JURNAL TEKNIK SIPIL CENDEKIA
e-ISSN : 2723-3375
doi : **10.51988/jtsc.v7i3.582**
**pp : 567-580**

# Preliminary Neighborhood-Scale Seismic Vulnerability Profile Of Residential Buildings In A Selected Urban Settlement In Singaraja Bali Using Fema P-154 Rapid Visual Screening

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Received : 10 Juni 2026 Revised : 20 Juli 2026 Accepted : 21 Juli 2026

***Abstract***

*Indonesia is highly exposed to seismic hazards; however, pre-earthquake neighborhood-scale assessments of residential seismic vulnerability remain limited, particularly in Indonesian urban settlements. This study aims to develop a preliminary neighborhood-scale seismic vulnerability profile of residential buildings in a selected urban settlement in Singaraja, Bali, using the FEMA P-154 Rapid Visual Screening (RVS) method. A total of 120 permanent residential buildings were selected through purposive sampling and assessed using the Level 1 visual screening procedure. The analysis focused on the distribution of RVS scores, estimated probability of collapse, building characteristics, and visual parameters contributing to seismic vulnerability. The results indicate that the final RVS scores ranged from 0.60 to 1.20, with an average score of 1.13, corresponding to an average estimated probability of collapse of 8%. Besides structural type, pounding potential was identified as the dominant visual characteristic, occurring in 65% of the surveyed buildings, indicating that the spatial configuration of residential development also contributes to neighborhood seismic vulnerability. Unlike conventional building-by-building screening, this study demonstrates the applicability of FEMA P-154 Level 1 for developing a neighborhood-scale seismic vulnerability profile that can support the prioritization of Detailed Seismic Evaluation (DSE) and community-level earthquake risk mitigation planning.*

**Keywords:** *Rapid Visual Screening, FEMA P-154, seismic vulnerability, residential buildings, earthquake risk mitigation.*



## INTRODUCTION

Indonesia is one of the most seismically active countries in the world due to its location at the convergence of the Indo-Australian, Eurasian, and Pacific tectonic plates [1], [2]. Consequently, this setting exposes many regions of the country to significant earthquake hazards, including Bali province. The impact of an earthquake is not determined solely by the intensity of ground shaking; the vulnerability of the built environment can also contribute to the damage caused by the natural disaster. Therefore, understanding the seismic vulnerability of existing buildings is an important component of earthquake risk reduction, especially in densely populated urban areas.

Residential buildings are among the most widely exposed building types during earthquake events [3], [4], [5], [6]. Damage to houses can directly result in economic losses, casualties, displacement, and disruption of social activities at the community level [3], [5], [6], [7], [8]. In Indonesia, many residential buildings are constructed incrementally and self-managed by owners often with varying levels of technical supervision, construction quality, and compliance with seismic design principles. This conditions create a highly diverse residential building stock ranging from relatively new developer-built houses to older self-built houses that may have undergone gradual expansion or informal renovations [3], [5], [9]. Such diversity makes residential buildings an important yet challenging target for seismic vulnerability assessment [10].

Urban residential settlements have additional characteristics that may increase seismic risk. As cities grow, land-use pressure often leads to high building density, limited separation between adjacent houses, and irregular patterns of building development. In many neighborhoods, houses of different ages, structural configuration, and construction quality coexist within a relatively small area [3], [5], [11]. Incremental modifications, such as vertical or horizontal extensions, may further alter the original structure configuration of a building [12]. When these changes are not accompanied by adequate seismic considerations, the vulnerability of houses and the overall neighborhood may increase [13]. In addition, the limited spacing between buildings can create a potential pounding effect during earthquakes, especially when adjacent structures have different dynamics characteristics [1], [12], [14].

Detail structural evaluation can provide a more accurate understanding of building capacity; however, it requires technical data, engineering analysis, sufficient access to the building, and considerable resources. These requirements make detailed evaluation difficult to apply as an initial assessment tool in residential areas with a large number of buildings. For this reason, a rapid preliminary assessment method is needed to identify buildings or neighborhoods that may require more detailed investigation. Rapid Visual Screening (RVS) provides a practical approach for this purpose because it allows the initial identification of seismic vulnerability based on observable building characteristics without requiring destructive testing or complex structural analysis.

