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Analysis of buildings in Tunceli – Pülümür district with the Canadian seismic screening method

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Abstract

This study, which was conducted in the Pülümür district of Tunceli, was carried out in an area with high seismic risk due to the region's proximity to the Bingöl-Yedisu Fault. In the study, the earthquake safety of the existing building stock was assessed using visual inspection methods. In this context, 172 buildings in the Pülümür district of Tunceli province were examined in detail in terms of earthquake safety using the Canadian Seismic Screening Method. In the analysis, seismic safety levels of the buildings, structural and nonstructural risks were taken into consideration and seismic priority indexes (SPI) were determined. The results of the study revealed that a large portion of buildings in the Pülümür district carry different levels of risk of earthquake. Specifically, the evaluated building stock was entirely constructed before the critical year of 2007 and exhibits high seismic vulnerability. This critical threshold is technically attributed to two main regional factors: the design practices predating the 2007 Turkish Earthquake Code and the absence of ready-mixed concrete technology in Tunceli province prior to that year. Furthermore, based on the method's classification, it is suggested that buildings with a Seismic Priority Index (SPI) greater than 20, which indicates "High" to "Very Hazardous" risk levels, should be prioritized for detailed assessment and retrofitting, and that local governments should develop incentive policies for these mitigation efforts.

1. Introduction

This study focuses on buildings in the Pülümür district of Tunceli, a region exposed to high seismic risk due to the North Anatolian Fault (Yedisu segment) in Eastern Anatolia. The Yedisu Fault, extending from Erzincan to Bingöl, is a major segment of the North Anatolian Fault and a key source of regional seismic activity due to its strike-slip motion. With an estimated recurrence interval of approximately 250 years and its last major rupture occurring in 1784 (Ms 7.6), the fault is considered to have a high potential for a future earthquake. Fig. 1 illustrates the active faults in the Tunceli–Erzincan region and the distribution of the mainshock and aftershocks of the January 27, 2003 Pülümür earthquake (Mw 6.5) [1].

Rapid visual assessment is a preliminary approach used to estimate the seismic performance of existing buildings based on limited data. It assesses earthquake risk through two key components: regional seismic hazard and structural vulnerability; however, it acknowledges that hazard maps do not directly represent the risk. This method involves trained observers conducting brief on-site inspections and assigning scores within a short period, averaging 10-15 minutes. However, due to inherent simplifications and the subjective nature of some assessment parameters, the results only provide approximate estimates of the risk of damage. Accordingly, a building classified as "not at risk" cannot be definitively considered earthquake-resistant, and such methods are not suitable for detailed seismic performance analysis or the design of strengthening interventions [2].

Rapid visual screening (RVS) methods are commonly employed as preliminary tools in seismic vulnerability assessment, particularly for large building inventories. Nanda and Majhi [3] developed a rapid seismic vulnerability assessment procedure tailored to building stocks in developing countries, demonstrating its applicability for identifying structures requiring further detailed evaluation. Perrone et al. [4] proposed a rapid visual screening methodology for reinforced concrete hospital buildings and applied it to case studies in Italy, highlighting its use for assessing the seismic safety of critical facilities. Furthermore, Kassem et al. [5] provided a comprehensive review of seismic vulnerability assessment methodologies, summarizing the

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principal empirical and analytical approaches adopted in the literature.

In the context of Turkey, the Canadian Seismic Screening Method has been successfully adapted and applied in several studies. Işık et al. [6] utilized this method to evaluate 200 reinforced concrete buildings in Muş Province, finding that a combined 95% of the buildings fell into medium or high-risk categories, demonstrating the method's effectiveness in determining regional risk distribution. Similarly, Yakup and Cumhur [7] confirmed the method's practical applicability in evaluating the seismic performance of risky reinforced concrete buildings in Yalova. Comparative studies by Metin and Öztürk [8], Işık [9], and Altıner [10] further proved that when adapted to Turkish conditions, the Canadian method enables the reliable categorization of building stocks independent of construction year regulations, making it highly advantageous. Additionally, Çelik et al. [11] applied a rapid assessment approach based on the National Research Council of Canada to buildings in Europe, concluding that this framework is highly suitable for prioritizing earthquake risks within the Turkish building stock, while emphasizing the need for comprehensive subsequent research.

The 172 buildings examined in this study were specifically selected to represent the primary residential and commercial building stock in the central district of Pülümür, which is located in the immediate impact zone of the anticipated Yedisu Fault rupture. Rather than representing the entire province of Tunceli, this sample provides a highly focused dataset of various structural typologies located at the most critical seismic proximity.

