aspect concerns the distribution of insured buildings across different structural typologies and urban areas. Insurance coverage is not systematically aligned with seismic vulnerability or exposure. Consequently, areas with high concentrations of vulnerable buildings may also exhibit low insurance coverage, further amplifying the potential socio-economic impact of a major earthquake.

The current structure of seismic insurance in Romania also limits its ability to influence risk reduction at the building level. In the absence of differentiated premiums that reflect seismic vulnerability or structural performance, there are limited financial incentives for building owners to invest in seismic strengthening measures. As a result, the interaction between structural risk mitigation and insurance remains weak.

Overall, the existing seismic insurance system provides an important but incomplete contribution to seismic risk management in Romania. While it offers a basic financial safety net, its current penetration, coverage limits, and limited integration with structural vulnerability considerations constrain its role in enhancing seismic resilience. Addressing these limitations is essential for reducing the gap between expected seismic losses and the financial capacity available for post-earthquake recovery.

6. Discussion

The analysis presented in the previous sections highlights the multifaceted nature of seismic risk and resilience in Romania. Structural vulnerability, seismic hazard, and exposure collectively define the potential for damage, but the consequences of a major earthquake extend well beyond structural performance alone. The ability to recover after a seismic event emerges as a critical component of overall resilience, requiring both technical and financial preparedness.

From an engineering perspective, structural mitigation measures such as seismic strengthening and improved design standards remain essential for reducing physical damage and loss of life. However, these measures are typically implemented gradually and often focus on a limited portion of the existing building stock. Even in scenarios where structural vulnerability is reduced, significant economic losses may still occur due to the large scale and concentration of exposed assets [19]. This observation reinforces the need for complementary mechanisms that address the financial dimension of seismic risk [20].

Insurance systems have the potential to play a significant role in bridging this gap. By providing a structured mechanism for risk transfer and loss compensation, insurance can support post-earthquake recovery and reduce the burden placed on public authorities and affected communities. However, the effectiveness of such systems depends strongly on their design, coverage levels, and degree of integration with structural risk reduction strategies.

In the Romanian context, the limited penetration of seismic insurance and the relatively low coverage limits constrain the impact of insurance on national-scale

recovery. These factors, combined with the absence of vulnerability-based premium differentiation, weaken the link between structural performance and financial protection. As a result, the current system does not fully capitalize on the potential synergies between engineering-based risk reduction and financial risk management.

A more integrated approach to seismic resilience would involve the coordinated development of structural and financial measures. From a conceptual standpoint, improvements in seismic performance achieved through retrofitting or strengthening interventions could be reflected in insurance conditions, thereby providing financial incentives for risk reduction. Such an approach would reinforce the role of engineering interventions not only in reducing damage, but also in enhancing financial preparedness.

Finally, it is important to recognize that seismic resilience is a systemic property that emerges from the interaction of technical, economic, and institutional factors. Insurance alone cannot ensure resilience, just as structural measures alone cannot guarantee rapid recovery. Effective seismic risk management requires coherent strategies that address both damage prevention and post-event recovery capacity. In this respect, insurance mechanisms should be viewed as integral components of a broader resilience framework, rather than as standalone solutions.

7. Conclusions

Seismic risk in Romania remains a major challenge due to the combined effects of a strong seismic hazard, a vulnerable existing building stock, and high levels of exposure in urban areas. While significant progress has been made in seismic design practice for new constructions, the potential consequences of future major earthquakes continue to raise serious concerns with respect to both structural damage and socio-economic impact.

This paper has emphasized that seismic resilience cannot be defined solely in terms of structural safety. Although engineering measures aimed at reducing vulnerability are essential, they are not sufficient to ensure rapid and effective recovery after a damaging seismic event. The financial capacity to support post-earthquake reconstruction represents a critical dimension of resilience that must be explicitly considered within seismic risk management frameworks.

Insurance mechanisms play an important role in addressing this financial dimension by facilitating the transfer and distribution of seismic losses. By providing access to post-event financial resources, insurance systems can support recovery processes and reduce the long-term disruption associated with major earthquakes. However, the current level of seismic insurance coverage in Romania, characterized by limited penetration and modest coverage limits, constrains the ability of insurance to significantly contribute to national-scale resilience.

The analysis highlights the existence of a clear protection gap between potential seismic losses and the financial resources available through existing insurance mechanisms. Reducing this gap requires not only improvements in insurance design and coverage, but also a closer integration between structural risk reduction measures and financial instruments. Such integration could enhance both damage prevention and

recovery capacity.