One of the most widely used RVS procedures is the method developed by Federal Emergency Management Agency (FEMA) through FEMA P-154 [15]. This method evaluates buildings using visual information related to structural system, building irregularities, construction era, soil conditions, and other special vulnerability-related characteristics. The final screening score provides an initial indication of seismic vulnerability and can be used to determine whether a building should be prioritized for detailed structural evaluation [12], [14]. Previous studies have shown that RVS methods are useful for supporting seismic risk management, particularly for prioritizing buildings that require further assessment or intervention.

Several studies have applied RVS-based approaches to different building types and regional contexts. Ruggieri et al. developed an RVS-based prioritization procedure for reinforced concrete school buildings in Italy and showed that the method can support decision-making for seismic risk reduction [16]. Kegyes – Brassai reviewed the development and implementation of conventional RVS methods, including FEMA-based procedures, and emphasized their role as practical tools for preliminary seismic risk assessment [15]. Other studies have also investigated the seismic vulnerability and fragility of residential buildings using empirical, analytical, or hybrid approaches [10], [17], [18], [19], [20], [21], [22]. Nevertheless, in the Indonesian context, studies focusing on pre-earthquake seismic vulnerability assessment of residential buildings remain limited, especially at the neighborhood-scale.

Despite the increasing application of RVS methods in Indonesia, most existing studies have focused on public or institutional buildings, such as schools and university facilities, or have evaluated buildings as isolated individual structures [1], [2], [8], [11], [23]. Consequently, limited information is available regarding the neighborhood-scale distribution of seismic vulnerability characteristics within residential settlements, where building density and interactions among adjacent buildings may collectively influence seismic risk. This knowledge gap is particularly relevant in rapidly developing urban areas of Bali, where residential neighborhoods consist of buildings with diverse construction ages, structural characteristics, and development histories. Developing a neighborhood-scale seismic vulnerability profile can therefore provide valuable baseline information to support community-level earthquake risk reduction and prioritization of further structural evaluation.

Therefore, this study aims to develop a preliminary neighborhood-scale seismic vulnerability profile of residential buildings in a selected urban settlement in Singaraja, Bali, using the FEMA P-154 Rapid Visual Screening (RVS) method. Rather than evaluating buildings solely as individual units, this study examines the collective distribution of seismic vulnerability characteristics within a residential neighborhood by integrating building typology, visual screening scores, estimated probability of collapse, and dominant vulnerability-related parameters. In doing so, the study demonstrates the applicability of the FEMA P-154 Level 1 procedure for neighborhood-scale seismic profiling and provides baseline information to support Detailed Seismic Evaluation (DSE) prioritization and community-level earthquake risk mitigation planning in Indonesian urban residential areas.

## METHODS

### Study Area

This study was conducted in a selected urban residential neighborhood in Singaraja city, Buleleng regency, Bali, Indonesia. The geographical location of the study area is illustrated in Figure 1.


**Figure 1. Location of the study area: (a) Bali Province, (b) Singaraja City in Buleleng Regency, (c) the surveyed residential neighborhood**

The study area was selected because it represents a typical urban settlement that has developed progressively over several decades. The neighborhood consists of residential buildings constructed during different development periods, ranging from self-built houses established in the 1990s to more recently developed housing clusters. Consequently, the area exhibits considerable variation in building age, structural configuration, construction quality, and development patterns, making it suitable for developing a preliminary neighborhood-scale seismic vulnerability profile.

In addition to variations in building characteristics, the selected neighborhood reflects common features of many Indonesian urban residential areas, including relatively high building density, limited separation distances between adjacent houses, and incremental residential development. These characteristics provide an appropriate setting for investigating the applicability of Rapid Visual Screening (RVS) as an initial tool for identifying seismic vulnerability within residential communities.

**Building sample**

The research object consisted of permanent residential buildings located within the selected study area. A total of 120 residential buildings were successfully surveyed during the scheduled fieldwork. The sample size was determined by the number of buildings that could be completely assessed within the available survey period while satisfying the predefined inclusion criteria. As this study was intended to develop a preliminary neighborhood-scale seismic vulnerability profile rather than to produce statistically representative estimates, the selected buildings should be interpreted as observable characteristics of residential buildings within the study area.

Purposive sampling was adopted because the FEMA P-154 Level 1 procedure requires adequate visual access to identify observable structural characteristics from exterior inspections. Buildings were included in the survey if they satisfied the following criteria: 1) the building functioned as a permanent residential house, 2) sufficient portions of the structural system were visually observable from public access without requiring entry into private property, 3) the building was located within the selected residential neighborhood [11], [14]. Buildings with severely obstructed facades or insufficient visual information for structural identification were excluded from the assessment.

