An overview of S-RVS methods necessity to enhance traditional RVS methods comparison with post-earthquake findings presented in a case study

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***Abstract*—Rapid visual screening (RVS) methods are used to estimate damages that may occur in a building before an earthquake or to determine vulnerability level of an existing building after an earthquake. These methods are examined under two major subtitles, traditional- and soft-RVS (S-RVS). In this paper, conventional RVS and S-RVS methodologies are briefly discussed, and real-world examples of these methodologies are presented. There is a bias between the results of conventional RVS methods since different linguistic variables (e.g., moderate, severe, etc.) have different meanings for experts. S-RVS techniques are recommended as a future version of conventional RVS methods, which are developed based on local building characteristics. To improve the accuracy of S-RVS techniques, more post-earthquake data is needed than traditional RVS methods.**

***Keywords*—Disasters; earthquakes; traditional rapid visual screening; soft rapid visual screening; pre- and post-earthquake vulnerability assessment**

I. INTRODUCTION

The seismic risk assessment of existing buildings is based on the consideration of three main stages, from simple to detailed: (1) rapid visual screening (RVS), (2) preliminary vulnerability assessment, (3) detailed vulnerability assessment. RVS techniques are based on survey forms for the specific considered building type (e.g., reinforced concrete buildings, masonry buildings, and so forth). The implementation of traditional RVS methodology takes approximately 15 to 30 minutes for assessment of each building [1]. Based on our experiences, identifying, and understanding the building and implementing the RVS technique may take up to 60 minutes for each building. On the other hand, the time required to assess each building enormously increases comparatively to traditional RVS techniques when detailed seismic assessment methodologies such as pushover analysis, incremental dynamic analysis, etc. are implemented.

In European countries, some of the existing buildings have reached their service life and it has been stated that some of the buildings are constructed without considering seismic standards or are designed in accordance with norms that consider moderate seismic effects [2]. The Figure 1 demonstrates the urgent need for implementation of traditional RVS techniques or enhanced S-RVS techniques to the European building stock to identify seismically vulnerable buildings. To mitigate the likelihood of socioeconomic loss, a regional seismic risk assessment of the building stock should be performed utilizing RVS methods such as conventional RVS or S-RVS procedures.

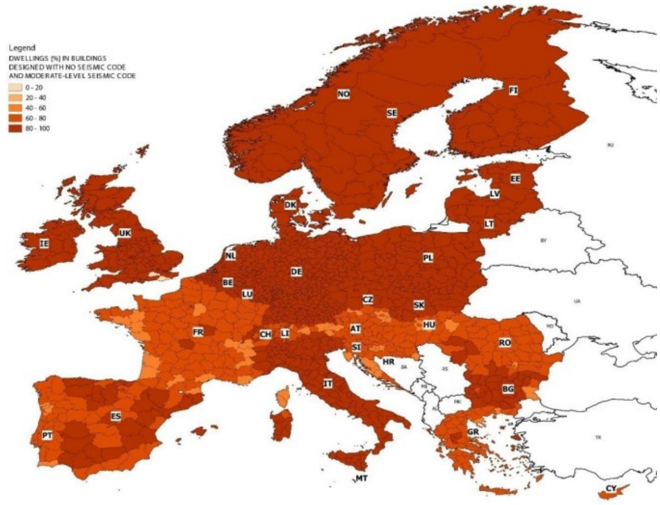

Figure 1: Percentage of buildings designed in accordance with and without lower seismic standards [2]

As there are many RVS approaches in the literature, they are making the selection of an appropriate methodology difficult based on the building type under examination for researchers or application engineers. This study intends to help researchers and practitioners in selecting appropriate methods. Furthermore, it offers real-world applications of conventional RVS and S-RVS approaches, helping researchers and application engineers to understand which features of these techniques are more appropriate to implement and what their limitations are. In this context, it is realized that future versions of traditional RVS methods could be developed by implementing the algorithms (machine learning (ML), fuzzy logic system (FLS), artificial neural networks (ANN), etc.) recommended in the literature based on S-RVS methods and post-earthquake data. This study consists of a brief description of widely implemented conventional RVS methods, main S-RVS methods used to assess structural vulnerability, a sample case study based on the FEMA P-154 RVS technique, real-world application of S-RVS methodologies, a brief discussion on the comparison of traditional RVS findings with post-earthquake data to assess the accuracy of the traditional RVS method, and a comprehensive conclusion to this paper.