Despite the widespread use of rapid screening methods, the literature predominantly focuses on post-disaster assessments. There is a significant lack of proactive, district-scale structural inventories specifically tailored to particular, potentially erupting fault lines such as the Yedisu Fault Line. To address this gap, the novelty of this study is based on three strategies:

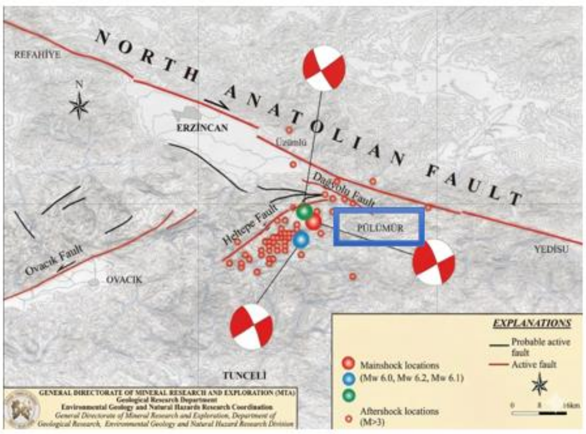

Fig. 1. Active faults of the Tunceli–Erzincan region and the mainshock–aftershock distribution of the January 27, 2003 Pülümür earthquake (MTA) [1]

1. Creating a structured local building inventory database for a region threatened by a potentially erupting earthquake,
2. Prioritizing risk for a district affected by a specific fault line based on Seismic Priority Indices (SPIs),
3. Providing actionable policy and strengthening prioritization implications for local authorities prioritizing a disaster.

2. Methodology

The Canadian Seismic Screening Method was used to scan the building stock, and the use of numerical parameters such as the Seismic Priority Index (SPI) provided a concrete methodology for the earthquake prioritization process of buildings. This approach offers greater accuracy and consistency by providing a measurable and comparable model, rather than traditional risk assessments based on general expressions. The Canadian Seismic Screening Method was developed by the National Research Council Canada (NRCC). In this method, various parameters—such as the seismicity of the region, soil type, load-bearing system type, structural irregularities, and the building importance factor—are used to calculate structural and non-structural index values. The Seismic Priority Index (SPI) is then determined by combining these indices. The main parameters used in the method are as follows [12,13]:

- Seismicity of the region where the building is located (A)
- Local soil conditions (B)
- Type of load-bearing system (C)
- Floor system (D)
- Irregularities present in the building (E)
- Building importance factor (F)

During the evaluation, a Structural Index (SI) that considers the potential damage and defects of the structure and a Non-Structural Index (NSI) that reflects the damage risk of non-structural components are calculated.These indices are defined by the following equations:

$$SI = A \times B \times C \times D \times E \quad (1)$$

$$NSI = B \times E \times F \quad (2)$$

$$SPI = SI + NSI \quad (3)$$

The scoring system begins with the A value (ranging from 1 to 4) determined based on the seismic risk of the region and the construction year. Next, the B value (ranging from 1 to 2) is determined by the soil type and construction year. The C value (ranging from 1 to 3.5) is determined based on the type of load-bearing system, the D value (ranging from 1 to 2) is determined according to structural irregularities, and the E value (ranging from 0.7 to 3) is determined according to the usage class. The F value, which represents non-structural risks, ranges between 1 and 6. These scores are provided in the evaluation form [12].

Table 1. Limit values for priority classification according to the Canadian Seismic Screening Method [12]

Score type	Limit values	Priority class
SI or NSI	1-2	Sufficient Earthquake Safety
SPI	<10	Low-Priority Buildings
SPI	10-20	Medium-Priority Buildings
SPI	20-30	High-Priority Buildings
SPI	>30	Very Hazardous Buildings

Based on the calculated SPI, buildings are classified into four risk categories: low, medium, high, and very hazardous (see Table 1). If the Structural Index (SI) or the Non-Structural Index (NSI) falls within the range of 1–2, the building is considered to have sufficient earthquake safety.

In determining local ground conditions (parameter B), no new geotechnical excavation was conducted as part of this rapid survey. Instead, soil classifications were systematically obtained from existing seismic micro-zonation reports from the Disaster and Emergency Management Presidency (AFAD) and local municipality records. This secondary data was supported by visual verification of surface topographic slopes and soil characteristics during field investigations.