**Rapid Visual Screening Procedures**

The seismic vulnerability assessment was carried out using the Level 1 Rapid Visual Screening (RVS) procedure described in FEMA P-154. The Level 1 procedure was intentionally adopted because the primary objective of this study was to develop a preliminary neighborhood-scale seismic vulnerability profile of residential buildings through a standardized rapid screening approach. The Third Edition of FEMA P-154 introduces an optional Level 2 screening procedure to obtain additional building information and improve the accuracy of the preliminary assessment for selected buildings. However, Level 2 is intended as a follow-up assessment after the initial screening stage and requires more detailed observations and additional structural information than those collected during the Level 1 survey [14]. Since this study focused on characterizing the overall vulnerability pattern of a residential neighborhood rather than refining the assessment of individual buildings, the Level 1 procedure was considered the most appropriate and methodologically consistent approach. Buildings identified as potentially vulnerable through the Level 1 screening can subsequently be prioritized for optional Level 2 screening or Detailed Seismic Evaluation (DSE), depending on the objectives of future investigation.

Field surveys were conducted through sidewalk observations following the standard FEMA P-154 inspection procedure. All observations were performed from outside the buildings without entering private property or exposing concealed structural elements. The assessment therefore relied exclusively on characteristics that could be visually identified during the field survey.

The following parameters were evaluated during the screening process:

a) Seismicity level
   FEMA P-154 determined seismicity level according to spectral response accelerations, $S_s$ and $S_1$, at $MCE_R$ level. The study area has $S_s\, MCE_R = 1.0269$ and $S_1 MCE_R = 0.4159$ [24]. Therefore, the study area was classified as a *high seismicity region* [14].
b) Structural types
   The 2015 edition of FEMA P-154 lists 17 structural types with key characteristics of construction materials and seismic force-resisting system types.
c) Structural irregularities
   Structural irregularities considered in the survey include plan irregularity and vertical irregularity (moderate or severe), whenever identifiable through exterior observations.
d) Construction era and building codes
   FEMA P-154 considers the timing of a building's construction relative to the adoption of seismic design codes in the region, namely *pre-code* and *post-*

*benchmark*. Pre-code applies if the building was constructed before the adoption and enforcement of a seismic design code for the building type. Post-benchmark applies if the building was constructed after a significantly improved seismic design code was implemented.

e) Soil information
Site classes or soil types are divided into six types: Type A for hard rock, Type B for average rock, Type C for very dense soil and soft rock, Type D for stiff soil, Type E for soft clay soil, and Type F for poor soil. If the soil type cannot be identified or estimated, Soil Type D should be assumed [14].

f) Special seismic-related conditions
Special conditions noted in FEMA P-154 are pounding potential between buildings, falling hazards from taller adjacent buildings, geological hazards or Soil Type F, and significant damage/ deterioration to the structural systems.

To maintain consistency during field observations, all buildings were assessed using the standardized FEMA P-154 Level 1 screening form. Each building was evaluated once by a single assessor during the field survey. Photographic documentation of the building façade and relevant structural features was collected simultaneously to support post-survey verification. After fieldwork, the completed screening forms were reviewed against the corresponding photographs to verify structural classification and recorded visual parameters before calculating the final RVS scores.

**Structural Classification**

The surveyed residential buildings were classified according to the FEMA P-154 structural types. Based on observable structural characteristics, two structural categories were identified within the study area: *Unreinforced Masonry* (URM) and *Concrete Moment Frame with Unreinforced Masonry Infill Walls* (C3).

Structural classification was performed based on the dominant structural characteristic observable during the exterior field survey. Since the Level 1 RVS procedure is intentionally limited to visual inspection, the identification of structural systems relied exclusively on visible structural elements without verification of concealed structural details, including reinforcement continuity, beam-column connections, and internal lateral load-resisting mechanisms. Consequently, when certain residential buildings exhibited structural characteristics that were not completely distinguishable through exterior observation alone, the classification was assigned to the closest applicable FEMA P-154 structural category based on the dominant observable features. This approach is consistent with the objective of Level 1 RVS as a rapid preliminary screening method for prioritizing buildings requiring more detailed structural evaluation.