II. Traditional RVS Methods:

The existing European building stock, which was constructed before seismic regulations, is large, and detailed seismic analyses are not possible to those buildings as it is computationally expensive. Hence, in the late 1980s, FEMA published the first traditional rapid visual screening methodology for rapid screening of existing buildings as "Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook" FEMA 154 (ASCE 1988) [3] and FEMA 155 (ASCE 1988) [4] to make necessary improvements. The RVS technique is being used to identify buildings that need to be retrofitted or demolished [5–8].

Some of the RVS methods are developed all around the world are FEMA 154 [9], FEMA P-154 [1], FEMA 155 [10], FEMA P-155 [11] in USA by the Federal Emergency and Management Agency (FEMA), NRC-93 [12] in Canada by the National Research Council (NRC), the Earthquake Master Plan of Istanbul (EMPI) [13] and RBTE-2019 [14] in Turkey, Gruppo Nazionale per la Difesa dai Terremoti (GNDT) [15] in Italy, India RVS methodology [16] developed by International Institute of Information Technology (IIT) Kanpur, EMS-98 [17] Scale and RISK-UE Project [18] by European Union (EU), Earthquake Planning and Protection Organization (OASP) proposed RVS in Greece [19]. In the years following the publication of the first methodology, some of the national RVS techniques were developed all around the world (e.g., Greece [19], India [16], Philippines RVS by Vallejo (2010) [20]) based on FEMA 154 [3,9] with respect to the local characteristics of the existing building stock of different regions.

Level-1 of FEMA P-154 methodology was applied by Haryanto et al. (2020) [21] for the seismic risk assessment of seven RC university buildings in Indonesia. The study conducted by Islam et al. (2020) [22] proposes a novel RVS methodology to distinguish structures that need detailed seismic assessment. The reliability of the proposed methodology is verified based on the post-earthquake data obtained from the 2016 Taiwan earthquake. Furthermore, there are several studies [23–25] in the literature that use conventional RVS techniques.

III. Soft RVS Methods:

Soft RVS (S-RVS) methodologies are mainly based on fuzzy logic system (FLS), artificial neural networks (ANN), and machine learning (ML) algorithms. These soft computing techniques are usually trained using post-earthquake data and their reliabilities are demonstrated by comparing them with post-earthquake data.

A. Fuzzy Logic System Based RVS:

Fuzzy logic system (FLS) is an algorithm that could represent the degree of truth of a notion as a number between 0.0 and 1.0 based on its degree of truth. Fuzzy logic was first proposed by Zadeh [26] in 1965. Then, in 1975, the type-2 fuzzy logic system (T2 FLS), which could also take into account vagueness and uncertainty in fuzzy logic algorithms, was published by Zadeh [27]. The type-1 fuzzy logic system (T1 FLS) and T2 FLS consist of input processing (fuzzification process the crisp input to FLS input), fuzzy inference engine (rule, and inference implemented to transformation of FLS input to FLS output), and output processing (T2 FLS is converted to T1 FLS using type reducer, and FLS output is converted to net output by applying defuzzifier step for T1 FLS) [28]. The main development in T2 FLS comparatively to the T1 FLS is that T2 FLS consider uncertainty and vagueness in fuzzy logic implementation.

FLS was initially applied for seismic risk assessment in the field of earthquake engineering in the 1970s [29] and later implemented to the RVS techniques in numerous studies utilizing the fuzzy logic's linguistic variable processing feature [30–40].

In the study by Dritsos and Moseley [40], it is explained how fuzzy logic and ANN algorithms should be used for the development of S-RVS methodologies. In addition, it has been stated that if there is enough data to train the ANN algorithm, utilizing the ANN algorithm with fuzzy logic will make a considerable amount of development in RVS techniques. As a result, it was stated that there is an urgent need to develop a more reliable and accurate RVS methodology.

The interval T2 FLS (IT2 FLS) algorithm was used by Harirchian and Lahmer [33] to develop RVS methods for reinforced concrete buildings in 2020. As a result of the study, it was stated that sufficient development could not be made due to the small amount of data used, but if there is enough data, the proposed technique can be developed to be more reliable and accurate.

