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Seismic Risk Prioritization of Stone Masonry Building Stock in Urla Peninsula Based on Rapid Assessment Techniques

Yavuz S. KARAVIN[1*]
Nefise AKDAG[2]
Ugur DEMIR[3]

ABSTRACT

This study aims to investigate seismic risk of stone masonry buildings in the Urla Peninsula, a region of historical and architectural significance within İzmir, Türkiye. A total of 100 stone masonry buildings were surveyed and documented with a focus on their architectural characteristics, including construction techniques, material types, structural configurations, and age. Data on the properties of all surveyed buildings are provided in an open-access database. Based on the survey, multiple rapid seismic performance assessment methods were applied to evaluate the vulnerability of these structures. These included: i) FEMA P-154 Rapid Visual Screening, ii) Provisions for the Seismic Risk Evaluation of Existing Buildings under Urban Renewal Law (RBTE-2019), iii) Seismic Vulnerability Index for Vernacular Architecture (SVIVA), and iv) the Masonry Quality Index (MQI). The comparative use of different methods is intended to investigate the relative influence of parameters shaping the seismic performance of the masonry building stock rather than to align their scores. The outcomes of this research are expected to contribute to the current risk mitigation efforts for stone masonry buildings in İzmir, thereby supporting regional seismic resilience planning.

Keywords: Building inventory, masonry, rapid assessment, seismic, stone.

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1 İzmir Institute of Technology, Department of Architecture, İzmir, Türkiye
yavuzkaravin@iyte.edu.tr - https://orcid.org/0009-0006-7537-3591

2 İzmir Institute of Technology, Department of Architecture, İzmir, Türkiye
nefiseakdag@iyte.edu.tr - https://orcid.org/0009-0005-1122-4338

3 İzmir Institute of Technology, Department of Architecture, İzmir, Türkiye
ugurdemir@iyte.edu.tr - https://orcid.org/000-0001-8319-2535

* Corresponding author

1. INTRODUCTION

One of the initial efforts regarding mitigation of the earthquake induced risks is creating an inventory of buildings in a specific region. As such, building inventories play a crucial role in disaster management, especially in the seismically active areas [1]. However, in larger scale areas, where the number of buildings reaches thousands, carrying out detailed inspections and subsequent structural analysis are unaffordable in terms of both time and cost constraints. Instead, it is more practical to determine basic structural features and construction practice through site surveys that might be coupled with seismic performance of investigated buildings, which thereby enables prioritization of the existing risks of building stock [2]. Also, classifying the buildings according to their basic structural features simplifies the vulnerability assessment of large-scale building stocks [3]. Construction quality and/or morphology, along with the general shape, dimensions of the buildings and their surroundings, are critical parameters that directly affect the seismic vulnerability of buildings, particularly unreinforced masonry ones [4-5]. Therefore, it is notably beneficial to identify and classify buildings by taking into consideration architectural characteristics in building inventory studies especially for disaster management purposes. An initial approach in this scope is revealing the distribution of buildings in certain regions according to their structural typologies such as reinforced concrete (RC) buildings, masonry buildings and steel or timber frame buildings.

Since seismic characteristics vary notably among these typologies, inventory components must be prioritized considering more vulnerable ones, for instance one such typology: *stone masonry building* (SMBs) [6-7]. Stone masonry is known to be one of the oldest structural systems used by humanity. In the last century, the invention of modern structural materials such as concrete and steel, and moreover, increasing cost of workmanship has decreased construction of SMBs [8-9]. However, SMBs still constitute a large part of existing building stock worldwide, defining most of the built cultural assets of nations [10-11]. As a general approach, prominent characteristics of stone masonry are defined as being simple in terms of construction practice [12]. Despite this simplicity, various types of masonry buildings and construction techniques can be found throughout the world [13]. Environmental conditions, available materials and construction traditions of nations create extensive diversity in SMBs. As a consequence of its heterogeneous characteristics, stone masonry walls are considered to be non-tensile structural elements and vulnerable against lateral loads [14]. Structural behavior of stone masonry walls is influenced by constituent materials, geometry of wall and other structural members of the building. Locally available stones are generally used in wall construction and mechanical properties of these stones vary across a wide range, as it can be also observed in mortar properties [15]. Additionally, geometrical features of unit members, walls and layout of the building have a crucial impact on the global behavior of masonry walls [16-18]. Flooring material, roof typology and presence of other structural members also affect the structural behavior of masonry systems. The plurality of parameters affecting seismic performance and variability of construction practices complicates risk assessment of SMBs.

Rapid, reliable, and realistic methods for ranking the seismic performance of building stock are essential for prioritization efforts-yet such procedures are largely absent from the official seismic design codes of most countries [19]. To address this deficiency, several rapid seismic assessment methods have been proposed depending on different approaches. While several rapid methods assess the seismic hazard level for building stocks of various sizes, some methods provide an index based scoring to assess seismic vulnerability of building stocks or an individual building. In particular, seismic vulnerability refers only to the inherent weakness of buildings against earthquake actions, independent of the seismic input. In contrast, seismic risk represents the potential consequences of an earthquake, which is obtained by combining hazard level of the region and vulnerability of buildings. Considering the time and cost constraints, both approaches in rapid methods do not include detailed measurement and analysis on-site, rather they mostly depend on visual impressions of experts. With regard to the "risk assessment" methodologies that can be applied for multiple structure typologies including masonry structures, FEMA (Federal Emergency Management Agency) P-154 Rapid Visual Screening (RVS) [20] comes to the forefront as a fast and easily applicable method. The method initially considers seismicity levels of the buildings' location and soil type of the site, accordingly the possible seismic input to the building. However, it is noteworthy to mention that section for unreinforced masonry buildings in RVS is notably limited. The method is mainly based on architectural irregularities in buildings and rules out and other deficiencies that can be observed in masonry buildings, particularly disregarding that masonry buildings where there is no box-behavior tend to mostly suffer from out-of-plane failure. Similar methods based on FEMA P-154 have been developed and used in Canada and Greece [21-22] to assess seismic risk in large size of building groups. As one of the earliest resources within this context in Türkiye, Istanbul Earthquake Master Plan (IDMP 2003) [23], proposed a two-stage assessment procedure for buildings with different structural typologies, considering the extensive and risky building stock of the city. For masonry buildings with one to five stories, both first and second-stage assessment methods were defined in this document. The first-stage method is a hybrid approach that evaluates building vulnerability through on-site visual inspections while also incorporating the seismic risk level of the building's location. The second-stage assessment, on the other hand, is a method that requires a higher level of building-specific information (e.g., structural system plan) and involves calculations such as wall stresses and shear forces. Later, the Provisions for the Seismic Risk Evaluation of Existing Buildings under Urban Renewal Law (RBTE-2019) method has been published by the Ministry for Environment and Urban Planning of Türkiye as a first stage seismic evaluation to prioritize seismic risk levels of building stock [24], based on the similar characteristics with the first-stage method defined in IDMP (2003). The method integrates risk and vulnerability approaches, as it begins by assigning each building, whether RC or masonry, a base score determined by the site's seismicity level and the number of floors the building has. Assigned score is then reduced by fifteen negativeness parameters observed in buildings, to include the vulnerability of the structure to the final assessment score. Apart from the findings above, numerous methodologies for multiple structural systems can be found beyond literature, yet the methodologies estimating particularly masonry buildings are rather scarce. In this regard, Borri et al. [17] proposed a visual method to evaluate structural behavior of masonry buildings through constituent material properties and construction typology of masonry walls, named Masonry Quality Index (MQI). In addition, Heras [25] developed the Seismic Vulnerability Index for Vernacular Architecture (SVIVA) method on the basis of a set of analytical studies considering the characteristics of vernacular architecture of Portuguese. Other rapid methods to assess seismic risk level of masonry buildings have also been reported in the literature [6, 26-28].

On the other hand, implementation of rapid assessment methods for territorial scale requires building inventory with data collected through site surveys. Considering the high seismicity and density of masonry structures in whole building stock [29], inventory studies followed by risk prioritization assessments hold great significance in certain regions of Türkiye. Besides, the risk report prepared by the Global Facility for Disaster Reduction and Recovery [30] estimates that İzmir, located in the western part of the Türkiye, is projected to suffer the highest income losses in case of an earthquake. The region contributes approximately $60 billion annually to the national economy, and it is estimated that İzmir could face an average annual loss equivalent to 4% of its gross product [31]. Although the earthquake risk in İzmir is extremely high, it is observed that only a limited number of studies have been conducted on this issue, particularly on the building inventory and characterization studies. The most comprehensive study is named İzmir Earthquake Master Plan (IzDMP), carried out in cooperation between İzmir Metropolitan Municipality and Boğaziçi University, to determine the seismic performance of buildings in the central districts of İzmir [32]. According to this inventory study, there were a total of 217,824 buildings within the borders of İzmir Metropolitan Municipality with a distribution of 190,419 RC buildings (%87), 23,362 masonry buildings (%11), and 4,043 other types of buildings (%2) as of the date of investigation. The study also indicates that masonry buildings are the riskiest structures compared to their current percentage within the entire building stock. Kahraman et al. [33] carried out a study to determine the seismic performance of the buildings in İzmir's Balçova and Seferihisar districts. The inventory study includes 10,550 buildings and their possible seismic behaviors, showing similar result with IzDMP. Although these inventories are comprehensive in terms of the number of buildings it contains, data related to SMBs in İzmir's peripheral districts and rural areas are not included up to now. One such region, the Urla Peninsula, includes many rural and historical settlements where the number of SMBs reaches significant numbers. The Urla Peninsula includes five districts of İzmir: Urla, Çeşme, Karaburun, Seferihisar and Güzelbahçe. The peninsula covers a quarter of İzmir's total surface area and hosts the %5 of İzmir's total population [34]. Associated with these districts, there are 43 villages in the Urla Peninsula [35]. The Aegean Region, in which the Urla Peninsula is located, is one of the seismically active zones in the world. Since early 1900s, there have been 695 earthquakes with moment magnitude bigger than Mw> 4.0 in this region [36]. Significant recent earthquakes in İzmir, which is the biggest city in Aegean, include Seferihisar earthquakes in 2005 with the Mw 5.7-5.9, Karaburun earthquake in 2017 with Mw 6.2 and the earthquake that felt in the large part of the İzmir in 2020 with Mw 6.6. In the latter, 120 people lost their lives, 1033 people got injured and 50 buildings collapsed [37]. In a narrower sense, the peninsula also hosts three active seismic faults Seferihisar, Gülbahçe and Mordoğan Faults [38]. The continuous seismic activity and the losses incurred, increased the importance of studies related to reducing the impacts of earthquakes in this region.