To facilitate interpretation of the vulnerability profile, the surveyed buildings were further grouped according to construction age and number of stories. Building age was categorized into three groups: older buildings (constructed before 2000), intermediate buildings (constructed between 2000 and 2015), and newer buildings (constructed after 2015). Building height was classified into one-story and two-story (or higher) buildings.

**Seismic Vulnerability Assessment**

The Level 1 RVS score was calculated following the FEMA P-154 procedure. Each building was initially assigned a Basic Score (BS) according to its structural (building) type. The Basic Score was subsequently adjusted using score modifiers that account for structural irregularities, construction era, site conditions, and other characteristics considered in the FEMA screening procedure

The final RVS score was calculated as:

$$S = BS + \Sigma M \quad (Equation\ 1)$$

where:
$S$ = the final RVS score
$BS$ = the Basic Score corresponding to the structural (building) types
$\Sigma M$ = the summation of score modifiers associated with the observed building characteristics

Lower final RVS scores indicate higher level of expected seismic vulnerability.

**Estimation of Probability of Collapse**

To facilitate interpretation of the screening results, the final RVS score was converted into an estimated Probability of Collapse ($P_c$) using the relationship provided in FEMA P-154.

$$P_c = 10^{\wedge(-S)} \quad (Equation\ 2)$$

where:
$P_c$ = the estimated probability of collapse
$S$ = the final RVS score

The calculated probability should be interpreted as a relative indicator of seismic vulnerability rather than as an annual probability of structural collapse.

**Data Analysis**

Data collected were analyzed in four sequential stages. First, descriptive statistical analysis was performed to summarize the distribution of RVS scores and estimated probabilities of collapse for all surveyed buildings. Second, the vulnerability profile was examined according to building characteristics, including structural type and construction age, to identify observable variations among different groups of residential buildings. Third, the frequency of visual characteristics contributing to seismic vulnerability, including structural irregularities and special seismic-related conditions, was analyzed to identify dominant vulnerability factors within the study area. Attention was given to pounding potential because this characteristic may influence seismic performance despite not directly modifying the Level 1 RVS score [14]. Finally, the overall results were synthesized to develop a preliminary neighborhood-scale seismic vulnerability profile of the selected residential area in Singaraja, Bali. The analysis was intended to provide baseline information for identifying buildings requiring Detailed Seismic Evaluation (DSE) and to support future earthquake risk mitigation planning at the community level.

**Research Workflow**

The overall research workflow is illustrated in Figure 2.

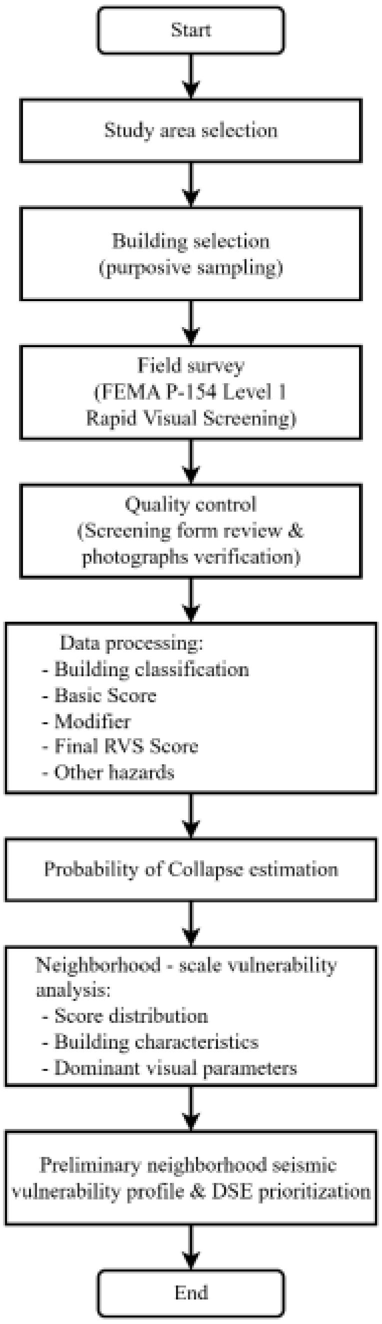


**Figure 2. Research workflow**

The study began with the selection of the study area and residential building samples, followed by field data collection using the FEMA P-154 Level 1 Rapid Visual Screening procedure. The collected data were subsequently used to classify building structural types, calculate final RVS scores and estimated probabilities of collapse, and analyze neighborhood-scale vulnerability characteristics to develop a preliminary seismic vulnerability profile and identify buildings that may require further evaluation.