In conclusion, enhancing seismic resilience in Romania calls for a comprehensive and integrated approach that combines engineering-based mitigation measures with effective financial risk transfer mechanisms. Recognizing insurance as a complementary component of seismic risk management, alongside structural interventions, can contribute to more robust and sustainable recovery following future seismic events.

References

[1] *E.-S. Georgescu, A. Pomonis*, "The Romanian earthquake of March 4, 1977, revisited: new insights into its territorial, economic, and social impacts and their bearing on the preparedness for the future", in Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China, 2008.

[2] *M. Bruneau, S. E. Chang, R. T. Eguchi, G. C. Lee, T. D. O'Rourke, A. M. Reinhorn, M. Shinozuka, K. Tierney, W. A. Wallace, D. von Winterfeldt*, "A framework to quantitatively assess and enhance the seismic resilience of communities", in Proceedings of the 3rd World Conference on Earthquake Engineering, 2003.

[3] *A. Gkimprixis, J. Douglas, E. Tubaldi*, "Seismic risk management through insurance and its sensitivity to uncertainty in the hazard model", Natural Hazards, 108, nr. 2, 2021, pp. 1629–1657. https://doi.org/10.1007/s11069-021-04748-z

[4] *K. Goda, F. Wenzel, J. Daniell*, "Insurance and Reinsurance Models for Earthquake", în Encyclopedia of Earthquake Engineering, Springer, Berlin, 2014, pp. 1–24.

[5] *H. Yoshikawa, K. Goda*, "Financial seismic risk analysis of building portfolios", Natural Hazards Review, 15, nr. 2, 2014, pp. 112–120.

[6] *K. Goda*, "Seismic risk management of insurance portfolio using catastrophe bonds", Computer-Aided Civil and Infrastructure Engineering, 30, nr. 7, 2015, pp. 570–582.

[7] *F. Pavel, R. Văcăreanu, J. Douglas, M. Radulian, C. Cioflan, A. Barbat*, "An updated probabilistic seismic hazard assessment for Romania and comparison with the approach and outcomes of the SHARE Project", Pure and Applied Geophysics, 173, nr. 6, 2016, pp. 1881–1905.

[8] *C. Arion, F. Pavel, R. Văcăreanu, C. Neagu, M. Iancovici, V. Popa, I. Damian*, "Seismic risk assessment of Romania", in Seismic Risk Assessment and Mitigation, Springer, 2018, pp. 251–265.

[9] *CEN*, "EN 1998-1: Eurocode 8 – Design of structures for earthquake resistance", Brussels, 2004.

[10] *Ministerul Dezvoltării Regionale și Administrației Publice*, "Cod de proiectare seismică P100-1/2013", București, 2013.

[11] *L. Hofer, M. A. Zanini, F. Faleschini, C. Pellegrino*, "Expected losses vs. earthquake magnitude curves, for seismic risk mitigation and for insurance purposes", Procedia Structural Integrity, 44, 2023, pp. 1824–1831.

[12] *M. Kohrangi, A. N. Papadopoulos, S. R. Kotha, D. Vamvatsikos, P. Bazzurro*, "Earthquake catastrophe risk modeling: application to the insurance industry", în Springer Tracts in Civil Engineering, Springer, 2021, pp. 239–274.

[13] *J. E. Daniell, B. Khazai, F. Wenzel, A. Vervaeck*, "The CATDAT damaging earthquakes database", Natural Hazards and Earth System Sciences, 11, nr. 8, 2011, pp. 2235–2251.

[14] *D. Asprone, F. Jalayer, S. Simonelli, A. Acconcia, A. Prota, G. Manfredi*, "Seismic insurance model for the Italian residential building stock", Structural Safety, 44, 2013, pp. 70–79.

[15] *K. Goda*, "Earthquake insurance gaps for Canadian homeowners", in Proceedings of the 3rd European Conference on Earthquake Engineering & Seismology (3ECEES) Bucharest, Romania, 2022.

[16] *World Bank*, "Financial protection against natural disasters: an operational framework", World Bank Group, Washington DC, 2014.

[17] *PAID România*, "Raport privind solvabilitatea și situația financiară", București, 2024.
[18] *Swiss Re*, "Lessons from recent major earthquakes", Swiss Reinsurance Company, Zürich, 2012.
[19] *S. Perazzini, G. Gnecco, F. Pammolli*, "A public–private insurance model for disaster risk management: an application to Italy", Italian Economic Journal, 10, 225–267, 2024. https://doi.org/10.1007/s40797-022-00210-6.
[20] *P. Grossi, H. Kunreuther*, "Catastrophe modeling: a new approach to managing risk", Springer, New York, 2005.