In addition, the Seismic Screening Form developed by Rainer et al. [12] was used in the seismic assessment of the structures examined in the study. The assessment results were compiled in a standardized tabular format widely used in the literature. Owing to the large size of the completed table, it was not included in the manuscript; however, it is available from the corresponding author upon reasonable request.

In this study, the seismic performance of 172 buildings was analyzed using the Canadian Seismic Screening Method, and the results were systematically evaluated. The data collected in the study provided a comprehensive assessment of the seismic resistance capacity of existing buildings, the properties of their structural elements, and their overall performance levels.

3. Results

In this study, evaluations were made using visual inspection methods to determine the damages and deficiencies in buildings located in Pülümür district of Tunceli province. The findings presented in this section show the types and extents of structural irregularities and weaknesses that may become important in the event of an earthquake in the examined buildings. The visual inspection process aimed to provide rapid and practical estimates of the seismic performance of buildings in Pülümür, the district closest to the Bingöl-Yedisu fault, which is expected to cause an earthquake in the near future, by emphasizing the basic factors that are important for earthquake-resistant structural design. The results were categorized and interpreted according to predefined evaluation criteria to support the planning of necessary interventions and to guide future seismic risk reduction strategies. Within the scope of the study, the seismic performance of 172 buildings was analyzed using the Canadian Seismic Screening Method, and the results were evaluated systematically. Two sample buildings are described in detail. A similar evaluation was conducted for the remaining 170 buildings, and their earthquake risk priorities were determined. The results, along with the identified irregularities, are presented in tabular form.

Located in the central district of Pülümür district and built in 1982 in accordance with the 1975 Turkish Earthquake Regulations [14], Pülümür B1 is a two-storey residential building with a masonry structural system. It is situated in parcel 1 of block 139, in an area of high seismic risk. Various parameters were used to compute the structural and non-structural index values for the evaluation. Table 2 presents the seismic screening parameters and the calculated indices (SI, NSI, and SPI) for the Pülümür B1 building based on the Canadian Seismic Screening Method.

Given the high seismic risk in the area, the first parameter used in evaluating the building's seismic performance was the seismicity level, with an effective seismic region score of 2. The soil conditions were scored at 1.5 due to the building being on loose soil in a sloping area. The masonry load-bearing system provided a score of 3.5. Structural irregularities such as vertical irregularities, severe projections, damaged structural elements, and deteriorations were assessed with a score of 1.69. As the building was constructed for normal residential use, the importance factor was set at 0.7. For the non-structural assessment, the risk of falling elements was scored as 3.

From these values, the Structural Index (SI) was calculated as 12.42 and the Non-Structural Index (NSI) as 3.15, yielding an SPI of 15.57. According to the method, an SPI between 10 and 20 classifies the building as "Medium Priority," indicating that the structure is not entirely safe but does not carry an extremely high risk.

Accordingly, recommendations for this building include strengthening measures. To address weaknesses in the load-bearing system, methods such as injection, steel reinforcement, or concrete strengthening may be applied. In addition, non-structural elements that pose a risk of falling should be secured and reinforced. For the loose soil conditions, stabilization techniques such as injection or deep foundation methods may be employed. Moreover, it is recommended that earthquake awareness programs be organized for the local community and that training on building safety be provided.

Similarly, data for all 172 buildings whose visual inspections were completed are compiled. Due to manuscript length restrictions and space limitations, it is not feasible to present the full dataset of all 172 evaluated buildings within the text. Therefore, Table 3 provides the calculated indices and structural parameters for 10 representative buildings as an example, ensuring that all risk classifications strictly adhere to the SPI boundaries defined in the methodology.

Table 2. Summary of seismic screening parameters and indices for the Pülümür B1 building

Parameter	Description	Value
A	Seismicity	2.0
B	Ground Conditions	1.5
C	Structural System	3.5
D	Irregularities	1.69
E	Building Importance	0.7
F	Non-Structural Hazards	3.0
SI	Structural Index	12.42
NSI	Non-Structural Index	3.15
SPI	Seismic Priority Index	15.57