Irwansyah et al. (2017) [41] utilized the FLS algorithm, which is trained based on post-earthquake data of non-engineered houses to evaluate the hazard rate of buildings. The results of Python [42] programming language based FLS training provided 93% accuracy in the identification of buildings' hazard rates.

Harirchian and Lahmer (2020) [32] implemented for RVS of reinforced concrete (RC) structures by considering IT2 FLS algorithm. Finally, the proposed S-RVS technique is 12-16% more reliable than the compared ML-based S-RVS methodology and 30-40% more reliable than the compared conventional RVS methods in determining the damage state of RC buildings based on damage assessment of buildings after a major earthquake.

In addition to the above briefly described studies, Ketsap et al. (2019) [36] implemented fuzzy logic based seismic risk assessment methodology to identify seismic risk class of buildings. As a consequence of the study conducted by [36], it has been stated that in addition to identifying the seismic risk class of the considered buildings, the proposed S-RVS technique could be implemented to classify the seismically hazardous buildings in terms of retrofitting priority.

B. Artificial Neural Networks (ANN) Based RVS:

FLS enables accurate judgments to be made based on uncertain data, however, ANN, an algorithm inspired by biological neural networks, addresses issues by training the algorithms based on training data [43]. According to [30,44], ANN contributes to the development of RVS methods utilizing expert opinion-based or post-earthquake data. In this manner, ANN algorithm was implemented in civil engineering applications for the first time for design objectives by Adeli and Yeh [45] in 1989.

Harirchian and Lahmer's [30] purpose is to predict optimum damage states and develop RVS approaches by training ANN within Python [42] programming language based on the post-earthquake data of RC buildings. As a result of this research, it is demonstrated that the preliminary vulnerability assessment might be performed using the ANN algorithm chosen to estimate damage states.

Konstantinos et al. (2019) [44] implemented an ANN algorithm for seismic vulnerability assessment of RC buildings. As a result, it is stated that ANN algorithm implementation in the determination of the damage states gives reliable results and could be used in civil engineering for preliminary vulnerability assessment in a near-real-time.

Harirchian et al. (2020) [46], implemented ANN algorithm based trained RVS methodology, which was trained based on the post-earthquake data of RC buildings collected from the 1999 Düzce, Turkey earthquake. It is stated that the proposed S-RVS approach is a reliable first-stage assessment technique to estimate damage states of RC buildings.

C. Machine Learning (ML) Based RVS:

ANN organizes data in such a way that it can make correct decisions on its own using neuron graphs. ML, on the other hand, employs advanced algorithms that require some human intervention in the early stages, parsing the data, learning from data, and making decisions based on what they learn from the data. Machine learning, a branch of artificial intelligence (AI), is utilized to enhance RVS techniques by utilizing post-earthquake data via artificial intelligence and statistical algorithms in computer technology, as well as to evaluate seismic vulnerability of building in a more reliable and accurate manner. Some widely used approaches of ML algorithms are supervised, unsupervised, and reinforced learning. According to Müller and Guido [47], the most commonly utilized type of ML algorithms is supervised learning.

In the literature, traditional RVS and S-RVS techniques for rapid seismic investigation of structures have been presented (e.g., FLS based RVS, ANN-based RVS, etc.). Among these recommended S-RVS techniques, the ML algorithms have been one of the most extensively used algorithms in recent years. The ML algorithms, like FLS and ANN, are used to train the algorithm utilizing post-earthquake or expert opinion-based collected data to generate more reliable and accurate structural vulnerability identification. In this regard, the following research from recent years are summarized to provide an overview and starting research point to the reader.

In the study conducted by Harirchian et al. (2021) [48], ANN and ML algorithms, which are the most widely used in S-RVS methods for evaluating the vulnerability of RC buildings, are trained using the Python [42] programming language, and improvements in the implemented S-RVS methodology have been observed compared to previous studies.

According to the research performed by Roeslin et al. (2020) [49], a supervised learning-based ML algorithm was trained using Python [42] programming language to process post-earthquake data from 2017 Puebla earthquake in order to perform rapid visual performance determinations.

Kovačević et al. (2018) [50] conducted research to rapidly determine seismic risk assessment of residential buildings utilizing the ML algorithm, which was trained using post-earthquake data collected by local engineers using locally developed survey forms following the 2010 Kraljevo earthquake. The findings of the study indicate that the implemented technique can additionally reflect the repair costs of the building stock assets under consideration.