Despite great numbers of SMBs in the Urla Peninsula and widely recognized high vulnerability of these buildings, no such study has been carried out relating to architectural-structural characteristics and seismic performance of this building stock. In response to this urgent need, a field study was conducted within the scope of this study to examine structural characteristics of SMBs in the Urla Peninsula. The paper subsequently presents seismic vulnerability and risk levels of 100 SMBs evaluated through four rapid seismic assessment methods, FEMA P-154, RBTE-2019, MQI and SVIVA. By identifying structural deficiencies frequently observed in the surveyed building stock, the study aims to contribute to prioritization of risk mitigation efforts across the province by focusing on which structural parameters most strongly influence the seismic performance evaluation of the surveyed masonry building stock. Although this is not the primary objective, the comparative approach also allows for commenting on the potential strengths and weaknesses of the utilized methods. A brief content related to observed architectural and structural characteristics of examined buildings is also presented in this paper, whereas another paper addressing these aspects in detail is further planned for publication.

2. INVENTORY COLLECTION AND GENERAL OBSERVATIONS

In the scope of the study, it was planned to conduct site surveys on 120 SMBs throughout the Urla Peninsula. During the on-site investigations, buildings which consist of masonry walls fully covered with plaster could not be assessed, since the selected methods require several inspections on masonry units and morphology. Therefore, the number of buildings assessed and prioritized according to risk level was limited to 100 buildings. Since the peninsula spreads out a large geography and the abundance of urban, sub-urban and rural settlements, sufficient distribution of buildings required several preliminary studies. It was aimed at creating a distribution that geographically spreads across the peninsula with consideration of the largeness, population and number of settlements (neighborhoods and villages). Accordingly, the mentioned features of five districts in the Urla Peninsula were collected, as shown in Table 1. However, presence and density of SMBs, which were explored through preliminary site visits and Google Maps Street View technology, have also affected the distribution. In relation to these aspects, the majority of examined buildings are in Urla district, which is located in the geographical center of the peninsula with the highest population and number of settlements. Number of investigated buildings is given in Table 1, while geographical distribution of those 100 SMBs is shown in Figure 1.

Table 1 - Districts in Urla Peninsula [34-35].

District	***Population***	***Number of Neighborhoods***	***Square Measure (km²)***	***Number of Investigated Buildings***
Urla	77599	37	704	49
Seferihisar	58570	22	386	9
Çeşme	50028	25	260	14
Güzelbahçe	38044	12	110	12
Karaburun	13379	16	436	16

Considering the required parameters according to all selected methods, a data collection form was developed for the site visit, mostly based on the form provided in RBTE-2019 with some modifications. The form consists of individual sections for twenty parameters, each designed according to possible options that might be observed on field study. Front page of the data collection form is given in Appendix A. Measurement survey was conducted in all buildings and the reverse side of the form is left blank for basic plan and elevation drawings of the buildings, based on the measurements conducted on-site.

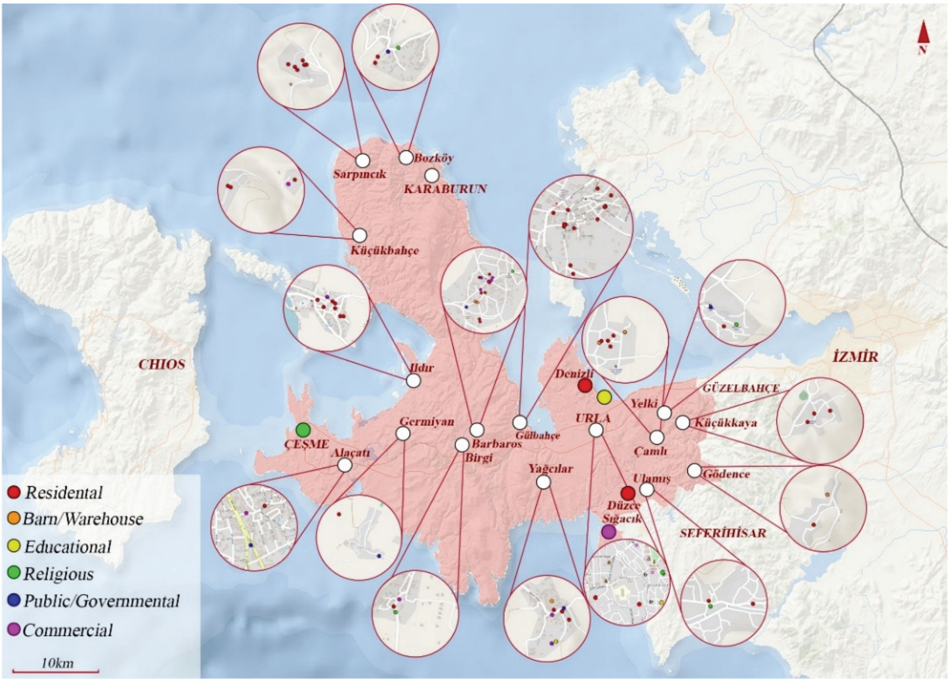

Figure 1 - Distribution of surveyed buildings with occupancy classes.

General observations have shown that 61 out of 100 investigated buildings were residential units. Eleven buildings, those used as barns or warehouses, were also examined in rural settlements of the peninsula. A single building was used as health clinic, 4 buildings were used for educational purposes (including public education centers and libraries), while 7 religious (mosques) SMBs were included in the inventory. A total of 16 buildings, used as hotels, cafes, offices and government buildings, were also surveyed and included into inventory. Typical examples of religious, educational and residential SMBs are given in Figure 2. SMBs in the rural areas of the peninsula were mostly constructed without any engineering guidance, and mostly before earthquake regulations were introduced in the country. Data regarding buildings' age was obtained through oral interviews with residents in general, and it was observed that SMBs in the peninsula have an average age above 100 years. Mosques constitute the group of the oldest buildings, while the oldest one was built nearly 700 years ago. Correspondingly, repairs and renovations are common in this building stock. However, renovations that can be classified as professional structural retrofitting are scarce and were observed only in public buildings.

SMBs in Urla Peninsula were broadly observed to have simple, squared and regular plan layout. Average footprint area was found approximately 80 m² among the examined buildings. Except for a single building with three floors, all surveyed buildings were observed to have a maximum of two floors. While buildings in rural areas were found to be detached in general, buildings in urban areas were broadly attached to a neighboring building. Buildings are mostly covered with timber gable or hip roofs, with a pitch that varies from 20 to 35 degrees. In addition to the unreinforced stone masonry, buildings that have been enlarged with RC frames were also encountered, particularly in religious buildings. The findings indicate that masonry walls have broadly irregular patterns, built with rubble stones and weak mortar, for instance mud and lime-based mortars. Stone types exhibit an extensive variability since the stones are extracted from local quarries near the mountainsides close to the villages, in addition to the stones obtained from industrial quarries in Balıklıova (Urla) and Alaçatı (Çeşme) [39]. Consequently, several types of sedimentary, metamorphic and magmatic formations were observed in the masonry walls (Figure 3). Another such critical observation is that the buildings mostly had timber floors (flexible diaphragms). Among 100 SMBs examined, only 15 of them were found to have RC diaphragms on their slabs. The presence of bond beams (hatıl) was also explored, and two thirds of buildings were observed to have no such beams, neither timber nor RC. Information regarding building location, age, function and photographs for all 100 buildings are published in an open-access form in Harvard Dataverse [40].

(a) *(b)* *(c)*

Figure 2 - Typical examples of examined SMBs with different occupancy classes: a) religious, b) residential, c) educational.

(a) *(b)* *(c)*

Figure 3 - Examples of stone and roof types from: a) Küçükkaya, b) Sarpıncık, c) Urla

3. RAPID SEISMIC ASSESSMENT

Utilizing the completed data collection forms, detailed on-site measurements, and photographic documentation, the seismic risk prioritization of 100 stone masonry buildings was performed through the application of multiple rapid assessment methodologies. The methodology, assumptions, and results associated with each assessment tool are systematically presented under the corresponding subsections. It should be noted that the applied methods differ in their conceptual foundations, with some producing risk-oriented scores (e.g., FEMA P-154, RBTE-2019) and others focusing on structural vulnerability indices (e.g., SVIVA, MQI). However, in the present study, the primary objective is not to directly compare the overall scores of these methods, but rather to examine how different sets of parameters influence the seismic performance evaluation of the surveyed masonry building stock. With this aim, a heat-map analysis is performed that quantifies the relative weight of each parameter across the methods and identifies which building characteristics (e.g., structural irregularities, material deficiencies) emerge as most critical for seismic behavior. Therefore, the methodological differences between risk-based and vulnerability-based frameworks do not undermine the consistency of the analysis, since the focus is not on comparing their absolute scores, but on understanding the role of frequently observed structural deficiencies. This comparative approach ultimately provides guidance on which deficiencies should be prioritized in risk reduction and retrofitting strategies.

3.1. FEMA P-154 RVS

FEMA P-154 Rapid Visual Screening of Buildings for Potential Seismic Hazards (RVS) method has been developed by the Federal Emergency Management Agency [20] to evaluate potential seismic risk in large groups of buildings. An average of 15 minutes is estimated to be spent to evaluate a building. Measurement is not required for this assessment, yet the method is mostly based on the architectural irregularities occurring in buildings. Two levels of scoring approach are provided in the method, Level 1 and Level 2 scoring, similar in the required detail level. Although buildings are divided into seventeen typologies according to their structural system, this paper mentions only unreinforced masonry buildings (URM), complying with the scope of the study. RC additions in SMBs were not evaluated, since it is expected that the score calculated for URM part of the building will be lower than the part with RC frame in all cases, considering the basic scores assigned to structural typologies.

The method provides different scoring forms depending on the seismicity level of the building site. Seismicity class of the site is divided into five as: Very High, High, Moderately High, Moderate and Low seismicity, and each seismicity level has its own Level 1 and Level 2 form, differing each other in scoring scheme. Seismicity level is determined according to short-period spectral acceleration (S_S) and 1-second spectral acceleration (S_1) given in location. S_S and S_1 values were obtained from the Seismic Hazard Map published by Disaster and Emergency Management Authority of Türkiye [41], using occupancy classes of buildings and soil type of the site. FEMA P-154 forms provide nine main occupancy classes, however, buildings are classified into building usage classes provided in the Turkish Building Earthquake Code [42] since occupancy classification of Seismic Hazard Map follows this code. Soil types of the site could not be reached during the site surveys. Therefore, soil type is assumed to be D class for all buildings, as it is suggested in the RVS Handbook [20].

