

## RAPID VISUAL SEISMIC SCREENING PROCEDURE FOR BUILDING STOCK IN BUCHAREST

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**Abstract:** Bucharest is classified as the second metropolis in Europe, subjected to important losses in the case of a destructive earthquake. Evaluation of the seismic vulnerability of the city represents a tremendous task requiring swift structural vulnerability assessment tools. The seismic structural assessment of old, un-engineered, buildings using complex assessment methodologies is tributary to many uncertainties, having a high impact on the results. In this paper, a rapid visual screening (RVS) procedure to assess the seismic structural vulnerability is introduced. The proposed RVS procedure was applied for 335 buildings located in Bucharest, randomly selected from a database of buildings for which more complex seismic assessment methodologies were applied. Seven structural criteria having a high impact on the seismic vulnerability of the buildings were identified, based on the observations after the last destructive 1977 earthquake. These criteria were introduced in a scoring system to determine a general score that describe the seismic structural vulnerability. Based on the general score, each building was classified into a tentative seismic risk class, and after that the priority of a detailed seismic assessment and retrofitting was established. The RVS showed a matching coefficient of 0.71 for buildings with high risk of collapse and 0.81 for buildings with moderate risk of collapse in comparison with more complex seismic assessment methodologies applied for the same buildings. The main advantage if the RVS procedure is obviously that is implemented without performing any structural calculations. Although the RVS procedure is subjective, it could be converted into a rapid quantitative analysis which can prioritize the interventions upon the buildings, while financial constraints specific to the administrative domain exist.

**Keywords:** earthquake, masonry, risk, rapid visual screening, seismic assessment, retrofitting

### 1. INTRODUCTION

Bucharest, the capital city of Romania, with more than 2 million inhabitants, is considered as a natural disaster hotspot (World Bank, 1978, Bala, 2014 and Annesley et al., 2005). Therefore, it is classified as the second metropolis in Europe, after Istanbul, subjected to important losses in the case of a destructive Vrancea earthquake with moment magnitude greater than seven (Mândrescu et al., 2007, Mărmureanu et al., 2011, Patroescu et al., 2011 and Bala, 2014).

Four major earthquakes with moment magnitudes between 6.9 and 7.7 hit Bucharest in the last 68 years. The most recent destructive earthquake on March 4, 1977, with a moment magnitude of 7.4, caused the death of 1,424 people in Bucharest (90% of the total number of death at national level) and

the injuring of 7,598 people (68% of the total number of injured people at national level), (Fattal et al., 1977). As a consequence, the evaluation of the seismic vulnerability of the city represents a tremendous task requiring swift structural vulnerability assessment tools.

The seismic structural assessment of old, un-engineered, buildings using complex assessment methodologies is tributary to many uncertainties, having a high impact on the results (Pantea & Constantin 2013). Armas (2006) published a spatial vulnerability study for the city of Bucharest in which the buildings height and age are mainly used to assess the seismic physical vulnerability of the building stock. A new assessment and retrofitting code was published (MDRAP, 2013) prescribing complex seismic assessment methodologies, in line with the latest developments in seismic engineering worldwide

(Erdik et al., 2011). However, implementation of these methodologies requires experienced engineers and significant budget and time. A prioritization of the seismic assessment process taking into account the seismic structural vulnerability of the buildings is necessary to speed up this process.

Development of simplified assessment methodologies based on rapid visual screening (RVS) is useful in this respect (Kapetana & Dritsos, 2007). Based on the results of RVS, a prioritization of the seismic assessment and retrofitting process is possible. RVS is not intended to replace more complex seismic assessment methodologies in identifying the proper retrofitting strategy.

The need for seismic RVS was previously recognized in other earthquake prone countries worldwide. In United States, FEMA 154 report "Rapid Visual Screening of Buildings for Potential Seismic Hazards: A Handbook" was published first in 1998 and revised in 2002 (FEMA, 2002). FEMA 154 recognized 15 distinct structural types and 5 characteristics that strongly influence the seismic vulnerability of a given building: height, vertical irregularity, horizontal irregularity, year of construction and soil type. In Turkey, Sucuoğlu et al., (2007) published an improved RVS procedure based on the methodology published initially by Middle East Technical University. In Canada, the National Research Council published the Manual for Screening of Buildings for Seismic Retrofitting in 1993 (NRC, 1993). In Greece, the Earthquake Planning and Protection Organization published the technical document provisions for pre-earthquake vulnerability and assessment of public buildings (OASP, 2000). Most of these methodologies were based on the provisions of FEMA 154 report.