# RESULTS AND DISCUSSION

## Characteristics of the Surveyed Residential Buildings

Table 1 summarizes the general characteristics of the surveyed residential buildings. Of the 120 buildings evaluated, 113 (94.2%) were single-story structures, while only seven (5.8%) had two stories. Regarding structural typology, Concrete Moment Frame with Unreinforced Masonry Infill Walls (C3) was the predominant structural system, representing 83.3% of the surveyed buildings, whereas Unreinforced Masonry (URM) buildings accounted for the remaining 16.7%. In terms of construction age, buildings constructed after 2015 constituted the largest proportion (75%), followed by buildings constructed between 2000 and 2015 (13.3%) and those built before 2000 (11.7%).

**Figure 3. Representative examples of URM buildings**

(a)

(b)

**Figure 4. Representative examples of C3 buildings: (a) 1-story (b) 2-story**

**Table 1. General characteristics of the surveyed residential buildings**

| Characteristics | Number | Percentage |
|---|---|---|
| Total building | 120 | 100% |
| 1-story building | 113 | 94.2% |
| 2-story building | 7 | 5.8% |
| Building type C3 | 100 | 83.3% |
| Building type URM | 20 | 16.7% |
| Age < 10 years | 90 | 75% |
| Age 10 – 25 years | 16 | 13.3% |
| Age > 25 years | 14 | 11.7% |

The predominance of single-story C3 buildings indicates that the investigated neighborhood is primarily composed of relatively modern residential construction. This observation reflects the gradual transition from traditional masonry construction toward reinforced concrete-based housing systems, which have become increasingly common in Indonesian urban residential developments over the past two decades. The relatively small proportion of URM buildings suggests that older construction practices are becoming less dominant within the study area, although these buildings remain an important component of the existing residential building stock.

The predominance of C3 buildings observed in this study is also consistent with previous residential building surveys in Indonesia.

Sharon et al. (2024) reported that confined masonry was the dominant residential structural typology in North Bandung, accounting for 57.9% of the houses surveyed [3]. Similarly, Singgih and Winarno (2025) found that confined masonry constituted the majority of the surveyed non-engineered residential buildings in Cilacap, although their study primarily focused on construction practices rather than seismic vulnerability assessment [5].

**Neighborhood-scale Seismic Vulnerability Profile**

Table 2 presents the overall Rapid Visual Screening (RVS) results for the surveyed residential buildings.

**Table 2. Summary of RVS results**

| Parameter | Score |
|---|---|
| Minimum final RVS score, $S_{L1\_min}$ | 0.60 |
| Maximum final RVS score, $S_{L1\_max}$ | 1.20 |
| Mean score | 1.13 |
| Median | 1.20 |
| Standard deviation | 0.15 |

The calculated RVS scores ranged from 0.60 to 1.20, with a mean score of 1.13, a median of 1.20, and a standard deviation of 0.15. The relatively small standard deviation, together with the median equal to the maximum observed score, indicates that the final RVS scores are strongly concentrated toward the upper end of the scoring range. Although all buildings satisfy the FEMA criterion for further evaluation, the relative variation in the RVS scores remains useful for describing neighborhood-scale vulnerability patterns and identifying buildings with comparatively higher preliminary seismic vulnerability.

To illustrate the overall distribution of the screening result, the frequency distribution of the final RVS scores is presented in Figure 5.