Seismicity class determining criteria according to S_S and S_1 values provided by FEMA handbook is given in Table 2. According to this classification, 4 out of 100 investigated buildings were in Very High seismicity, 92 buildings were determined to be in High seismicity location, while 4 buildings remained in Moderately High seismicity. RVS scoring for both Level 1 and Level 2 consist of a basic score provided for each building type and score modifiers representing the adverse parameters for buildings. Basic scores and modifiers in Level 1 and Level 2 scoring exhibit numerical variation depending on the used form. Table 3 shows Level 1 scoring schemes provided by FEMA P-154 for URM buildings as an example, while Level 2 scoring schemes can be found in the RVS Handbook [20], to comply with the current page limitations.

Table 2 - Seismicity regions according to RVS Handbook [20].

Seismicity Region	S_S	S_1
Low	$S_S < 0.250g$	$S_1 < 0.100g$
Moderate	$0.250g \leq S_S < 0.500g$	$0.100g \leq S_1 < 0.200g$
Moderately High	$0.500g \leq S_S < 1.500g$	$0.200g \leq S_1 < 0.400g$
High	$1.000g \leq S_S < 1.500g$	$0.400g \leq S_1 < 0.600g$
Very High	$S_S \geq 1.500g$	$S_1 \geq 0.600g$

Final Level 1 score (S_{L1}) is determined by summing the modifiers with the basic score, as given in Table 3. Since the soil type for each building was assumed to be D class, modifiers regarding soil type were not applied in any case. Post-benchmark defines the buildings constructed after significantly improved local earthquake code (determined as TSDC 1998 [43] for this study). However, no modifier is provided for URM buildings in all seismicity levels. First earthquake code in Türkiye was published in 1940, therefore, buildings constructed before this year are marked Pre-Code. For the buildings located in moderately high seismic zones, -0.1 modifier was applied, while this parameter does not have an impact

Table 3 - Basic scores and modifiers for Moderately High, High and Very High Seismicity regions described in [20].

Parameters	***Basic Score and Modifiers***		
	Moderately High	***High***	***Very High***
Basic Score	1.2	1	0,9
Severe VL1	-0.8	-0.7	-0.6
Moderate VL1	-0.5	-0.4	-0.3
PL1	-0.5	-0.4	-0.3
Post-Benchmark	NA	NA	NA
Pre-Code	-0.1	0	0
A-B Soil Type	0.6	0.3	0.1
Soil Type E (1-3 Floors)	-0.3	-0.2	0

for the buildings in Very High and High Seismic zones. Possible vertical irregularities (V_{L1}) observed in buildings are divided into two for Level 1 scoring, severe or moderate V_{L1}. Diaphragm level difference and in-plane setbacks of vertical load-bearing members are named split level in the handbook and also assigned as moderate V_{L1}. Weak and soft stories and out-of-plane offsets are defined to be severe V_{L1}. Weak story is the most common severe V_{L1} observed in the SMBs in the Urla Peninsula. Besides, plan irregularities (P_{L1}) were also found significantly common among examined buildings. FEMA P-154 states that significant differences in the amount of the load-bearing walls in two directions causes torsional irregularity, a type of P_{L1}. Reentrant, irregular plan layouts and diaphragm openings exceeding half of the whole diaphragm area, observed only in mosques as mezzanine floors, are also designated as P_{L1} in Level 1 scoring. The boundary conditions and decision criteria related to these parameters are described in detail in the RVS Handbook [20].

Along with the individual scoring of all discussed parameters in Level 1, interaction with neighboring buildings, presence of gable walls and retrofitting implementations for masonry buildings are also included in the Level 2 scoring. Base score for Level 2 scoring (S') is found by subtracting V_{L1} and P_{L1} modifiers from Final Level 1 score, since these deficiencies will be repeated under separated sub-categories. The expressions to find base and final score for Level 2 scoring are given in Equations (1-2). Situation of sloping site, weak/soft storey, setbacks and split levels were evaluated according to Level 2 forms, for related seismicity level. Apart from the sloping site modifier, the buildings, where load-bearing walls were significantly different in height, were considered to have "Other V_{L2}" since this situation may lead to distinct rigidity of walls against out-of-plane loading. Irregular opening layout in masonry walls, both horizontally and vertically, negatively affect in-plane behavior and therefore, such cases were considered as "Other V_{L2}". Modifiers in the group of plan irregularities (P_{L2}) including torsional irregularities, non-parallel load-bearing systems, reentrant corners and diaphragm openings, were evaluated separately. Presence of gable walls, possible pounding effect and comprehensive retrofit conditions are evaluated in (M) group, as directed in RVS forms. Diaphragm levels of neighboring buildings could not be observed in many cases. While considering the pounding effect in this situation, the most critical case was selected to be conservative, and it was assumed that there is more than 60cm (described as 2 feet in RVS handbook) between diaphragm levels of two neighboring buildings.

RVS defines a minimum score for both Final Level 1 and Final Level 2 scores, indicating that these values cannot be lower than 0.2 (for low seismicity zones this value is indicated to be 0.4). Moreover, upper bounds (cap) for total V_{L2}, P_{L2} and pounding modifiers are defined. These limitations are provided in RVS to prevent overestimated final scores, since the negative final scores mean that collapse probability is higher than %100, which is not possible. However, this study does not aim to estimate collapse probability for each building, rather it aims to prioritize the risk level among studied SMBs and find out the architectural/structural features that lead buildings to be more vulnerable. Based on this approach, minimum scores for Final Level 1 and Level 2 scores and cap for modifiers were not used in the scoring.

$$S' = (S_{L1}-V_{L1}-P_{L1}) \quad (1)$$

$$S_{L2} = (S'+V_{L2}+P_{L2}+M) \quad (2)$$

3.2. RBTE-2019

The Turkish Ministry for Environment and Urban Planning published Provisions for the Seismic Risk Evaluation of Existing Buildings under Urban Renewal Law (RBTE-2019) [24] to determine risk priorities for RC and masonry building stock. Determining the seismicity level of the building site is the first phase of assessment for each building typology. Unlike FEMA P-154, seismicity level (described as hazard zone in RBTE-2019 guideline) is determined according to design spectral acceleration (S_{DS}), which is calculated by multiplying S_S and soil type coefficient (F_S). Values of S_{DS} are directly obtained, again, from the Seismic Hazard Map published by AFAD (2018) [41], using the building usage class and soil type of the site. While determining building usage class, instructions given by TBDY-2018 were followed, however, soil type for buildings is assumed as ZD class (refers "D" in FEMA P-154) since this data could not be reached, and also, to be fairly comparable with FEMA method. The method assigns buildings to base points depending on the hazard zone and number of floors existing in the buildings. Determination of hazard zone according to S_{DS} and soil type, and correspondingly, masonry buildings' base point accounted for each hazard zone is given in Table 4. For all examined buildings in scope of this study, S_{DS} values are found to be higher than 1.0, therefore all buildings are determined to be in hazard zone 1. Subsequently, a single building with three floors was assigned 90 base points, 38 buildings with two floors were assigned 100 points and the remaining 61 buildings were evaluated with a base point of 110. Final assessment score is named performance point (PP) in this method, calculated as summing the base point (BP) with structural system point (SSP) and total of each negativeness parameter (N_i) multiplied with negativeness parameter point (NP_i), as given in Equation (3). SSP is taken 60 for reinforced masonry, 30 for confined masonry and 0 zero for unreinforced masonry. Since there was no reinforced or confined masonry among examined buildings, SSP was taken 0 in all cases.

Table 4 - Base points assigned for hazard zones [24].

Hazard Zone	S_{DS}	*Soil Type*	*Base Point*		
			1-Storey	*2-Storey*	*3-Storey*
1	≥1.0	ZC/ZD/ZE	110	100	90
2	≥1.0 $1.0 \geq S_{DS} \geq 0.75$	ZA/ZB ZC/ZD/ZE	120	110	100
3	$1.0 \geq S_{DS} \geq 0.75$ $0.75 \geq S_{DS} \geq 0.50$	ZA/ZB ZC/ZD/ZE	120	110	100
4	$0.75 \geq S_{DS} \geq 0.50$ $S_{DS} \geq 0.50$	ZA/ZB All	130	120	110

$$PP = BP + SSP + \sum (N_i \times NP_i) \tag{3}$$

Fifteen negativeness parameters are provided in the RBTE-2019 guideline, designed regarding the possible deficiencies and negative conditions in masonry buildings. The parameters are evaluated according to existence (present or absent) or rated qualitatively (good, average, poor). Parameter values define numeric versions of existence and quality conditions. For instance, parameter value of 1 for existing damage refers to the presence of damage, while value of 0 refers to absence of damage. In qualitative evaluation, parameter values of 0, 1 and 2 refer to the conditions of good, average and poor, respectively. To take into account different weights of parameters on global performance of the buildings, different values of negativeness parameter points are assigned for each parameter. All negativeness parameters, parameter values and negativeness points are given in Table 5.