However, in each methodology different structural types and structural characteristics having high impact on the seismic vulnerability of the buildings were considered. Kapetana & Dritsos (2007) observed that the applied RVS procedures gave scattered results and the importance of calibrating the procedures on the characteristics of the building stock in a given area was recognized.

In RVS both the seismic hazard in a given site/area and the seismic structural vulnerability of the building should be considered. Implementation of a RVS procedure for Bucharest is advisable because a large number of buildings are confined in a relatively small area and the density of the building environment is relatively high. RVS can be successfully used to assess the vulnerability of the building stock to seismic action.

In this study, the following objectives were completed to propose a RVS procedure for the old,

un-engineered, building stock in Bucharest:

- *Identification of the existing structural typologies* most vulnerable to seismic action. Information available in the literature and past experience of the authors in structural vulnerability assessment of existing buildings were used;
- *Identification of the structural and architectural criteria that have a high impact* on the seismic structural vulnerability. Information regarding the seismic damage sustained by the buildings (mainly during the 1977 earthquake) were used;
- *Setting up a scoring system* based on the *typologies* and the *criteria* previously identified and calibration of this scoring system based on the results obtained using more complex seismic structural assessment methods on a large number of randomly selected buildings. Checking of the scoring system for a randomly selected range of buildings and confirmation of the proposed RVS procedure.

## 2. RVS SELECTED CRITERIA

The following *structural typologies* were identified (HAZUS, 2000, Lungu et al., 2002, Bostenaru-Dan, 2009, MDRAP, 2013) as common for the building stock in Bucharest, most vulnerable to seismic action:

- Masonry structures (unreinforced) with timber floors, steel joists and masonry composite floors or solid concrete floors – built mainly before 1920;
- Weak concrete frame structures with solid masonry walls-built mainly before 1945;
- Concrete structures with large precast wall panels-built in between 1960-1980;
- Concrete structures with cast-in-place shear walls-built mainly after 1980;
- Concrete frames structures-built mainly in between 1960-1992;
- Steel moment resisting frames, composite concrete-steel structures-built after 2000.

After the earthquake of March 4, 1977, a large number of buildings were destroyed or heavily damaged. The old masonry buildings, with or without concrete elements, sustained damage ranging from minor cracking of the masonry walls to total collapse. The following types of damage were largely identified in the post-earthquake inspection (Fattal et al., 1977): diagonal cracks in masonry piers and spandrels, shear cracks in columns and beams and spalling of concrete cover in concrete elements. The unsatisfactory behavior of old buildings was largely caused by the weak lateral strength and severely limited ductility, poor quality of the construction

materials, significant horizontal and vertical irregularities, presence of weak and flexible stories, lack of horizontal rigid diaphragms, pounding of adjacent buildings and discontinuous seismic load path. Usually, buildings being placed at the corner of the streets sustained more severe damage.

Based on the above observations the following *structural typologies* were selected in this research to be included in the RVS procedure for old, un-engineered, buildings:

- Masonry structures (unreinforced),
- Weak concrete frame structures with masonry walls (called “masonry and concrete” in the following),
- Concrete structures.

On the selected structural typologies, it is widely recognized that the below *building criteria* has a high impact on the seismic structural vulnerability:

- Horizontal regularity: the building was considered with a horizontal regular shape if it had symmetry (about two orthogonal axes) and compact shape with not important setbacks (set-backs area is less than 20% of the area enclosed by the convex polygonal line enveloping the main floor). As in many situations the horizontal shape of the building could not be determined just by side-walk inspection, available mapping on-line applications were used. Usual shapes of irregular buildings in Bucharest, as considered in this study, are presented in figure 1;
- Vertical regularity: a building was considered regular in elevation if it had no systematic setbacks, from one story to another. Examples of buildings with vertical irregularity, as classified in this study, are presented in figure 2. A building having only one set-back at the top story was considered regular;
- Building height expressed through the number of stories, *n*. Only the stories in the upper structure were counted. Considering their structural deficiencies, building were classified in 4 categories based on their height: very tall buildings ( $9 \leq n$ ), tall buildings ( $6 \leq n < 9$ ), middle-rise buildings ( $4 \leq n < 6$ ) and low-rise buildings ( $n < 4$ ).
- Architectural layout of the ground floor in comparison with the layout of the upper floors. During the side-walk inspection it was noted if the destination (functionality) of ground-floor is different from the other stories, (Fig. 3);
- Position of the building with respect to the adjacent buildings: independent building (having no interaction with other buildings), interior building (located between other similar buildings, not separated by a seismic joint, with high probability of interaction) or corner buildings (located at the

street corner or at the end of a buildings row, near an adjacent building, not separated by a seismic joint) (Fig. 4);