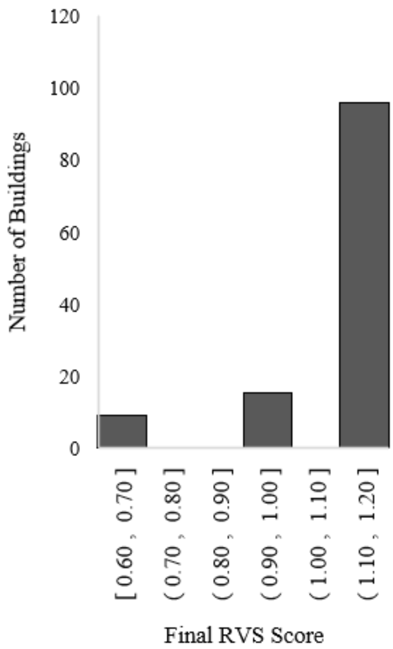


**Figure 5. Frequency distribution of final FEMA P-154 RVS scores for the surveyed residential buildings**

Figure 5 shows that approximately 80% of the surveyed residential buildings are concentrated within the highest score interval (1.1–1.2), while only a relatively small proportion falls within the lower score intervals. This distribution indicates that the residential building stock in the study area generally exhibits low preliminary seismic vulnerability according to the FEMA P-154 Level 1 assessment. The concentration of high RVS scores is consistent with the predominance of confined masonry (C3) buildings which constitute the majority of the surveyed structures and generally receive higher basic scores under the FEMA P-154 methodology. In contrast, the lower score intervals are primarily associated with unreinforced masonry (URM) buildings and structures exhibiting unfavorable visual characteristics, particularly pounding potential.

Unlike the conventional application of FEMA P-154, which primarily supports building-level screening for identifying candidates for further evaluation, this study interprets the screening results collectively to characterize the seismic vulnerability profile of an entire residential neighborhood. This neighborhood-scale perspective provides baseline information for identifying relative vulnerability patterns across the residential building stock, enabling more effective prioritization of subsequent Detailed Seismic Evaluation (DSE), supporting the allocation of limited mitigation resources, and assisting local governments in planning community-level earthquake risk reduction strategies.

The broader application of seismic vulnerability assessment at the community or regional scale has also been highlighted in previous studies. Ansari et al. (2023) emphasized that regional seismic vulnerability assessment provides an important basis for governments and decision-makers in allocating mitigation resources and reducing earthquake risk across urban areas. While their assessment integrated demographic and structural characteristics to classify regional vulnerability, the present study applies FEMA P-154 Level 1 RVS to develop a preliminary seismic vulnerability profile of a residential neighborhood. Both approaches demonstrate the value of area-based assessments in supporting evidence-based seismic risk management [22].

It should be noted that the RVS score represents a preliminary screening indicator rather than a direct measure of structural capacity or expected earthquake performance. Buildings with similar screening scores may still respond differently during future earthquakes because the Level 1 procedure does not explicitly consider structural detailing, material quality, reinforcement configuration, construction workmanship, or other factors affecting seismic performance [12]. Consequently, the RVS results should be interpreted as a prioritization tool for preliminary seismic assessment rather than as definitive indicators of structural safety.

The overall distribution of RVS scores reflects the relatively homogeneous characteristics of the surveyed residential buildings, as presented in Table 1. Most buildings share similar structural systems, construction periods, and building heights, resulting in a generally consistent level of preliminary seismic vulnerability across the study area. Nevertheless, the remaining variability in the final RVS scores suggests that specific visual vulnerability modifiers incorporated in the FEMA P-154 procedure, particularly structural irregularities and pounding potential, continue to influence the seismic vulnerability of individual buildings. A more detailed examination of these factors according to building characteristics is presented in the following section.

**Seismic Vulnerability by Building Characteristics**

To provide a more comprehensive understanding of the seismic vulnerability profile within the study area, the RVS results were further examined according to two primary building characteristics, namely structural type and building age. Since the building sample was selected based on visual accessibility in accordance with the Level 1 RVS procedure, the analyses presented in this section are descriptive in nature. Therefore, they are not intended to establish statistical relationships between building characteristics and seismic vulnerability, but rather to provide preliminary insights into the variations observed among the surveyed residential buildings.

<u>*Structural types*</u>

Table 3 compares the average final RVS scores and estimated probability of collapse, $\boldsymbol{P_c}$ for the structural types identified within the study area.

**Table 3. Average final RVS scores and estimated probability of collapse by structural type**

| Structural type | # of buildings | Ave. final RVS score | Ave. $P_c$ |
|---|---|---|---|
| C3 | 100 | 1.18 | 7% |
| URM | 20 | 0.90 | 14% |

In general, URM buildings exhibited lower average RVS scores than C3 buildings. This difference is consistent with the Basic Scores assigned by the FEMA P-154 methodology, indicating that the inherent characteristics of the primary structural system was the dominant factor influencing the final screening score. Although several C3 buildings experienced score reductions due to structural irregularities, construction era, or site-related modifiers, these adjustments were generally insufficient to alter the relative ranking between the two structural systems.