Table 3. Data and risk status of all buildings

No	Irregularity in vertical	Irregularity in plan	Short column	Soft story	Hammering	Heavy overhang	Building visual quality (poor)	SI	NSI	SPI	Risk Status
1	✓	-	-	-	-	✓	✓	17.74	3.0	20.74	High-Priority
2	✓	-	-	-	-	-	✓	12.42	1.05	13.47	Medium-Priority
3	✓	-	-	-	-	✓	✓	12.42	3.15	15.57	Medium-Priority
4	✓	✓	-	-	-	-	✓	26.25	4.5	30.75	Very Hazardous
5	✓	-	-	-	-	-	✓	36.4	2.0	38.4	Very Hazardous
6	✓	✓	-	-	-	-	✓	18.38	3.15	21.52	High-Priority
7	✓	-	-	-	✓	-	✓	16.17	1.05	17.22	Medium-Priority
8	✓	-	✓	-	✓	-	✓	4.95	4.5	9.45	Low-Priority
9	✓	✓	-	-	✓	-	✓	64.68	8.4	73.08	Very Hazardous
10	✓	-	-	-	✓	-	✓	61.6	6.0	67.6	Very Hazardous

The analyses conducted with the Canadian Seismic Screening Method provide an important framework for determining the seismic performance of the building stock and developing solution proposals in this context. The results obtained from the 172 buildings analyzed in this study enable the evaluation of both local structural characteristics and contributions to the global structural engineering literature. The scope of the study includes not only the determination of seismic risks but also the development of strategic proposals to reduce the effects of these risks. This analysis has presented the general risk status of the region in the categories of low, medium, high and very dangerous with sufficient earthquake safety obtained by classifying the SI, NSI and SPI values. Fig. 2 shows the Risk Status Percentages and Building Numbers for the buildings.

Based on the SPI classification of the 172 buildings inspected, the following were reached:

a) Low Priority (SPI < 10): 5 buildings (2.9%). Based on pre-screening parameters, these buildings represent the lowest relative seismic risk among the evaluated building stock, showing fewer visually significant structural defects and a lower probability of serious damage compared to other categories.

b) Medium-Priority (SPI 10-20): 56 buildings (32.6%). These buildings demonstrate moderate structural vulnerabilities. Although they lack the severe visual defects seen in the high-risk tiers, the assessments indicate the presence of minor structural weaknesses or design flaws that could lead to moderate damage. Therefore, while not an immediate emergency, they still necessitate future detailed structural evaluations.

c) High-Priority (SPI 20-30): 27 buildings (15.7%). This group possesses significant defects and structural weaknesses, posing a serious risk during earthquakes. Poor design practices, material quality deficiencies, and incompatibility in the structural system adversely affect their seismic performance.

d) Very Hazardous (SPI > 30): 84 buildings (48.8%). This clearly indicates that a large proportion of the building stock in the region poses severe seismic risks. Alterations and retrofitting in this category must be addressed urgently to ensure life safety.

The findings show that a significant proportion of the buildings analyzed fall into high-risk categories. In particular, the 48.8% in the "very dangerous" category constitutes a critical alarm for the overall functioning of the building stock. There are serious deficiencies in the material quality, design features and geometrical arrangements of buildings. These results provide detailed data on the seismic ranges of the regional building stock, and this data can be used as a reference for structural performance assessment.

To establish a robust analytical framework, the relationship between risk status and structural system was statistically examined. Since all buildings evaluated were constructed before current regulations (specifically the 2007 regulation adopted in this study) and the widespread use of ready-mixed concrete, Table 4 presents a cross-tabulation of risk priority classes according to the primary load-bearing system (reinforced concrete vs. masonry), a key factor determining seismic performance.

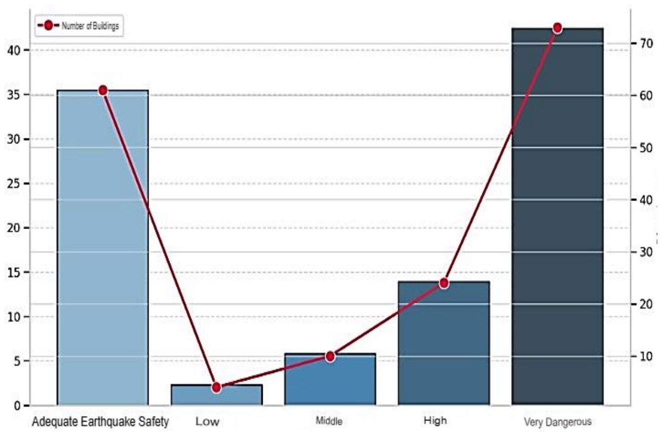

Fig. 2. Risk status percentages and building numbers

Table 4. Cross-tabulation of risk priority classes by structural system

Structural System	High-Priority	Low-Priority	Medium-Priority	Very Hazardous	Total
Masonry	15	3	36	41	95
Reinforced Concrete	12	2	20	43	77
Total	27	5	56	84	172