IV. Real World Example of Traditional RVS Methodologies

Conventional RVS methods are used in field studies for either pre- or post-earthquake assessment. If the traditional RVS technique is utilized for pre-earthquake seismic mitigation of building stock in an earthquake-prone area, the validation of the traditional RVS method used for pre-earthquake vulnerability mitigation could be confirmed via post-earthquake screening data. The implementation process of traditional RVS methods is presented in Figure 2 to determine seismic vulnerability of an individual building or building stock. Some details of the time-consuming steps of shown in Figure 2 implemented beyond the direct visual inspection of buildings include pre-field planning (8-40 hours), choosing the FEMA P-154 RVS form based on site-specific soil properties and seismicity and determining code adaptation dates (8-12 hours), screener training (6-8 hours/screener) based on site-specific building types, and reviewing the building data before fieldwork (15-75 minutes/building) [1].

The building characteristics generally considered to implement selected RVS technique are building type (e.g., reinforced concrete, masonry, steel, timber, etc.), number of stories (which provides a general perspective to the experienced screener about building height), building construction year and the considered regulation year, adjacency (the separation amount between buildings is checked to consider possible pounding effects), soil conditions, seismic zone, plan, and vertical irregularities, building appearance quality, short columns, non-structural elements quality, and so forth.

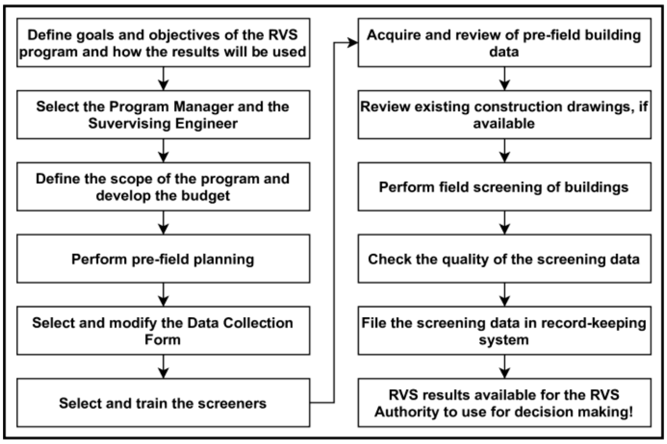

Figure 2: Implementation process of conventional RVS methodologies [1]

To demonstrate the accuracy of the FEMA P-154 method, the findings from the RVS implementation are compared with the post-earthquake data collected from the 2019 Albania earthquake. Prior to 1990, 50.9 percent of existing structures were constructed without concerning the seismic code; however, 49.1 percent of existing buildings in Tirana, Albania, were built with consideration for the seismic code [51]. Structures built before 1993 had 24 percent damage, whereas structures constructed after 1993 have 10 percent damage in Tirana [51]. Some of the data gathered by the team dispatched to Albania by the Hungarian government is used in this study. 14 buildings from Tirana were selected for assessment, from these buildings categorized as low (5), medium (5), and heavy (4) damage states, were examined by implementing the post-earthquake RVS technique to the building stock following the 6.3 in Richter scale 2019 Albania earthquake. Eight of the 14 buildings assessed in this study are URM, five are RC, and one is a hybrid of URM and RC. The FEMA RVS approach, which was initially published in 1988 as FEMA 154 (ASCE 1988) [3], was revised in 2002 as FEMA 154 [9] and most recently updated in 2015 as FEMA P-154 [1]. The most recent published FEMA P-154 [1] RVS methodology is divided into two stages: Level 1 and Level 2. Level 1 data collection forms consist of building identification part (address, building name, latitude, longitude, etc.), building occupancy (number of stories, year built, occupancy, soil type and so forth), basic score, modifiers, final level 1 score (S_{L1}), extend of review, other hazards, required actions, and questioning level 2 screening. Optionally, the Final Score (FS) is determined by implementing the Level 2 RVS data collection form based on numerous structural score modifiers. Also, level 2 RVS contains nonstructural checklist to estimate nonstructural seismic performance. FS has values ranging from 0 to 7, with a high value indicating better anticipated seismic performance and a low value indicating the considered building is seismically hazardous. Buildings having a score less than the FS value of 2, which is identified as "cut-off" score, should be inspected by an experienced design professional. Buildings that take values over the "cut-off" score, on the other side, are deemed to have adequate seismic performance.