- Stiffness of the horizontal diaphragm: buildings with reinforced concrete slabs at each floor were considered as having rigid horizontal diaphragms, otherwise flexible diaphragms were considered. To determine the nature of the floor, swift access in the building was necessary. If concrete staircases were noticed than concrete slabs at each floor were assumed;
- Presence of oriel or bow windows: these types of windows were widely used in old buildings in Bucharest. Offsetting the masonry walls in the façades, outside of the building base, weakened the structural system and lengthens the seismic load path.
- Existing visible damage in piers and spandrels. As most of the buildings were not retrofitted after the 1977 earthquake, it was still possible to notice structural damage from side-walk surveys (Fig. 5);
- Visible local retrofitting of structural elements. During the side-walk inspection it was observed that some buildings have limited retrofitting work, such as jacketing of columns or masonry wall in the ground floor, indicating major seismic damage of those structural elements.

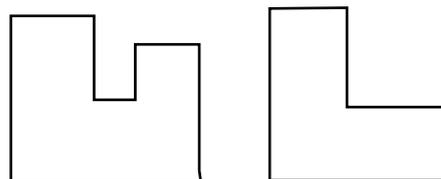


Figure 1. Common types of irregular horizontal configurations

Basically, seven criteria were selected in this study to determine the seismic structural vulnerability of an existing old, un-engineered, building by RVS. These were: structural typology, number of stories, structural irregularity, building interaction with other buildings (position of building), existing (observed) damage, architectural layout of the ground floor (in comparison to the upper floors), construction year, and presence of rigid diaphragm and presence of oriel or bow windows.

To determine the influence of each criterion, a simplified scoring system was introduced. A general score,  $R_{VS}$ , characterizing the seismic vulnerability of a given building, was calculated for each building as:

$$R_{VS} = 100 - \sum_{i=1}^7 \Omega_i \cdot R_i, \quad (1)$$

where:  $R_i$  and  $\Omega_i$  are score shares for each criteria  $i$ .



Figure 2. Vertically irregular concrete and masonry structures



Figure 3. Different architectural layout of the ground floor in comparison with the upper stories



Figure 4. Pounding of adjacent buildings



Figure 5. Earthquake damaged wall piers

### 3. SCORING SYSTEM

With the support of Bucharest Municipality, detailed seismic assessment was performed for approximately 750 buildings by different engineers since the 1990<sup>th</sup> (MLPAT, 1992). The initial purpose of this effort was to create a priority list for retrofitting of old damaged buildings in Bucharest (Lungu, 2009), (National Institute of Statistics, 2009). Each building was ranked in a seismic risk class (I, II, III or IV). According to the Romanian Seismic Assessment Code (MLPAT, 1992 and MDRAP, 2013), seismic risk class I represents the category of the buildings with high risk of collapse at the incidence of the next design earthquake. Buildings ranked as seismic risk class II have minor to moderate risk of collapse but major structural damage are expected. Buildings ranked as seismic risk class III presents low risk of collapse but moderate damage are expected.

The assessment results were published Bucharest Municipality (PMB, 2014). According to this large database, 372 buildings were classified as class I (high seismic risk), and urgent structural retrofitting was recommended for them. 302 were classified as class II (moderate seismic risk, extensive structural and non-structural damage being expected) and 75 were identified as having a minor seismic risk (class III). In this study, out of these 750 buildings, 335 randomly selected were inspected to calibrate the proposed scoring system.

An inspection form was used for each building to collect data regarding the structural vulnerability criteria previously listed. An inspection team consisting of two inspectors (civil engineers) with less than 2 years working experience performed the sidewalk inspections and collected the necessary data. For each building the inspection lasted between 15 and 20 minutes. Several photos were taken for each building. In some cases, access into the buildings was necessary to fill up the inspection form. Most of the inspected buildings were located in Bucharest city center (Fig. 6).