Four parameters are evaluated to determine whether out-of-plane weaknesses exist or not. If the total parameter values for slab type, wall-to-wall connection, wall-to-slab connection and mortar type are equal or larger than 3, this situation refers to an out-of-plane weakness and a penalty point of -10 is applied for the building. Building alignment negativeness parameters are evaluated in four options. For the buildings in detached position, parameter value and parameter point are applied as 0. On the other hand, if a building is located between two buildings and the diaphragm level of the building is at the same level with neighboring buildings, parameter point is applied as 0 again, for the cases of different diaphragm levels this value is applied as –5. If a building is located at the end of the block, parameter point is taken -5 for same diaphragm levels and -10 for different diaphragm levels with neighboring buildings. Since the diaphragm level of the neighboring buildings could not be measured in many cases, it was assumed that diaphragm levels were different, for the sake of conservatism. For some of the qualitative parameters, the classification of good, average and poor conditions are not described in detail by RBTE-2019 guideline, and left to expert judgment. Based on this approach, several assumptions were adopted to ensure consistency in the final performance score. While determining material quality, presence of rounded, uncoursed or thin, flat and fragile stones and mud mortar were assumed to be of poor quality. Masonry walls built with dressed stones and cementitious mortar or masonry walls built with cut-stones were considered of good quality. All other cases were assumed average quality. While determining masonry workmanship, masonry walls built with stones of similar size assembled in regular horizontal joints and staggered vertical joints were considered as good quality. Rubble masonry walls built with stones which exhibit excessive variation in size were considered poor quality. The conditions falling between these two scenarios were assumed as average quality of workmanship. If wall-to-wall connection had been made with interlocked and large cut-stones (where it is observable), this situation was considered to be a good connection, and all other cases were assumed to be poor wall-to-wall connection. The RBTE guideline suggests to assume that RC slabs have rigid diaphragms, while other slab type/materials form flexible diaphragms. Definitions of good and poor conditions of wall-to-slab connection are not well described in the RTBE-2019 guideline, as it is only mentioned that presence of beams refers to good connection between wall and horizontal diaphragm. However, wall-to-slab connection is one of the key factors that ensures effective transfer and proper management of diaphragm action by the masonry walls [44]. Although RC slabs are typically defined as rigid diaphragms capable of distributing lateral loads among walls, in cases where slabs are only partially supported or lack anchorage and/or RC tie beams, the resultant diaphragm may increase the seismic vulnerability of weak masonry walls by imposing higher lateral demands and thereby promoting out-of-plane failures [45-46]. On the other hand, during the field surveys it was not possible to systematically observe the details of the wall-to-slab connections. Considering this limitation and the importance of this parameter, a conservative assumption was adopted. Buildings with RC beams of visibly good quality and dimensions (whether the beam fully bears on the wall cross-section and its height) along all load-bearing walls were evaluated as having a good wall-to-slab connection, whereas in all other cases the connection was classified as poor. To consider the presence of soft and weak storey, guidance given in FEMA P-154 Level 2 scoring forms was used to ensure consistency between two methods. Accordingly, if total wall length is less than %75 of that at the storey above, this situation refers to the presence of a soft storey. If the height of ground floor load-bearing walls are more than 1.3 times the height of the storey above, this situation was considered as the presence of weak storey. All remaining parameters were evaluated as directed in the RBTE-2019 guideline.

Table 5 - Negativeness parameters, parameter values, parameter points provided in RBTE-2019 [24].

<table>
<tr><th colspan="2" rowspan="2">Negativeness Parameters</th><th colspan="3">Conditions Related to Parameter Values</th><th colspan="3">Parameter Point for Number of Floors</th></tr>
<tr><th>0</th><th>1</th><th>2</th><th>1</th><th>2</th><th>3</th></tr>
<tr><td colspan="2">Material Quality</td><td>Good</td><td>Avg.</td><td>Poor</td><td>-10</td><td>-10</td><td>-10</td></tr>
<tr><td colspan="2">Masonry Workmanship</td><td>Good</td><td>Avg.</td><td>Poor</td><td>-5</td><td>-5</td><td>-5</td></tr>
<tr><td colspan="2">Existing Damage</td><td>Absent</td><td>Present</td><td>-</td><td>-5</td><td>-5</td><td>-5</td></tr>
<tr><td colspan="2">Plan Geometry</td><td>Regular</td><td>Irregular</td><td>E. Irregular</td><td>-5</td><td>-10</td><td>-10</td></tr>
<tr><td colspan="2">Amount of Wall</td><td>High</td><td>Avg.</td><td>Low</td><td>-5</td><td>-5</td><td>-10</td></tr>
<tr><td colspan="2">Bond Beam (hatıl)</td><td>Present</td><td>Absent</td><td>-</td><td>-5</td><td>-5</td><td>-5</td></tr>
<tr><td colspan="2">Opening Regularity</td><td>Regular</td><td>Partially R.</td><td>Irregular</td><td>0</td><td>-5</td><td>-5</td></tr>
<tr><td colspan="2">Level Difference</td><td>Absent</td><td>Present</td><td>-</td><td>-5</td><td>-5</td><td>-5</td></tr>
<tr><td colspan="2">Soft/Weak Storey</td><td>Absent</td><td>Present</td><td>-</td><td>0</td><td>-5</td><td>-5</td></tr>
<tr><td rowspan="4">Out-of-Plane</td><td>Rigid Diaphragm</td><td>R.C.</td><td>Other</td><td>-</td><td rowspan="4">-10</td><td rowspan="4">-10</td><td rowspan="4">-10</td></tr>
<tr><td>Wall-to-Wall</td><td>Good</td><td>Poor</td><td>-</td></tr>
<tr><td>Wall-to-Slab</td><td>Good</td><td>Poor</td><td>-</td></tr>
<tr><td>Mortar Type</td><td>Cement</td><td>Other</td><td>-</td></tr>
<tr><td colspan="2">Roof Material</td><td>Other</td><td>Earthen</td><td>-</td><td>-10</td><td>-10</td><td>-10</td></tr>
<tr><td colspan="2">Building Alignment</td><td>Detached</td><td>Attached</td><td>-</td><td>-</td><td>-</td><td>-</td></tr>
</table>

3.3. MQI

Masonry Quality Index (MQI) method has been proposed by Borri et al. [17] to correlate qualitative properties of masonry, in other words “rule of the art”, with mechanical properties of masonry walls. Beside its analytical framework, the method only requires rapid visual inspection of masonry walls and classifies behavior of masonry walls under vertical, in-plane and out-of-plane loads as A (good quality), B (average quality) and C (poor quality). The method consists of 7 parameters related to the quality of constituent materials and construction of masonry walls. Each parameter is evaluated in three possible conditions, fulfilled (F), partially fulfilled (PF) and not fulfilled (NF). This qualitative evaluation is associated with numerical values. Since the impact of parameters on different loading conditions varies, different numerical values are provided for vertical, in-plane and out-of-plane loading. Parameters and related numeric values for qualitative evaluation are given in Table 6.

Table 6 - Parameters in MQI [17].

Parameter	***Vertical Loading***			***Out-of-Plane Loading***			***In-Plane Loading***		
	F	***PF***	***NF***	***F***	***PF***	***NF***	***F***	***PF***	***NF***
SM	1	0,7	0,3	1	0,7	0,5	1	0,7	0,3
SD	1	0,5	0	1	0,5	0	1	0,5	0
SS	3	1,5	0	2	1	0	2	1	0
WC	1	1	0	3	1,5	0	2	1	0
HJ	2	1	0	2	1	0	1	0,5	0
VJ	1	0,5	0	1	0,5	0	2	1	0
MM	2	0,5	0	1	0,5	0	2	1	0

The parameter SM (stone mechanical properties and conservation state) is evaluated as NF, if the damaged elements constitute more than half of the whole stone units in the wall. Masonry walls consisting of soft stones (sandstone or tuff stone) or damaged elements constituting 10%-50% of the wall are considered as PF. If damaged or degraded elements constitute less than 10% of the masonry wall or hardstones are used in the construction of the wall, this situation is estimated to be F. Stone/brick dimension analysis (SD) is categorized as NF, if walls contain over 50% of elements with the largest dimension smaller than 20 cm. PF walls feature more than 50% of elements between 20–40 cm and include a mix of different element sizes. F walls have over 50% of elements with the largest dimension greater than 40 cm. SS (stone shape) parameter is evaluated according to coarseness of the stone unit. Rubble, rounded or pebble stonework refers to NF, barely or perfectly cut stones refers to F and all other co-presence cases refer to PF for this parameter. In the surveyed buildings, the presence or absence of header stones could not be directly observed. For this reason, the WC (wall leaf connections) parameter was evaluated following the guidelines proposed in the Borri et al. [17]. Accordingly, when the wall cross-section is not visible, qualitative assessment is adopted: the condition 'small stones compared to wall thickness' corresponds to the absence of header stones and refers to NF, wall thickness larger than stone large dimension corresponds to the presence of some headers and evaluated as PF (for double-leaf walls). When the wall thickness is found to be similar to the large dimension of the stone, this condition corresponds to Class F for this parameter. These criteria were taken into account during the application of the method in this study. While deciding the quality of HJ (horizontal joints), fully continuous horizontal joints are designated to be F class and discontinuity in horizontal joints is classified as NF class. Intermediate conditions in this parameter are defined as PF, as it still depends on the visual inspection. For the VJ (vertical joints) parameter, well-staggered vertical joints are classified as F, partially staggered as PF, and non-staggered as NF. For rubble masonry with dry joints, the presence of mud or other weak mortars leads to the MM (mortar mechanical properties) parameter being classified as NF. Dry joint cut stone masonry and cementitious mortars are classified as F, while degraded cement-based mortars and lime-based mortars are classified as PF, as illustrated in Borri et al. [17].

The expression to find MQI points for all loading conditions is given in Equation (4). On the other hand, classification criteria for each loading condition according to calculated MQI points, is given in Table 7. The lowest class obtained among the three loading conditions was determined as the overall MQI class of the building for this study.

$$MQI = SM \times (SD + SS + WC + HJ + VJ + MM) \quad (4)$$

Table 7 - Determination of MQI category [17].

	Category		
	C	***B***	***A***
In-Plane	MQI ≤ 3	3 <MQI ≤ 5	5 <MQI ≤ 10
Out-of-Plane	MQI ≤ 4	4 <MQI ≤ 7	7 <MQI ≤ 10
Vertical	MQI ≤ 2.5	2.5 <MQI ≤ 5	5 <MQI ≤ 10

3.4. SVIVA

Seismic Vulnerability Index for Vernacular Architecture [25, 47] was developed on the basis of vulnerability index method (Benedetti & Petrini, 1984, as cited in [47]). Although the method is adjusted considering the vernacular characteristics of SMBs in Portugal, it is also suggested to be usable in different regions in the world. The method includes 10 parameters that may affect the global behavior of SMBs. Conditions for the 10 parameters are divided into 4 categories, A, B, C and D. Category A defines lowest vulnerability while category D defines highest vulnerability, the worst condition. These conditions are also correlated with numeric values as 0, 5, 20, 50 for A, B, C, D respectively. As is the case for the MQI method, different weights for each parameter are defined. Parameters and related numeric representations with weights are given in Table 8. Final vulnerability score (I_V) is calculated by multiplying numeric values for conditions and weight coefficient for each parameter.

Table 8 - Parameters, classification values and weights described in SVIVA [47].