The findings of the traditional RVS application were compared with post-earthquake data of the selected buildings in this study. Some of the buildings had horizontal and/or vertical modifications after construction. The addition of balconies to the connected division is a particularly noticeable alteration in the structural systems of some unreinforced masonry (URM) buildings.

To compare post-earthquake data and conventional RVS techniques, pre-earthquake images of selected buildings have collected using Google Earth software, and a rapid seismic assessment has been implemented. The handled final scores based on the traditional RVS implementation for pre-earthquake seismic risk assessment of existing building stock were lower than FEMA P-154 cut-off score. This shows that detailed analysis is needed to determine the vulnerability levels of the screened buildings under an impending earthquake. In comparison with post-earthquake data, the findings of conventional RVS revealed that FEMA results were consistent in terms of detecting potential damage. Furthermore, it has been noted that buildings classified as being in a high damage state during post-earthquake evaluation had comparatively lower final scores.

V. Real World Example of Soft-RVS Methodologies

S-RVS techniques are developed using post-earthquake data or expert opinion-based data. The reliability of these methods and validation after the teaching phase is completed by comparison with the separated data. To improve the reliability and accuracy of S-RVS techniques, additional post-earthquake or expert opinion-based data should be gathered and enough amount of parameters that influence structural behavior need to be included in the computations [48].

FEMA P-154 RVS methodology has been implemented to the selected buildings utilizing visual data collected from Google Earth. When the results from this study are compared to the data collected after the 2019 Albanian earthquake, it is observed that the implemented methodology is quite conservative. Therefore, there is a need to develop an S-RVS technique that can reliably reflect post-earthquake data. However, the data collected in this study is insufficient to develop an S-RVS technique; nevertheless, as stated in the literature [32,41,44,46,48], S-RVS methods enhance damage state prediction of existing buildings. In this context, the objective is to collect enough data to make improvements in S-RVS techniques in future investigations.

VI. Discussion

Engineering structures are susceptible to hazard during an impending earthquake. In this regard, there are key questions to consider when comparing RVS-based seismic risk assessment techniques [52]. (1) What is the focus of the RVS techniques being applied to reduce the loss of life and property that may occur in a possible earthquake? (2) What are the alternative methods that can be applied for seismic risk assessment of existing buildings within a reasonable time as in traditional RVS techniques? (3) What can be done with the data obtained, considering that an appropriate method has been applied for seismic risk assessment?

The primary objective of pre-earthquake risk mitigation is to identify seismically hazardous buildings to take necessary precautions by conducting a seismic risk assessment for existing engineering structures before an impending earthquake. For URM buildings and RC buildings with unreinforced masonry infill walls, the basic score is bigger than 2 as a “cut-off” score for Low seismicity. Scores for irregularities and pre-code parameters’ weight are negative. The Final Score reaches the safety level only when the soil type is A or B for some seismicity levels. In addition, even the soil type is known and there is no irregularity, the maximum final score value that could be achieved is less than the "cut-off" score for Very High, High seismicity for considered building types. The computations revealed that even one building did not reach the "cut-off" score level, and the damage state identification findings were not entirely compatible with the post-earthquake data. The FEMA P-154 Level 1 technique was determined to be conservative. In this manner, S-RVS methods could be implemented to make developments in the traditional RVS methods based on the collected post-earthquake, and expert opinion-based data. Therefore, S-RVS methods based on FLS, ANN, and ML are being developed as an alternative to traditional RVS approaches to perform seismic risk assessment of building stock in a computationally reasonable time. Numerous successful S-RVS method applications [32,44,46,48] to identify the damage states of RC buildings have been provided in the literature; after all, a unique S-RVS methodology must be developed to identify the damage states of other buildings (e.g., masonry buildings) accurately and reliably in seismically hazardous regions in a short period of time.

After implementation of an appropriate methodology, RVS techniques could be verified and compared. Comparison of traditional RVS methods is difficult, however, comparison and validation of S-RVS techniques are easier when they trained based on the same data. S-RVS methods may therefore be verified, and methods that appear to be more trustworthy than conventional RVS methods could be made more accurate by considering more data and required parameters [48].