Based on the collected information, a database was created. For each inspected building, the seismic risk class obtained by detailed seismic assessment was recorded together with the data regarding the fulfillment of the seven structural vulnerability criteria identified in the previous paragraph. Comprehensive data filtering was performed to study the influence of each structural characteristic on the vulnerability of the buildings. The general score  $R_{VS}$  for all buildings was calculated using various values sets for the score shares,  $R_i$  and  $\Omega_i$ .  $R_i$  and  $\Omega_i$  were selected in such a manner to make the general score,  $R_{VS}$ , to range from 0 to 100. The final set of values for the score shares  $R_i$  and  $\Omega_i$  were selected to obtain the best match between

the results of the RVS procedure conducted in this study and the results of detailed assessment from the database published by the Bucharest Municipality. The selected  $R_i$  and  $\Omega_i$  values are given in table 1.

Based on this general score, a “Tentative Seismic Risk (TSR) Class” (I, II, III or IV) was assigned to each building. Ranges of the  $R_{vs}$  factors for each TSR Class proposed in this research are given in Table 2. Values presented in this table were calibrated considering a uniform seismic hazard for the city of Bucharest. They are not valid for other cities as the site conditions are not explicitly accounted in the scoring system.

#### 4. RESULTS

The proposed RVS procedure was applied for 335 buildings located in Bucharest, randomly selected from a database of buildings for which more complex seismic assessment methodologies were applied. The majority of the inspected buildings belong to the decay 1920-1960, with a number of floors between 4 to 8 (around 75%). A general score describing the seismic risk associated with a building was calculated by assigning a score share for each criterion.

Table 1 - Scoring system for RVS of existing buildings

i	Structural characteristic	$R_i$		$\Omega_i$	
1	Structural typologies: concrete-masonry, masonry or concrete	20	Masonry and concrete	$n < 6$	0.5
				$6 \leq n < 9$	0.75
				$9 \leq n$	1
			Masonry	$n < 4$	0.75
				$4 \leq n$	1
Concrete		0.5			
2	Structural irregularities: vertical or horizontal	20	Horizontal	0.75	
			Vertical	0.25	
			Horizontal and vertical	1	
			None	0	
3	Position in respect with other buildings	5	Corner	1	
			Interior	0	
			Independent	0	
4	Visible damage in structural elements	25	Visible damage	$n < 4$	0.4
				$4 \leq n < 6$	0.6
				$6 \leq n < 9$	0.8
				$9 \leq n$	1
			None	0	
5	Different architectural configuration of the first floor and/or presence of oriel or bow windows	10	Both	1	
			Just bow or oriel windows	0.5	
			Just different configuration	0.5	
			None	0	
6	Construction year, y	20	$y \leq 1940$	1	
			$1940 \leq y < 1950$	0.75	
			$1950 \leq y < 1963$	0.5	
			$1963 \leq y < 1977$	0.25	
			$1977 \leq y$	0	
7	Rigid horizontal diaphragm and/or local retrofitting of structural elements	-15	Both	1	
			Rigid diaphragm	0.67	
			Local retrofitting	0.33	
			None	0	

n - the total number of floors

Table 2 - Tentative assessment of the seismic risk by rapid visual screening – Bucharest

Tentative Seismic Risk (TSR) Class			
I	II	III	IV
High risk of collapse	Moderate risk of collapse, high damage expected	Low risk of collapse, moderate damage expected	Insignificant risk of collapse, low damage expected
$R_{vs}$			
$0 < R_{vs} \leq 40$	$41 < R_{vs} \leq 70$	$71 < R_{vs} \leq 90$	$90 < R_{vs} \leq 100$