A similar trend is observed in the estimated probability of collapse, with URM buildings exhibiting an average probability of collapse (14%) approximately twice that of C3 buildings (7%). This finding is consistent with the widely recognized lower seismic resistance of unreinforced masonry structures compared with reinforced concrete frame systems with masonry infill.

Considering all 120 surveyed buildings, the average estimated probability of collapse was approximately 8%. This value reflects the predominance of C3 buildings within the study area, which generally exhibited lower collapse probabilities than URM buildings. Consequently, although the overall neighborhood profile indicates relatively low preliminary seismic vulnerability, the presence of URM buildings remains an important contributor to the observed variability in seismic vulnerability.

<u>*Building ages*</u>
Although this study was not designed to statistically evaluate the influence of building age on seismic vulnerability, the field observations suggest a tendency for older buildings to exhibit lower RVS scores than relatively newer buildings. This tendency may be associated with differences in construction practices rather than age alone. Based on field observations, older houses within the study area were generally constructed incrementally through self-built development, whereas newer residential buildings were predominantly developed as planned housing clusters with relatively uniform layouts and structural configurations. These differences in construction characteristics may have contributed to the variation in the preliminary seismic vulnerability identified through the Rapid Visual Screening procedure.

It should be emphasized that building age itself should not be interpreted as the direct cause of increased seismic vulnerability. Rather, construction age serves as an indirect indicator of differences in construction practices, structural detailing, and residential development patterns that evolved over time. Therefore, the observed tendency for older buildings to exhibit lower screening scores should be interpreted within the broader context of building development characteristics rather than as the effect of age alone.

**Visual Characteristics Contributing to Seismic Vulnerability**
This study also examined the presence of visual characteristics that may influence the seismic performance of residential buildings. These characteristics included vertical irregularity, plan irregularity, pounding potential, falling hazards, geological hazards, and structural deterioration. The frequency of each observed characteristic is summarized in Table 4.

**Table 4. Frequency of special visual characteristics**

| Parameter | Freq. |
|---|---|
| *Severe vertical irregularity* | 0 |
| *Moderate vertical irregularity* | 0 |
| *Plan irregularity* | 9 |
| *Pounding potential* | 78 |
| *Falling hazards* | 0 |
| *Geological hazard* | 0 |
| *Structural deterioration* | 0 |

The screening results indicate that pounding potential was the most frequently observed visual characteristic, being identified in 78 of the 120 surveyed buildings (65%). In contrast, plan irregularity was identified in only nine buildings, while no buildings exhibited severe vertical irregularity, moderate vertical irregularity, falling hazards, geological hazards, or visible structural deterioration.

The predominance of pounding potential is likely associated with the characteristics of urban residential development in the study area, where relatively high building density and limited separation distances between adjacent houses are common. Field observations showed that many residential buildings were constructed with minimal spacing, and several were arranged in configurations that could permit structural interaction during strong earthquake shaking. Such conditions were observed not only in incrementally developed self-built residential areas but also in planned housing clusters characterized by relatively uniform building layouts. Although pounding potential does not directly modify the final Level 1 RVS score, its high frequency suggests that it represents an important neighborhood-level seismic characteristic rather than an isolated building deficiency. Consequently, the widespread occurrence of pounding potential indicates that urban development patterns should be considered alongside individual building characteristics when interpreting preliminary seismic vulnerability.

**Figure 6. Representative examples of adjacent residential buildings exhibiting pounding potential due to insufficient separation distance**

According to FEMA P-154, pounding potential, falling hazards, geological hazards, and structural deterioration are classified as special conditions that should be documented during the Level 1 screening process because they may influence the actual seismic performance of a building. Although these parameters do not directly modify the final Level 1 RVS score, documenting their presence provides valuable supplementary information for understanding the overall seismic vulnerability characteristics of the surveyed neighborhood.

While the observed visual characteristics provide important information regarding building-specific vulnerabilities, the interpretation of the final RVS score also depends fundamentally on the structural classification assigned during the Level 1 screening process because the structural type determines the corresponding Basic Score used in FEMA P-154. During the field survey, several residential buildings exhibited reinforced concrete tie columns along masonry walls; however, continuous reinforced concrete ring beams and other confinement details required to confidently identify a confined masonry structural system were not visually observable. Since the Level 1 RVS procedure relies exclusively on exterior visual inspection, concealed structural details could not be verified during the assessment. Consequently, whenever the available visual evidence was insufficient to justify classification into a reinforced concrete structural category, these buildings were conservatively classified as Unreinforced Masonry (URM). This engineering judgement was adopted to reduce the possibility of underestimating preliminary seismic vulnerability rather than to imply that the buildings were definitively unreinforced masonry structures.