Table 5. Distribution statistics (Median and IQR) for analyzed ındices

Index	Median	IQR (Interquartile Range)	Min	Max
SI	23.1	49.0	4.95	153.0
NSI	3.15	6.08	1.05	27.0
SPI	26.85	57.4	9.45	160.0

The distribution of risk priority classes shows that both masonry and reinforced concrete buildings are predominantly concentrated in high-risk categories. Masonry buildings are slightly more prevalent in high-risk categories compared to reinforced concrete structures; however, reinforced concrete buildings also have a significant proportion in high-risk groups, indicating that the structural system alone does not completely mitigate seismic risk. Overall, the findings from Table 4 point to a generally weak building inventory that requires more detailed assessment. Furthermore, Table 5 provides the median and Interquartile Range (IQR) statistics for the index distributions, offering a clearer picture of data centrality and dispersion without being skewed by extreme outliers.

The statistical distribution in Table 5 highlights significant heterogeneity in the building stock's seismic vulnerability. Notably, the median SPI of 26.85 places the central tendency of the dataset firmly in the "High Priority" risk tier. Furthermore, the exceptionally wide Interquartile Ranges for SI (IQR = 49.0) and SPI (IQR = 57.4) indicate massive structural disparities among the buildings. This mathematically proves that while a minor segment of the inventory may perform adequately, a substantial tail of outlier buildings possesses catastrophic structural deficiencies.

The SPI is a comprehensive and effective indicator for assessing building safety as it includes both structural and process characteristics. Thanks to its wide distribution and outliers, it is very successful in revealing both general trends and risky structures. In this context, SPI is a parameter that can make a critical contribution to decision makers in building stock screening, risk prioritization and disaster management planning. The graph in Fig. 3 compares the distribution of SI, NSI, and SPI variables.

The graph in Fig. 3 presents a comparative analysis of the distribution of the SI (Process Index), NSI (Structural Irregularity Index), and SPI (Overall Performance Index) variables. The SI index shows a median value of approximately 23 across the site, and its wide distribution suggests that building characteristics are quite variable. Outliers exceeding 100 represent structures in poorer condition than other structures. The NSI index, with a median of around 3, is concentrated within a narrower range than the SI index. This indicates that most structures have a certain amount of irregularity, but also that very high irregularity exists. For the SPI index, an index median of approximately 27 suggests low performance across the sample structures. Conversely, the wide distribution between 9 and 160, with outliers reaching 160, indicates significant performance variation due to different building types, ages, maintenance status, and irregularity profiles. Additionally, it is seen that buildings with SPI values below 20 are generally classified as Low or Medium Priority, while buildings with SPI values of 30 and above are mostly classified as Very Hazardous. This shows that SPI is highly correlated with risk classification and that it is possible to perform risk analysis with this method. According to the sample set's outliers, there is a high risk of structural deterioration and/or irregularities in some of the site's existing buildings. The outlier SPI values that result from the study can be considered as a risk-oriented intervention considering the early warning system.

Additionally, the statistical summary given in Table 5 is consistent with the box plot in Fig. 3. Accordingly, SI and SPI values show a wider distribution and higher variability compared to NSI. Furthermore, the presence of high-value outliers indicates that these indices have a right-skewed distribution.