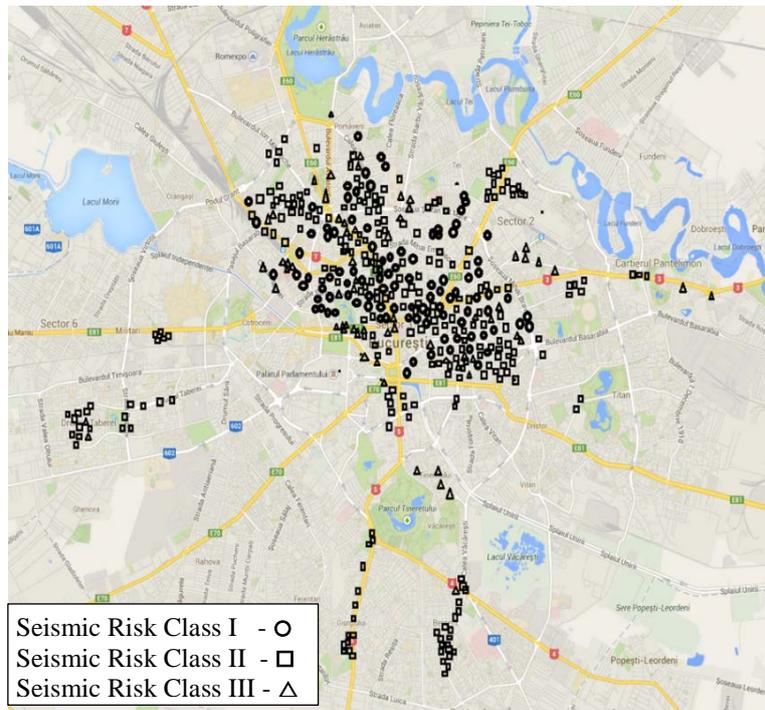


Figure 6 – Geographical distribution of the inspected buildings

Table 3 - Distribution of inspected buildings with respect to each vulnerability criterion

No of buildings for each criterion (% from total number of inspected buildings for each seismic risk class)	Structural typology			Horizontal diaphragm		Horizontal regularity		Elevation regularity	
	Concrete masonry	Masonry	Concrete	Flexible	Rigid	Regular	Irregular	Regular	Irregular
Seismic risk class I	45	53	1	53	47	30	70	61	39
Seismic risk class II	46	22	32	21	79	49	51	79	21
Seismic risk class III	56	21	23	12	88	63	37	86	14
No of buildings for each criterion (% from total number of inspected buildings)	Position of the building			Bow/oriel windows		Visible damage		Ground Floor Layout	
	Corner	Intermediate	Independent	Yes	No	Yes	No	Different from upper fl.	Same with upper floors
<i>Seismic risk class I</i>	59	16	24	43	57	62	38	32	68
<i>Seismic risk class II</i>	52	22	26	31	69	53	47	26	74
<i>Seismic risk class III</i>	51	19	19	19	81	9	91	39	61

The randomly selected buildings were used to calibrate the proposed scoring system. Based on the general score, each building was classified into a tentative seismic risk class, and after that the priority of a detailed seismic assessment and retrofitting was established.

With the proposed RVS procedure, we conclude that 34% of the 335 inspected buildings belong to TRS class I, 55% to TRS class II and 10% to TRS class III. According to the detailed seismic assessment made by

experienced engineers, for the same inspected buildings 34% were ranked as seismic risk class I, 44% were ranked as class II and 16% were ranked as class III. The RVS showed a matching coefficient of 0.71 for buildings with high risk of collapse and 0.81 for buildings with moderate risk of collapse in comparison with more complex seismic assessment methodologies applied for the same buildings. The main advantage of the RVS procedure is obviously that it is implemented without performing any structural calculations. The

RVS can be performed swiftly through a sidewalk survey. 15 to 20 minutes are required to fill up the inspection form for one building. Only limited access into the building is required. The inspection can be performed by un-experienced civil engineers or students. Advanced experience in seismic behavior of buildings is not required.

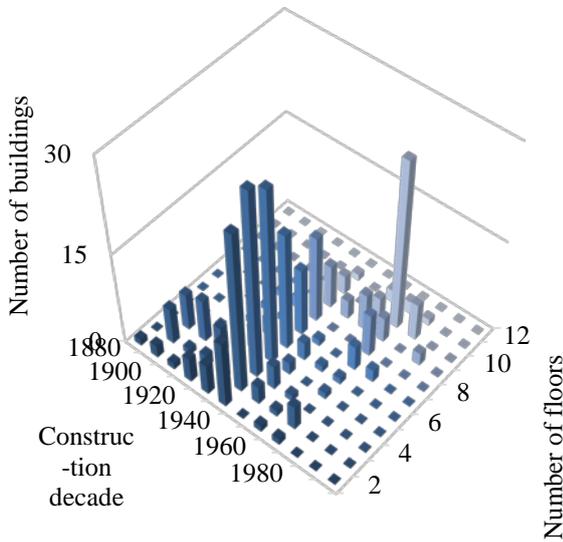


Figure 7. Distribution of inspected building with respect to the construction decade and number of floor.

### 5. CONCLUSIONS

A RVS screening procedure is necessary for the assessment of structural seismic vulnerability in

Bucharest and to prioritize the retrofiting process. RVS is intended as a preliminary analysis tool and not to replace more complex seismic assessment methodologies. The method, rapid visual seismic screening, although is subjective, it could be converted into a rapid quantitative analysis which can prioritize the interventions upon the buildings, while financial constraints specific to the administrative domain exist. The RVS procedure can be developed based on the existing database of seismic evaluated buildings, published by Bucharest Municipality. The available information regarding the damage sustained by the buildings after 1940 and 1977 earthquakes in Bucharest can be used to identify the vulnerabilities of the buildings stock.