The practical challenge encountered in this study is consistent with previous observations that the direct application of FEMA P-154 may become less straightforward when local residential building typologies are not fully represented within the original structural classification framework. For example, Yekrangnia et al. (2023) reported that the original FEMA P-154 structural types do not explicitly include confined masonry buildings, despite their widespread use in several regions, motivating the development of region-specific Basic Scores for this structural type. Their study highlights that local residential building typologies may not always be fully represented within the original FEMA P-154 classification framework, and that regional adaptation may improve the applicability of rapid visual screening under certain construction contexts. Although the present study did not modify the FEMA P-154 scoring system, the field observations similarly demonstrate that engineering judgement remains necessary when structural details required for classification cannot be confidently identified through exterior visual inspection alone [25].

In the present study, all surveyed buildings produced final screening scores below the FEMA P-154 recommended cut-off value of 2.0 [14]. Accordingly, strict application of the guideline would recommend that all buildings proceed to Detailed Seismic Evaluation (DSE). This outcome is primarily influenced by the combination of the assigned Basic Scores and the available score modifiers. Under the High Seismicity Region form, URM and C3 buildings receive Basic Scores of 1.00 and 1.20, respectively. For both structural types, the post-benchmark construction era modifier is designated as Not Available (N/A) in the FEMA P-154 procedure. Consequently, the opportunity for the final screening score to exceed the recommended cut-off value becomes inherently limited.

Within the context of this study, however, the presence of pounding potential was not interpreted as an additional criterion for recommending Detailed Seismic Evaluation. Instead, it was considered an important characteristic for describing the dominant seismic vulnerability profile of the investigated residential neighborhood. This finding suggests that, in addition to structural type and building configuration, the overall neighborhood vulnerability profile is also influenced by urban development patterns that result in relatively small separation distances between adjacent residential buildings.

## CONCLUSION

This study developed a preliminary neighborhood-scale seismic vulnerability profile of residential buildings in a selected urban area of Singaraja, Bali, using the FEMA P-154 Level 1 Rapid Visual Screening (RVS) procedure. The assessment showed that the surveyed neighborhood was predominantly composed of Concrete Moment Frame with Unreinforced Masonry Infill Walls (C3) buildings, while Unreinforced Masonry (URM) buildings represented a smaller proportion of the residential building stock. The calculated RVS scores ranged from 0.60 to 1.20, indicating a relatively homogeneous distribution of preliminary seismic vulnerability throughout the study area.

Among the observed visual characteristics, pounding potential emerged as the most prevalent condition, whereas vertical irregularities, falling hazards, geological hazards, and visible structural deterioration were not identified during the field survey. These findings suggest that the seismic vulnerability profile of the investigated neighborhood is influenced not only by the structural characteristics of individual buildings but also by the spatial configuration of the built environment, particularly the limited separation distances between adjacent residential buildings.

The findings demonstrate that the FEMA P-154 Level 1 procedure provides a practical and efficient approach for developing a preliminary neighborhood-scale seismic vulnerability profile of residential areas. While the method is not intended to replace detailed structural evaluation, it provides valuable baseline information for identifying neighborhood vulnerability patterns, prioritizing Detailed Seismic Evaluation (DSE), and supporting community-level earthquake risk mitigation planning. The field application also demonstrates the importance of engineering judgement when structural classification cannot be established confidently from exterior visual inspection alone.

Future studies are encouraged to integrate detailed structural investigations, non-destructive testing, or numerical analysis to validate the screening results. In addition, further research should investigate visual classification approaches for residential buildings with partially observable structural details to improve the consistency of structural identification during rapid visual screening. Expanding the assessment to different residential typologies and urban settings would further enhance the applicability of neighborhood-scale seismic vulnerability assessment for residential buildings in Indonesia.

## ACKNOWLEDGMENT

The authors gratefully acknowledge the financial support provided by the Research and Community Service Institute (LPPM), Universitas Pendidikan Ganesha, through the 2025 DIPA Research Grant Program. The authors also express their sincere appreciation to all parties who assisted during the field survey and data collection process.

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