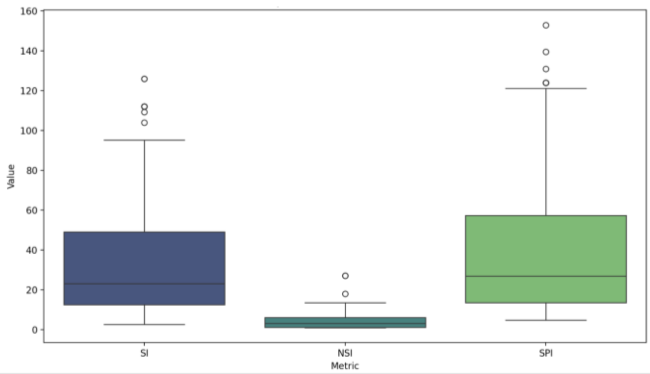

Fig. 3. Distribution of SI, NSI and SPI variables of the data

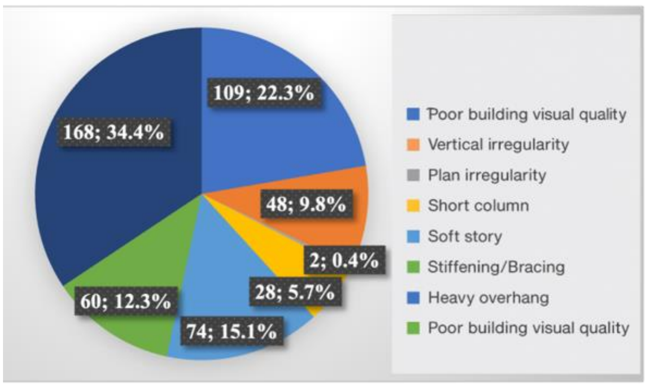

Fig. 4. Frequency of each type of irregularity

Fig. 4 shows a graph of the irregularities of the buildings. The results reveal that a significant number of the buildings screened have structural irregularities and poor visual quality. As shown in Fig. 4, 34.4% of the buildings had poor "building visual quality", i.e. negative conditions in terms of material strength or general workmanship. The vertical irregularity rate was 22.3%, the heavy overhang rate was 15.1%, and the plan irregularity rate was 9.8%. These data show that many buildings contain solutions that do not comply with the regulations during the design and implementation phases.

In addition, the presence of features such as soft stories (12.3%), hammering (5.7%) and short columns (0.4%) are factors that may negatively affect the performance of buildings against earthquake effects. Especially soft story formation is known to increase the risk of damage by increasing the displacement differences between stories during an earthquake.

4. Conclusions

Using data obtained from buildings examined in the Pülümür district of Tunceli, this study provides a detailed dataset on the seismic performance of structures in the region and establishes a practical and scientific foundation for transitioning from macro-level regional earthquake risk maps to micro-scale assessments.

Conducted using the Canadian Screening Method, this study has revealed the current state of the building stock in the Pülümür district in terms of earthquake safety. Accordingly, a significant portion of buildings constructed prior to the 2007 earthquake code fall into the "Very Hazardous" (48.8%) and "High Priority" (15.7%) categories based on SPI metrics. These structures with high vulnerability levels commonly exhibit characteristics such as low visual quality (34.4%) and vertical irregularities (22.3%). The wide interquartile ranges of SI and SPI values mathematically validate these structural differences; while a small portion of the building stock demonstrates adequate performance, a significant portion is found to have serious structural deficiencies.

The distribution of SI and SPI values indicates that the seismic performance of the examined structures varies significantly and that the structures do not exhibit homogeneous earthquake resistance. In contrast, the concentration of NSI values within a narrow range indicates that the overall resistance capacity of the building stock is limited.

To mitigate these vulnerabilities, the following conclusions and recommendations are presented within the scope of this study:

1. The SPI dataset created in this study can be used as a "triage" tool. This enables the effective use of municipal resources, allowing detailed structural analyses to be prioritized for buildings with an SPI value above 30.

2. Considering the region's socio-economic conditions, targeted incentive programs can be developed to reinforce or facilitate the urban renewal of pre-2007 masonry and reinforced concrete structures, particularly those in the high-risk category.
3. The prevalence of soft-story irregularities (12.3%) and heavy overhangs (15.1%) indicates that design principles were not sufficiently adhered to in pre-2007 buildings. Therefore, municipal inspection processes should be reviewed, and technical training on the effects of such geometric irregularities should be expanded.

The rupture of the Yedisu Fault is a scientifically plausible scenario, and such rapid visual screening studies serve as an early warning mechanism. In the future, integrating this dataset with machine learning models will enable the dynamic prediction of building risk classifications. The risk prioritization approach presented in this study aims to contribute to reducing loss of life and enhancing the resilience of the building stock by providing decision-makers with an evidence-based roadmap for transitioning from post-disaster response to pre-disaster risk reduction.

Declarations

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Conflict of interests

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Author contributions

All authors contributed equally to this study. All authors have read and approved of the final manuscript and accept equal responsibility for its content.

Data availability statement

Supplementary data associated with this article, including figures, datasets, and additional analyses, are available from the corresponding author upon reasonable request.

Use of generative AI and AI-assisted technologies

In preparing this article, the authors carefully utilized AI-powered technologies for linguistic enhancement, translation support, and the conversion of data collected entirely manually by the authors, into graphs, while meticulously checking all results. No analytical content was generated using AI tools. These tools were used solely to improve readability, and the authors are solely responsible for the final integrity, scientific accuracy, and originality of the content.

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