Parameter		***Class***				***Weight***
		D	**C**	**B**	**A**	
P1	Wall Slenderness	50	20	5	0	1.00
P2	Maximum Wall Span	50	20	5	0	0.50
P3	Type of Material	50	20	5	0	1.50
P4	Wall-to-Wall	50	20	5	0	0.75
P5	Horizontal Diaphragm	50	20	5	0	1.50
P6	Roof Thrust	50	20	5	0	0.50
P7	Wall Openings	50	20	5	0	1.50
P8	Number of Floors	50	20	5	0	1.50
P9	Existing Damage	50	20	5	0	0.75
P10	In-Plane Index	50	20	5	0	0.50

Both quantitative and qualitative parameters are included in this method and evaluation of these parameters is well-defined in the related doctoral thesis [25]. The P1 and P2 parameters are directly evaluated through numerical values. The P1 parameter is calculated as the ratio of the free wall height to the wall thickness; cases where this ratio is below 6 are classified as Class A, while those where it exceeds 12 are classified as Class D. The P2 parameter is directly associated with the free length of the walls, where wall spans shorter than 5 m are classified as Class A, spans between 5–7 m as Class B, spans between 7–9 m as Class C, and spans exceeding 9 m as Class D. While estimating the Type of Material parameter (P3), masonry walls with cut stones or walls with partially coursed stones, cementitious mortar, staggered vertical joints and continuous horizontal joints are related to A class. Masonry walls with uncoursed-rounded stones, mud mortars and totally undesired wall texture are considered to be D class. All other cases are ranged systematically and evaluated as B or C class. For the evaluation of the P4 parameter, cases where all wall-to-wall connections are constructed with large, well-shaped interlocking stones are classified as Class A, while situations where the connections are only partially of this type are classified as Class B. Conversely, cases where none of the connections contain key stones and where degraded elements and/or cracks are present are classified as Class D. Situations where such unfavorable conditions are observed not entirely but predominantly are defined as Class C. The quality of horizontal diaphragms is evaluated based on the combined assessment of three structural features: (i) beam-to-wall connection, (ii) diaphragm-to-wall connection, and (iii) diaphragm stiffness. Since beam-to-wall and diaphragm-to-wall connections could not be systematically observed during the surveys, a conservative approach was adopted, in line with RBTE-2019, by considering the importance of this parameter as it is aforementioned. According to this approach, since the details of beam-to-slab and diaphragm-to-wall connections could not be observed in detail, the P5 parameter was not classified as A in any of the surveyed buildings. RC (rigid) slabs combined with RC beams bearing on all load-bearing walls were classified as B, whereas RC slabs directly supported on walls were classified as C. As the presence of timber bed plates and other connection types/materials could not be observed, a conservative approach was adopted, and all timber floors were classified as C. Finally, in cases where no diaphragm was present and gable roofs were directly supported on the walls, the classification was set to D. For P6 parameter, the roofs were made of timber frame, covered with roof tile, were assumed to be lightweight ($\leq$0.9 kN/m^2). Since the roof inclination could not be measured on-site, it was determined visually, in an approximate manner. P7 (wall openings) and P10 (in-plane index) are a form of quantitative parameters, and their calculations have been made following the guides given by Heras [25], using the plan and elevation drawings of the buildings sketched on-site.

4. RESULTS AND DISCUSSION

The final assessment scores of 100 buildings were evaluated using four distinct methods, each based on different analytical and empirical approaches. These methods vary in their scoring procedures, the parameters they consider, and the relative weights assigned to those parameters. As a result, the final scores differ across methods, offering a comparative perspective on their methodological frameworks. Positive correlations among scores suggest a consistent indication of seismic risk, whereas negative correlations point to parameters that may be overlooked or overemphasized. In either case, it is necessary to discuss the underlying frameworks of the methods to explain variations in performance predictions. Such a discussion not only highlights common architectural and structural features that increase the vulnerability and seismic risk of the building stock but also helps to prioritize risk mitigation efforts by identifying the most critical deficiencies observed across the surveyed buildings. For all investigated buildings, assessment scores according to each method are given in Appendix B. Subsequently, in order to enable coherent comparison across methods, final assessment scores obtained from each method were normalized to a 0-100 scale considering the possible minimum and maximum points that might be obtained for a building in each method. Based on the normalization, the calculated final scores for each building in all four methods are shown in Figure 4. The possible minimum and maximum assessment scores (PP) in RBTE-2019 are -95 and +130, respectively. The obtained minimum and maximum scores for the investigated building stock are 15 and 95, respectively. The considerable difference between the potential minimum score and the lowest score obtained from the surveyed buildings arises from the fact that the RBTE-2019 method significantly lowers the scores of taller masonry buildings by both reducing the base score and increasing the parameter points (NP_i) for certain parameters as the number of stories increases. While the method allows for the assessment of masonry buildings up to five stories, the investigated buildings consist of three-story buildings in maximum. Consequently, the RBTE-2019 results tend to fall above the mid-range, reducing the capability of this graph (Figure 4) to adequately emphasize the severe structural deficiencies observed in the buildings. As it is aforementioned, the minimum score threshold was not applied in FEMA P-154 scoring in order to provide full ranking of the buildings based on modified points. Bearing this in mind, Level 2 scores were found to be in range of -1.4 and 1.1, while their possible minimum and maximum values are -1.9 and 3.2. Additionally, it can be seen in Figure 4 that the scores obtained from the RVS are below the midline. There are thoughts to be two major reasons for the relatively low scores. The first is that, with the exception of three of the buildings examined, all are located in a High or Very High seismicity zones, and accordingly, their Basic Scores were assigned as 1 and 0.9. The other reason is that the positive points from this method are obtained through structural strengthening, and it can be said that structural strengthening is quite rare in the building stock examined. Overall MQI score, which is the minimum score obtained for a building amongst vertical, in-plane and out-of-plane scoring, was utilized in the general evaluation of this method. The results of the MQI were predominantly situated below the midline, as seen in Figure 4. This is underscored by the fact that six of the buildings received a score of 0, which signifies the poorest quality of masonry wall construction. Final assessment score for SVIVA method, I_V, represents vulnerability degree of SMBs, which means higher I_V scores correspond to more unfavorable conditions. Therefore, obtained I_V scores were subtracted from the possible highest Iv score (500), so that larger scores reflect a superior structural state, in line with the other methods. The assessment scores were found 36.25 at minimum and 292.5 at maximum. It is noteworthy that Figure 4 intentionally compares the individual ranking of examined building inventory by leveraged methods yet not comparing their precision in this regard.

To better understand the reason behind differences among final scores and reveal the parameters leading buildings to be more vulnerable, parameters' impacts and frequencies in the building stock are examined through heat maps [48] for the methods of RBTE-2019, MQI and SVIVA, as shown in Figures (5-8). The vertical axis of the heat maps includes the parameters defined in the three methods while horizontal axis is divided into 100 cells, representing the number of the examined buildings. The buildings are grouped according to the occupancy classes in horizontal axis, to provide better understanding of common deficiencies observed in distinct building groups. Color gradient defines $N_i \times NP_i$ for parameters in RBTE-2019 and *class x weight* for parameters in SVIVA. In other words, darker colors represent the worse conditions described for each parameter and the higher impact of the parameters on final assessment scores. Lighter colors represent better conditions and lower impact of the parameters. On the other hand, the color gradients presented in Figures 7 and 8 indicate the numeric scores of parameters directly defined by the MQI methodology. Since the study mainly focused on seismic performance of the buildings, vertical loading conditions in MQI method were not taken into account and only in-plane and out-of-plane assessments were illustrated in heat maps.

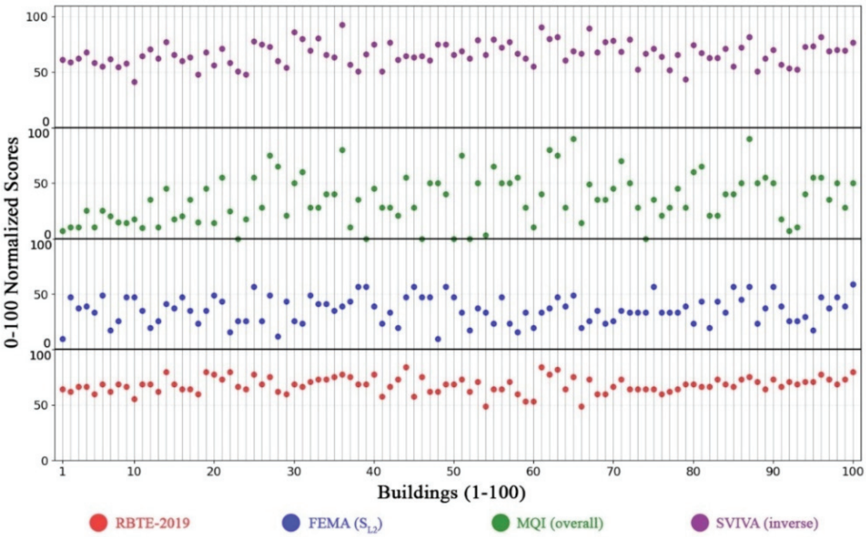

Figure 4 - Normalized assessment scores (0-100) for each method.

It is clearly observed from Figures 5 and 6 that material quality has the most remarkable impact on the seismic performance of SMBs, according to the methods of both RBTE-2019 and SVIVA. For the inventory of this study, material quality is observed to be worse in mostly residential buildings and buildings used as barn or warehouses. This situation is considered to be more related to buildings in rural areas, considering that SMBs were mostly constructed with locally available, barely coursed or rounded stones. The SMBs punished by the out-of-plane parameter in RBTE-2019, are mostly buildings that have no rigid horizontal diaphragm. Taking this into account, heat maps also indicate the importance of floor diaphragm type and wall-to-slab connection. The impact of this parameter seems to be more critical in SVIVA method, while the prevalence and negative effect of flexible floor diaphragm and poor wall-to-slab connection is seen for all occupancy classes. Another common impactful parameter is the number of floors. Although the number of floors does not exceed 3 in SMBs in the peninsula, heat maps indicate the importance of this parameter, showing that even two-storey buildings may lead to more vulnerability than one-storey buildings. Heat maps also visualize that multiple stories are common in residential buildings, and other building types mostly consist of single floors. The parameters related to masonry workmanship quality and adjacency (presence or absence of pounding effect) in RBTE-2019, also seem to be critical, and moreover, negative cases are mostly observed in residential buildings.