The following structural and architectural criteria, having a high impact on the seismic structural vulnerability of existing buildings in Bucharest, were selected in this study: total number of floors, structural typology, structural vertical and horizontal regularity, height of the building, year of construction, type of horizontal diaphragms, presence of soft ground floor, presence of oriel or bow windows, exiting visible damages and/or local retrofitting of structural elements and position relative to other buildings. A general score describing the seismic risk associated with a building was calculated by assigning a score share for each criterion. Based on the general score, each building was classified into a tentative seismic risk class.

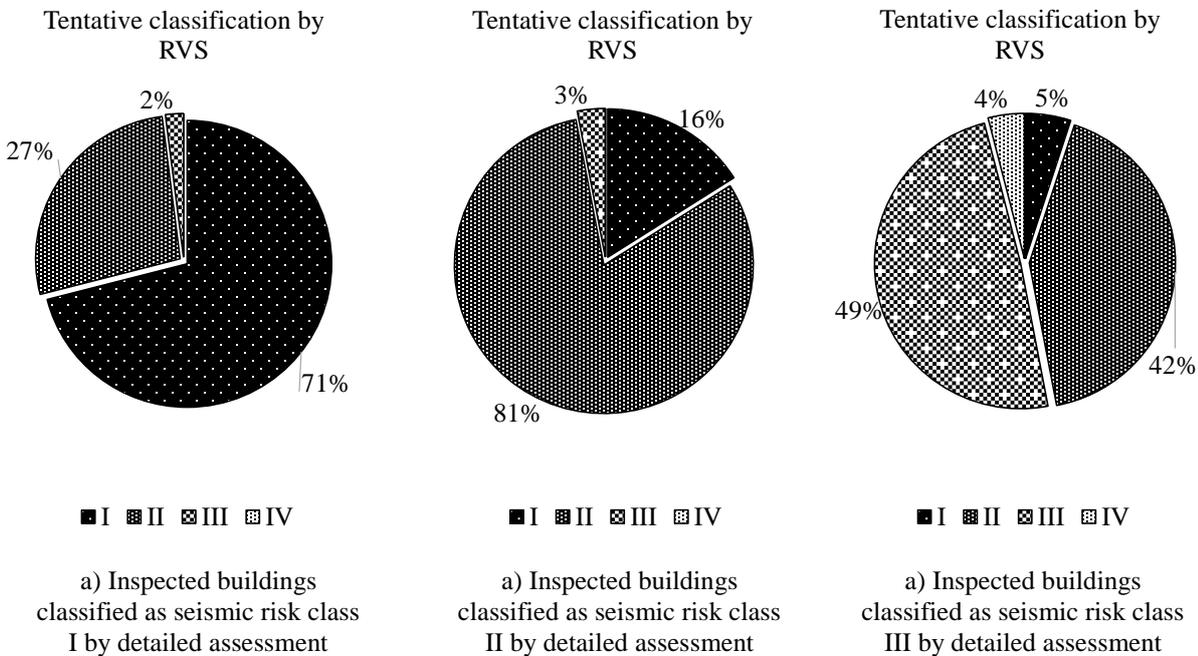


Figure 8 - Results comparison between the RVS and the detailed assessment

Based on this, the priority of a detailed seismic assessment and retrofitting can be established. RVS can be used to perform vulnerability studies for the building stock in Bucharest and to speed up the seismic evaluation and retrofitting in Bucharest by prioritization of the available resources.

RVS, as introduced in this paper, can be performed swiftly through a sidewalk survey. 15 to 20 minutes are required to fill up the inspection form for one building. Only limited access into the building is required. The inspection can be performed by unexperienced civil engineers or students. Advanced experience in seismic behavior of buildings is not required.

This study case represents just an exercise on the calibration of a RVS procedure for the building stock in Bucharest based on the available database of vulnerable buildings published by the Bucharest Municipality. Complementary efforts are required to include all buildings listed in the database, to reduce the matching distance and to improve the criteria for side-walk screening. The application of the proposed RVS is limited to three structural typologies.

Further research is necessary to include other typologies (for example, precast concrete panels) largely used in the past in Bucharest. The results of vulnerability studies performed by different authors for such buildings typologies can be used to calibrate the score shares.

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