VII. CONCLUSIONS

Traditional RVS and S-RVS techniques are discussed through examples from the literature in this research, and real-world application examples of FEMA P-154 RVS method to Tirana, Albania are provided. The application of the FEMA P-154 RVS technique has been carried out by collecting pre-earthquake street view pictures of existing buildings from Google Earth software. The findings of the traditional RVS method implementation are compared with the post-earthquake data from the 2019 Albanian earthquake. By comparing the post-earthquake data of 14 buildings to the outcomes of conventional RVS technique implementation, it is demonstrated that the implemented FEMA RVS method is conservative. The findings obtained by implementing the FEMA methodology reveal the requirement for comprehensive seismic risk assessment of these buildings. Because even the detailed seismic assessment of fewer buildings than the number of buildings considered in this study is computationally expensive, more precise approaches in terms of time and results are required. In this manner, S-RVS methods would offer a possibility to provide preliminary vulnerability assessment to be able to investigate the seismic resistance of the buildings for which there is a need for further detailed seismic assessment. To develop an S-RVS methodology, which could consistently identify the damage states of the considered building stock in this study, further data is required to be collected. In this context, more post-earthquake data collection is required to improve the reliability and accuracy of traditional RVS and S-RVS methodologies.

REFERENCES

[1] Federal Emergency Management Agency (FEMA), FEMA P-154: Rapid visual screening of buildings for potential seismic hazards: A Handbook, Applied Technological Council (ATC). (2015).

[2] European Commission. Joint Research Centre., Building stock inventory to assess seismic vulnerability across Europe., Publications Office, LU, 2018. https://data.europa.eu/doi/10.2760/530683 (accessed July 2, 2021).

[3] Federal Emergency Management Agency (FEMA), FEMA 154 (ATC - 21): Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook, (1988).

[4] Federal Emergency Management Agency (FEMA), FEMA 155 (ATC - 21 -1): Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation, (1988).

[5] Federal Emergency Management Agency (FEMA), FEMA 155: Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation, (2002).

[6] P. Kapetana, S. Dritsos, Seismic assessment of buildings by rapid visual screening procedures, Earthquake Resistant Engineering Structures. (2007).

[7] M.A. Ansary, M.Y. Reja, I. Jahan, Rethinking the public building as post disaster shelters - in the context of old Dhaka, (2010) 10.

[8] H. Azizi-Bondarabadi, N. Mendes, P.B. Lourenço, N.H. Sadeghi, Empirical seismic vulnerability analysis for masonry buildings based on school buildings survey in Iran, Bulletin of Earthquake Engineering. 14 (2016) 3195–3229. https://doi.org/10.1007/s10518-016-9944-1.

[9] Federal Emergency Management Agency (FEMA), FEMA 154: Rapid visual screening of buildings for potential seismic hazards: A handbook, (2002).

[10] Federal Emergency Management Agency (FEMA), FEMA 155: Rapid Visual Screening of Buildings for Potential Seismic Hazards: Supporting Documentation, (2002).

[11] Federal Emergency Management Agency (FEMA), FEMA P-155: Rapid visual screening of buildings for potential seismic hazards: Supporting documentation, (2015).

[12] National Research Council (NRC), Manual for screening of buildings for seismic investigation, National Research Council of Canada, Ottawa, Canada, 1993. https://doi.org/ISBN 0-660-15381-5.

[13] A. Ansal, K. Özaydın, A. Edinçliler, M. Erdik, L. Akarun, H. Kabasakal, N. Aydınoğlu, Z. Polat, B. Şengezer, F. Sağlam, V. Akgiray, G. Fişek, G. Barbarosoğlu, A. Sağlamer, H. Sucuoğlu, P. Özdemir, P. Gülkan, N.Z. Gülersoy, M. Balamir, E. Özer, Z. Celep, G. Özcebe, N. Karancı, D. Ural, Earthquake Master Plan for Istanbul, Metropolital Municipality of Istanbul, Planning and Construction Directorate, Geotechnical and Earthquake Investigation Department, Istanbul, Turkey, 2003.

[14] Ministry for Environment and Urban Planning, Principles for Identifying Risky Buildings, (2019).

[15] Gruppo Nazionale per la Difesa dai Terremoti (GNDT), Rischio sismico di edifici pubblici – Parte I: aspetti metodologici, (1993).

[16] D.C. Rai, Seismic Evaluation and Strengthening of Existing Buildings, (2005) 1–120.

[17] G. Grünthal, European macroseismic scale 1998, (1998).