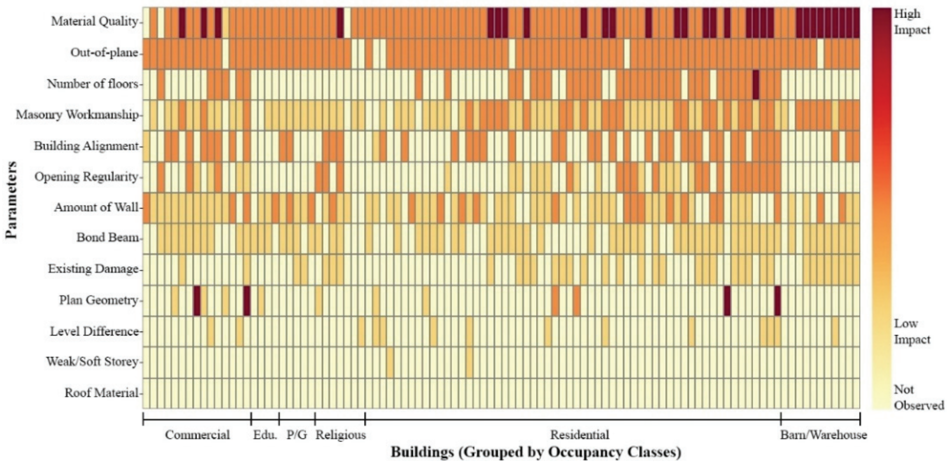

Figure 5 - Impact and frequency of parameters according to occupancy classes for RBTE-2019 method (Edu.: educational buildings, P/G: public or governmental buildings).

Figure 6 - Impact and frequency of parameters according to occupancy classes for SVIVA method (Edu: educational buildings, P/G: public or governmental buildings).

As shown in Figure 7, the MQI evaluation for in-plane loads indicates that the observed walls generally exhibit the most unfavorable conditions for the parameters mortar quality (MM), stone shapes (SS), and vertical joint irregularity (VJ). Another noteworthy observation, based on the wall leaf connections (WC) parameter determined through qualitative assessment, is that despite the considerable thickness of the examined walls in the Urla Peninsula, they were constructed with relatively small stones, suggesting the probable absence of headstones. As seen in Figure 8, this parameter is also the most significantly dominant one in the out-of-plane evaluation according to MQI method. Apart from the slightly more influential SS and HJ parameters, the other factors show a similar frequency of occurrence and adverse effect on the out-of-plane behavior of the walls.

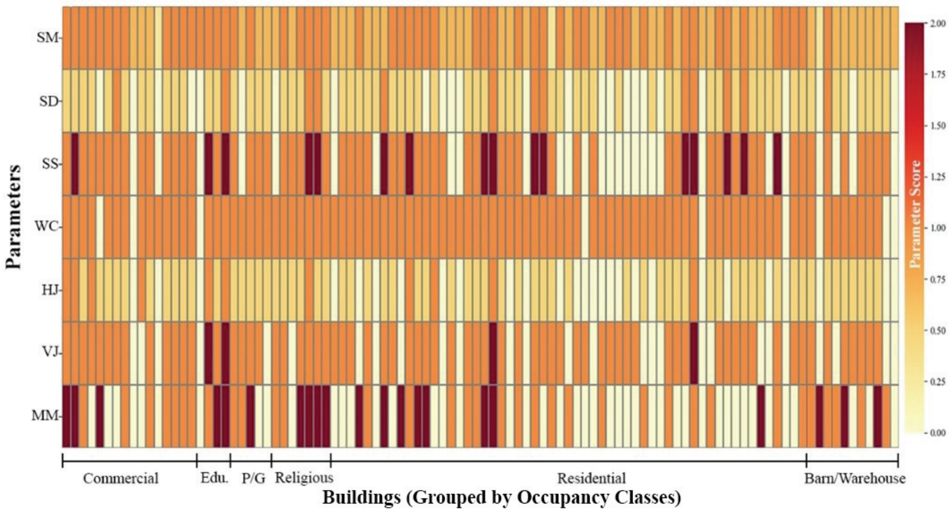

Figure 7 - Parameters and scores for In-Plane MQI assessment (Edu: educational buildings, P/G: public or governmental buildings).

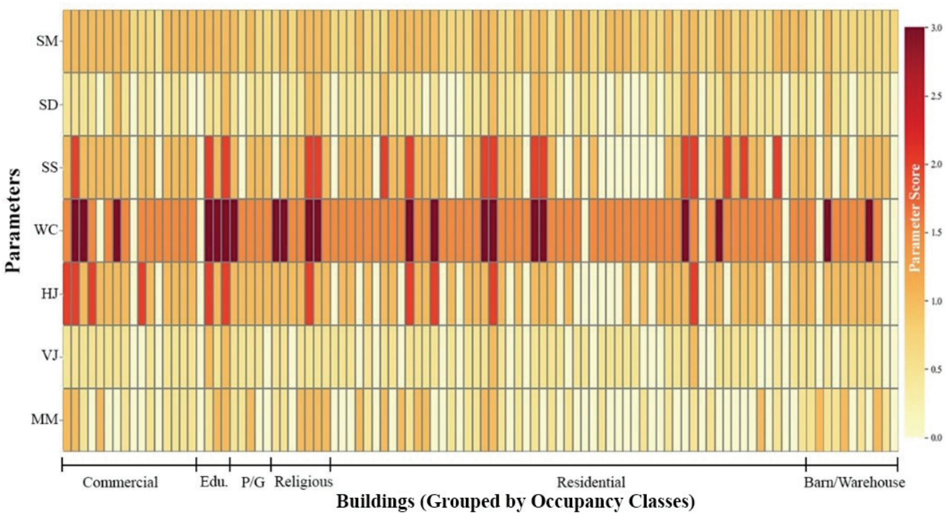

Figure 8 - Parameters and scores for Out-of-Plane MQI assessment (Edu: educational buildings, P/G: public or governmental buildings).

Figure 9 presents the basic scores obtained from FEMA RVS for the 100 investigated buildings, together with the total penalty scores assigned in Level 2 scoring under the VL2, PL2, and M groups of modifiers. Since Level 2 scoring represents a more detailed version of Level 1, Level 1 scoring is not shown in the figure. As illustrated in Figure 9, the majority of the buildings are located in the High Seismicity zone, while four buildings are situated in Moderately High and another four in the Very High Seismicity zone, which indicates that most buildings start the evaluation with a Basic Score of 1. It should be noted that for Level 2 scoring, the initial score (S′) is calculated by adding the Basic Score and only the pre-code parameter from Level 1 scoring (i.e., -1 point for the buildings located in the Moderately High Seismicity zone) and is therefore not displayed in the figure. The figure shows that buildings are most penalized by up to -1 and -1.1 points through VL2 and PL2 parameters, whereas penalties equal to or greater than -1 typically occurred in the M group, mostly due to the pounding effect. The simultaneous presence of pounding effect and gable walls resulted in seven buildings receiving severe penalties of -1.7 and -1.6, leading to significantly low scores. Buildings penalized under the VL2 parameter generally exhibited weak/soft storey and/or in-plane setback conditions. The PL2 parameter was typically associated with torsional irregularity, where considerable differences in the lengths of load-bearing walls in the x and y directions reduced the scores assigned through the RVS procedure.

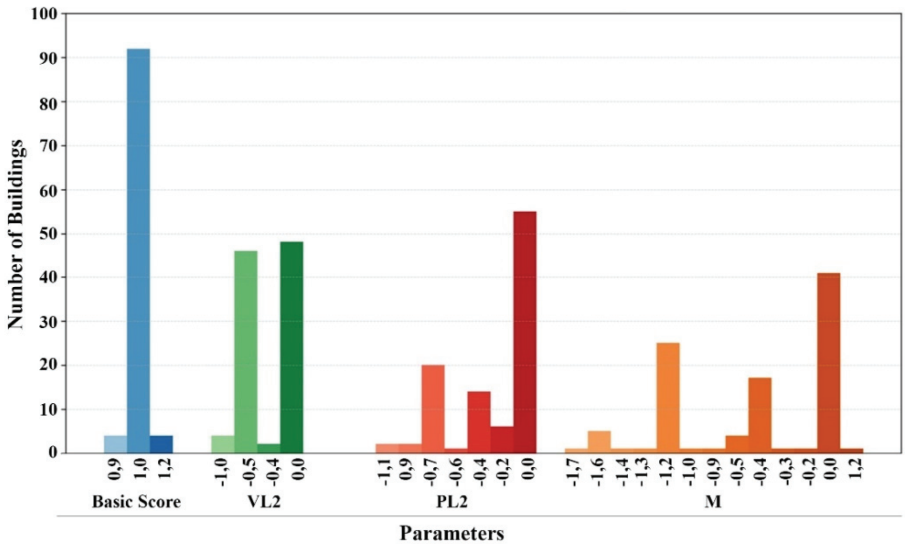

Figure 9 - Histogram of buildings by Basic Score and VL2, PL2 and M modifiers in RVS Level 2 Scoring.

To further comparatively analyze the impact of prominent parameters in the heat maps, violin graphs [48] are used, evaluating the parameters related to masonry wall quality and diaphragm type, as shown in Figures 10 and 11 respectively. Vertical axis for these graphs, again, refers to the 0-100 normalized final assessment scores obtained from each method. The heat maps have shown that residential buildings and barn/warehouses exhibit common deficiencies compared to other occupancy classes. Therefore, building occupancy classes are grouped into two sections for violin graphs, O1 and O2. Residential buildings, barns and warehouses are represented as O1 (Occupancy-1), and all other usage types are represented by O2 (Occupancy-2). It is worth mentioning again that the lowest score obtained from vertical, in-plane and out-of-plane scoring in MQI method used as an overall MQI score in violin graph. Figure 10 shows the distribution and effect of the "poor or good" quality of material and masonry walls, evaluated through distinct methods. Since there is no parameter relating to the quality of masonry wall in FEMA P-154, this method was not included in this evaluation. Light green (G1) refers to the conditions that both material quality and masonry workmanship are "poor" according to RBTE-2019, and darker green (G2) refers all other possible conditions for these parameters. With a similar approach, light orange (Y1) represents the D class for P3 (Type of Material) in SVIVA, and darker orange (Y2) refers to all other cases. Since the MQI method provides a general evaluation about masonry wall quality, the overall scores of MQI method were included in the graph. However, color hue classification was not applied to MQI method, since good or poor quality of walls is already scored in the y axis of the graph. Figure 10 indicates that "poor" wall quality is more common in O1 buildings, commonly supported by the three methods. According to the MQI method, it is observed that the majority of buildings in the O2 group fall within the mid-range, whereas in the O1 group, the clustering appears lower on the graph. Notably, results from the SVIVA method indicate that buildings with the poorest wall quality receive lower average scores compared to buildings with higher-quality walls. Examining the RBTE-2019 results, although the scenario with the lowest wall material quality and workmanship in O1 group buildings shows scores similar to other scenarios, it is observed that buildings in the O2 group with the poorest wall quality are quite rare, and this small subset exhibits lower average scores compared to the rest. At this point, the presence of structures used as barn-warehouses in the O1 group, which generally exhibit low observed quality, cannot be disregarded. These findings also suggest that in building groups open to the public, where user loads are variable, regular maintenance is performed, and material and workmanship quality tend to be higher than in residential buildings, the methods tend to assign higher scores to masonry wall parameters. This, in turn, contributes to an increased structural quality in terms of seismic vulnerability.

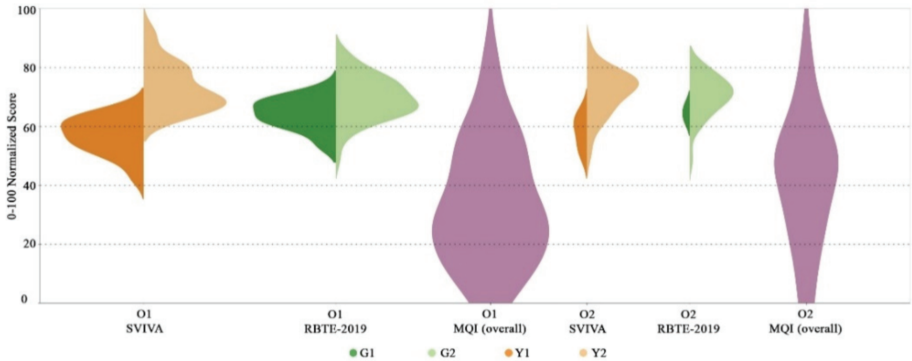

Figure 10 - Final assessment score according to masonry wall quality (G1: buildings with "poor" material and masonry workmanship quality, G2: other conditions for material and masonry workmanship quality, Y1: "D" class Type of Material, Y2: "A, B, C" class Type of Material, O1: occupancy class-1, O2: occupancy class-2).

A similar approach was applied to compare the distribution of diaphragm types among the examined buildings and their evaluation scores. Buildings were classified according to the type of horizontal diaphragm, with rigid diaphragms representing RC slabs and flexible diaphragms representing all cases without RC slabs. It should be noted that wall-to-slab connections, which affect out-of-plane behavior, were not considered in these graphs; rather, the analysis focused directly on the relationship between slab type distribution and the resulting scores. As shown in Figure 11, in the O1 group, the distribution of rigid and flexible slabs is relatively balanced, although the average score of buildings with rigid slabs is slightly higher. In the O2 group, rigid slabs are relatively rare, yet these buildings achieve notably higher scores. However, it should be noted that out-of-plane vulnerabilities arising from additional loads that rigid concrete slabs could introduce, combined with poor wall-to-slab connections and wall workmanship, could not be assessed here. Nonetheless, the graph indicates that the methods assign slightly higher scores to buildings with rigid diaphragms, while buildings with flexible diaphragms constitute a comparatively more vulnerable group.

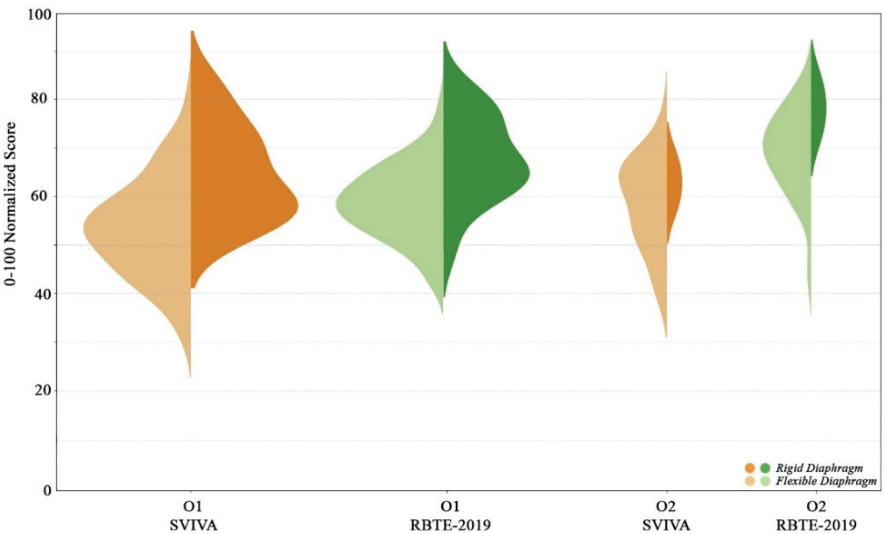

Figure 11 - Final assessment scores according to diaphragm type (O1: occupancy class-1, O2: occupancy class-2).

5. CONCLUSION

Inventory studies play the initial role on assessing seismic risk for territorial scale. Identifying architectural and structural features and estimating vulnerability through rapid seismic assessment methods for representative numbers of buildings, streamlines the risk assessment and mitigation process, especially in high seismicity regions. One such region, the Urla Peninsula, which constitutes notable part of İzmir, is known to host a substantial number of stone masonry buildings (SMBs). In this study, 100 SMBs in the Urla Peninsula were examined on-site. Data related to building age, occupancy class, situation of restoration, building alignment, masonry wall quality, slab type and other structural elements were collected, and each building was photographed. A measurement survey was also conducted to draw plan and elevation layouts of the buildings. Using the data collected, seismic risk and vulnerability of 100 SMBs were assessed through four rapid methods, FEMA P-154, RBTE-2019, MQI and SVIVA. By combining these methods, the study aimed to provide building-specific assessments of seismic risk and vulnerability while increasing the number of parameters considered for each building to achieve more reliable results. Furthermore, this multi-faceted approach allowed for discussion of certain limitations inherent in each individual method. The following conclusions can be drawn from the findings:

- FEMA P-154 and MQI methods generally produced scores below the midline, reflecting the high seismicity of the region and vulnerabilities in masonry walls, such as irregular vertical joints, missing headstones, and low-quality mortar. In contrast, RBTE-2019 and SVIVA methods yielded relatively higher scores due to methodological factors, yet low ratings persisted for out-of-plane behavior and wall quality. Poor diaphragm-wall connections and the type of horizontal diaphragm further reduced SVIVA scores.
- Heatmap and violin plot analyses identified the most frequent and impactful deficiencies. Key parameters influencing RBTE-2019 and SVIVA scores included masonry wall and material quality, diaphragm type, number of floors, and adjacency to other buildings. Poor wall quality was more common in O1-class buildings (residences, barns, warehouses) than in O2-class buildings (educational, religious, commercial, public). Rigid floor diaphragms were rarely observed, particularly in O2 buildings; buildings with RC floors performed better across methods. Pounding effects further lowered scores for adjacent buildings.
- Seismic risk reduction for stone masonry building stock in İzmir should prioritize: (i) SMBs with masonry walls made of rounded, uncoursed stones and mud mortar, especially in rural residences, barns, and warehouses, (ii) SMBs with inconsistent horizontal joints and non-staggered vertical joints, (iii) residential SMBs lacking rigid floor diaphragms, (iv) SMBs adjacent to neighboring buildings with level differences in slabs.
- To strengthen regional seismic risk mitigation strategies, further studies should include fragility curve development, detailed micro and macro-scale structural analyses, and experimental investigations of typical stone masonry walls in the Urla Peninsula. Such efforts can support more effective prioritization and strengthening of the existing building stock.

Acknowledgement

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Appendix A

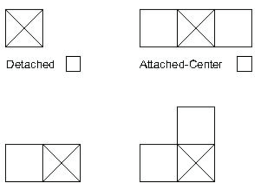
DATA COLLECTION FORM for MASONRY BUILDINGS

BUILDING INFORMATION	Building Code:	Occupancy Class:		Former Occupancy Class:
	Building Age:	LOCATION	Province: / District:	Neighborhood: / Coordinates:

1. Structural Damage: Yes ☐ No ☐ If any ....

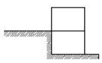
2. Repair/Restoration: Yes ☐ No ☐ If any ....

3. Building Alignment:



Detached ☐ Attached-Center ☐ Attached ☐ Attached-Corner ☐

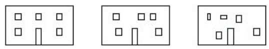
4. Level Difference: Yes ☐ No ☐



Front- Back Facade: ....

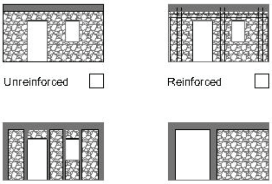
Side Facade: ....

5. Opening Layout:



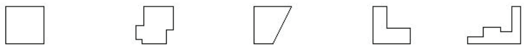
Regular ☐ Partially Regular ☐ Irregular ☐

6. Masonry Structure Type:



Unreinforced ☐ Reinforced ☐ Confined ☐ Hybrid ☐

7. Plan Geometry:



Regular Rectangular ☐ Reentrant ☐ Trapezoid Irregular ☐ L Shaped Irregular ☐ Irregular ☐

Number of Floors:

Basement: Yes ☐ No ☐

Height Diff. with Adjacent Building:

Diaphragm Level Diff. with Adjacent Building:

Sloping Site: Yes ☐ No ☐

8. Wall Thickness	Exterior .... Interior	**9. Avg. Stone Dimension** ....
10. Stone Type	Lime ☐ Granite ☐ Hybrid ☐ Andesite ☐ Slate ☐ Other	**Stone Orientation Type:** Uncoursed ☐ Barely-coursed ☐ Cut-Stone ☐
11. Adhesive Material:	Lime ☐ Soil ☐ Dry-Joint ☐ Cement ☐ Hybrid ☐ Other	**Horizantal Joint:** Regular ☐ Irregular ☐ Hybrid ☐ None ☐ **Vertical Joint:** Regular ☐ Irregular ☐ Hybrid ☐ None ☐
12. Plaster:	Yes ☐ No ☐ Exterior ☐ Interior ☐	**Plaster Material:** Lime ☐ Cement ☐ Adobe ☐ Mud ☐ Other ....
13. Bond Beam:	Yes ☐ No ☐ Wall Top ☐ Window Top ☐ Window Base ☐	**Bond Beam Material:** RC ☐ Concrete ☐ Timber ☐ Steel ☐ Other ....
14. Lintel:	Yes ☐ No ☐ Flat ☐ Arched ☐	**Lintel Material:** RC ☐ Concrete ☐ Timber ☐ Stone ☐ Other ....
15. Slab Type:	RC ☐ Timber ☐ Steel ☐ Other	**Slab/Wall Connection:** Embedded in the Wall ☐ Partially Embedded in the Wall ☐ Extending Beyond Wall ☐
16. Roof Type:	Flat ☐ Shed ☐ Hip ☐ Gable ☐ Slope:	**Roof Structural Material:** RC ☐ Soil ☐ Timber ☐ Steel ☐ Other ....
17. Additional Structural Support:	Yes ☐ No ☐ Vertical ☐ Horizontal ☐	**Additional Structural Support Material:** RC ☐ Concrete ☐ Timber ☐ Steel ☐ Other ....
18. Corner Wall Joint:	....	
19.Vertical Irregularities:	Sloped Land ☐ Soft Story ☐ Weak Story ☐ SetBack ☐ Split Level ☐ Short Pier ☐ Other	
20.Plan Irregularities:	Torsional ☐ Non-Parallel ☐ Reentrant ☐ Diaphram Openings ☐ Other	

Screener's Notes:

use back side for drawings...

Appendix B

Building Name	District	Neighborhoo d	Occupancy Class	FEMA P-154 S_{L2}	RBTE-2019 PP	MQI Overall Class	SVIVA I_V
U-Gu-01	Urla	Gülbahçe	Residential	-1,4	50	C	192,5
U-Gu-02	Urla	Gülbahçe	Residential	0,5	45	C	203,75
U-Gu-03	Urla	Gülbahçe	Residential	0	55	C	187,5
U-Gu-04	Urla	Gülbahçe	Residential	0,1	65	C	131,25
U-Gu-05	Urla	Gülbahçe	Residential	-0,2	50	C	176,25
U-G-06	Urla	Gülbahçe	Residential	0,6	60	C	225
U-Gu-07	Urla	Gülbahçe	Residential	-1	45	C	191,25
U-Gu-08	Urla	Gülbahçe	Residential	-0,6	60	C	226,25
U-Gu-09	Urla	Gülbahçe	Residential	0,2	55	C	210
U-Gu-10	Urla	Gülbahçe	Residential	0,2	30	C	292,5
U-Gu-11	Urla	Gülbahçe	Residential	-0,1	60	C	177,5
U-Gu-12	Urla	Gülbahçe	Residential	-0,9	60	C	146,25
U-Ya-01	Urla	Yağcılar	Barn	-0,6	55	C	187,5
U-Ya-02	Urla	Yağcılar	Health Clinic	0,2	85	B	113,75
U-Ya-03	Urla	Yağcılar	Residential	0	60	C	172,5
U-Gu-13	Urla	Gülbahçe	Residential	0,5	50	C	198,75
U-Ya-04	Urla	Yağcılar	Commercial	-0,6	50	C	181,25
U-Ya-05	Urla	Yağcılar	Residential	-0,7	40	C	260
U-Ya-06	Urla	Yağcılar	Warehouse	-0,1	85	B	161,25
U-Ya-07	Urla	Yağcılar	Educational	0,6	80	C	218,75
U-Ya-08	Urla	Yağcılar	Residential	0,3	70	A	143,75
U-Ba-01	Urla	Barbaros	Commercial	-1,1	85	C	207,5
U-Ba-02	Urla	Barbaros	Commercial	-0,6	55	C	247,5
U-Ba-03	Urla	Barbaros	Barn	-0,6	50	C	260
U-Ba-04	Urla	Barbaros	Residential	1	80	A	111,25
U-Ba-05	Urla	Barbaros	Residential	-0,6	60	C	123,75
U-Ba-06	Urla	Barbaros	Commercial	0,6	75	A	136,25
U-Ba-07	Urla	Barbaros	Commercial	-1,3	45	B	200
U-Ba-08	Urla	Barbaros	Religious	0,3	40	C	230
U-Ba-09	Urla	Barbaros	Office	-0,6	60	B	68,75
U-Ba-10	Urla	Barbaros	Residential	-0,7	55	B	143,75
U-Ba-11	Urla	Barbaros	Warehouse	0,6	65	C	151,25
U-Ba-12	Urla	Barbaros	Warehouse	0,2	70	C	97,5
U-Ba-13	Urla	Barbaros	Residential	0,2	70	B	171,25
U-Ba-14	Urla	Barbaros	Residential	-0,1	75	B	181,25

U-Ba-15	Urla	Barbaros	Residential	0,1	80	A	28,75
U-Ba-16	Urla	Barbaros	Residential	0,3	75	C	215
U-Ba-17	Urla	Barbaros	Residential	1	60	C	247,5
U-Ba-18	Urla	Barbaros	Barn	1	60	C	170
U-Bi-01	Urla	Birgi	Commercial	0,1	80	B	123,75
U-Bi-02	Urla	Birgi	Residential	-0,7	35	C	255
U-Bi-03	Urla	Birgi	Religious	-0,2	55	C	117,5
K-Bo-01	Karaburun	Bozköy	Religious	-0,9	70	C	192,5
K-Bo-02	Karaburun	Bozköy	Residential	0,5	95	B	177,5
K-Bo-03	Karaburun	Bozköy	Residential	1	35	C	183,75
K-Bo-04	Karaburun	Bozköy	Public	0,5	75	C	177,5
K-Ku-01	Karaburun	Küçükbahçe	Residential	0,5	45	B	195
K-Cu-01	Karaburun	Çukurmahalle	Hotel	-1,4	45	B	123,75
K-Cu-02	Karaburun	Çukurmahalle	Residential	1	60	B	123,75
K-Ku-02	Karaburun	Küçükbahçe	Residential	0,5	60	C	172,5
C-Al-01	Çeşme	Alaçatı	Hotel	-0,6	80	A	131,25
C-Al-02	Çeşme	Alaçatı	Residential	-0,9	55	C	165
K-Me-01	Çeşme	Merkez	Public	0	65	B	106,25
K-Me-02	Çeşme	Merkez	Educational	-0,2	15	C	240
K-Sa-01	Karaburun	Sarpıncık	Residential	-0,7	50	A	101,25
K-Sa-02	Karaburun	Sarpıncık	Residential	0,5	60	B	116,25
K-Sa-03	Karaburun	Sarpıncık	Residential	-0,7	65	B	113,75
K-Sa-04	Karaburun	Sarpıncık	Residential	-1,1	50	B	143,75
K-Sa-05	Karaburun	Sarpıncık	Residential	-0,2	25	C	187,5
K-Sa-06	Karaburun	Sarpıncık	Residential	-0,9	25	C	225
C-Il-01	Çeşme	Ildır	Residential	-0,2	95	B	40
C-Il-02	Çeşme	Ildır	Residential	0	80	A	76,25
C-Il-03	Çeşme	Ildır	Residential	0,5	90	A	91,25
C-Il-04	Çeşme	Ildır	Residential	0,1	50	C	195
C-Al-03	Çeşme	Alaçatı	Office	0,7	75	A	156,25
C-Il-05	Çeşme	Ildır	Residential	-0,9	25	C	142,5
C-Il-06	Çeşme	Ildır	Residential	-0,6	70	B	52,5
C-Il-07	Çeşme	Ildır	Residential	-0,1	40	C	161,25
S-Se-01	Seferihisar	Sığacık	Hotel	-0,7	40	C	112,5
S-Se-02	Seferihisar	Sığacık	Commercial	-0,6	55	B	108,75
G-Ca-01	Güzelbahçe	Çamlı	Residential	-0,1	70	A	158,75
G-Ca-02	Güzelbahçe	Çamlı	Residential	-0,2	50	B	101,25
C-Il-08	Çeşme	Ildır	Warehouse	-0,2	50	C	237,5
G-Ca-03	Güzelbahçe	Çamlı	Warehouse	-0,2	60	C	143,75

G-Ca-04	Güzelbahçe	Çamlı	Residential	1	50	C	142,5
G-Ca-05	Güzelbahçe	Çamlı	Residential	-0,2	40	C	180
G-Ca-06	Güzelbahçe	Çamlı	Warehouse	-0,2	45	C	241,25
S-Go-01	Seferihisar	Gödence	Residential	-0,2	50	B	172,5
S-Go-02	Seferihisar	Gödence	Warehouse	0,1	60	C	282,5
G-Ye-01	Güzelbahçe	Yelki	Office	-0,7	60	A	126,25
G-Ye-02	Güzelbahçe	Yelki	Residential	0,3	55	A	162,5
G-Ye-03	Güzelbahçe	Yelki	Religious	-0,9	55	C	185
S-Ul-01	Seferihisar	Ulamış	Religious	0,3	70	C	185
S-Ul-02	Seferihisar	Ulamış	Residential	-0,2	60	B	143,75
S-Ul-03	Seferihisar	Ulamış	Residential	1	55	B	225
C-Me-01	Çeşme	Merkez	Religious	0,5	70	B	137,5
C-Ge-01	Çeşme	Germiyan	Residential	1	75	A	90
C-Ge-02	Çeşme	Germiyan	Assembly	-0,7	65	B	245
S-Du-01	Seferihisar	Düzce	Residential	0	50	B	187,5
S-Du-02	Seferihisar	Düzce	Residential	1	70	B	150
G-Ku-01	Güzelbahçe	Küçükkaya	Residential	0,1	55	C	215
G-Ku-02	Güzelbahçe	Küçükkaya	Residential	-0,6	65	C	232,5
G-Ku-03	Güzelbahçe	Küçükkaya	Residential	-0,6	60	C	237,5
U-Me-01	Urla	Merkez	Commercial	-0,4	65	B	136,25
U-Me-02	Urla	Merkez	Religious	-0,7	65	B	132,5
U-Me-03	Urla	Merkez	Residential	0	90	B	68,75
U-Me-04	Urla	Merkez	Residential	0	70	C	155
U-Me-05	Urla	Merkez	Educational	0,5	60	B	150
U-De-01	Urla	Denizli	Residential	-0,4	70	C	151,25
U-Is-01	Urla	İskele	Assembly	1,1	85	B	117,5