APPLICATION AND COMPARISON OF TWO METHODS FOR THE ESTIMATION OF THE VULNERABILITY AND SEISMIC RISK OF HISTORICAL UN-REINFORCED MASONRY RESIDENTIAL BUILDINGS IN ALBANIA

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ABSTRACT

This paper discusses the vulnerability and seismic risk of historical unreinforced masonry URM buildings in Albania to earthquake-induced loads. Professionals have been using many methods to estimate the global and local structural capacity and performance of existing buildings. Non-linear methods are widely recognized and successfully applied even though they are relatively new and time-consuming. For a more practical and rapid evaluation of the need for structural consolidation of a large number of damaged buildings after strong earthquakes, two simplified methods can be used for the preliminary seismic evaluation of the structural capacity of buildings. In this research, the procedures used are described and the results of the application of these simplified methods in 11 minor existing residential buildings are shared. The first method is the FEMA P-154 method of evaluation of the probability of partial/total collapse. The second method is the Simplified Methodology by Dìaz Fuentes (2016), combined with the theoretical Principle of Virtual Works for the overturning of masonry panels. Both methods, it has been evaluated only the out-of-plane behaviour of masonry panels, as a mode of failure, since in-plane behaviour is strongly influenced by the level of compressive stresses. The comparison of results from the two methods shows that rapid evaluation methods are reliable for the preliminary selection of buildings, which might suffer partial/total collapse.

KEYWORDS: URM, seismic risk, vulnerability, hazard, rapid evaluation.

INTRODUCTION: CULTURAL HERITAGE STONE MASONRY BUILDINGS IN ALBANIA

After the strong earthquake of 2019, a lot of work should have been done in the direction of assessing the structural capacity of cultural heritage sites, damaged or not, but only a few months later the Covid-19 pandemic worsened the situation, forcing the focus to be directed from the above problem to a more urgent matter of global importance. Now, when we are living a "new normality", surely we as civil engineers need to return to such a delicate issue when it is known that Albania is in an area with high seismic risk, which is present at all times. The registry of cultural monuments in Albania consists of thousands of cultural monuments: castles, churches, mosques, castles, bridges and viaducts and minor buildings. Albania is located in the south-western part of the Eurasian Plate, convergent to the Adria Plate, therefore most of its territory and these cultural heritage monuments are located in areas of high seismicity. In the last decade, the public and private interest in the cultural

heritage has emerged and restoration processes took place or are ongoing in most of the historical centres and many buildings throughout Albania. A critical aspect of the restoration process is the structural consolidation and its components. Historically, the restoration process included common-sense interventions in how to improve the mechanical properties and global behaviour of buildings. Since they were firstly introduced in the 80s, modern numerical analysis with Finite Element Models, Discrete Element Models, and Frame Equivalent Models were widely used by structural engineers for the calculation of internal forces/stresses, deformations and building capacity. However, these modelling techniques need a lot of data and information about the building as input, professional expertise and powerful software to run the analysis. In addition, designers use this modelling when they have a defined scope of work and a design brief, assigned by the client. Therefore, buildings out of the interest of investors face the risk of neglect. To increase the awareness of the stakeholders and to improve the professional preliminary evaluation of these buildings, structural engineers can use different approximate methods. Federal Emergency Management Agency FEMA drafted the FEMA P-154 Data Collection Form. The form is based on the statistical analysis of fragility curves of 36 different types of buildings and has undergone different improvements over the years. On the other hand, another method is the Simplified Methodology proposed by Diaz Fuentes (2016), which can be used in combination with the Principle of Virtual Works; this method is quite simple and relies on the equilibrium equations of rigid bodies. Both of these methods can be applied for rapid screening and preliminary seismic evaluation of existing buildings. In this article, the two methods will be compared to check their accuracy when applied to the Albanian traditional minor buildings.

METHODS USED FOR THE SEISMIC EVALUATION OF THE URM BUILDINGS

Actual codes refer mainly to four types of analysis and procedures for the seismic analysis of existing Unreinforced Masonry URM buildings and modelling. They are widely used by structural engineers because of their reliable results on the seismic behaviour of structures during earthquakes. However, their greatest disadvantage is the time needed to build simplified models and the high level of expertise for the conversation between the real structure and the simplified model. In Tab. 1, are presented the respective advantage and disadvantages of these analyses, where being time-consuming is a minus for all of them. In addition, all of them require the aid of FEM modelling.

Tab. 1 Overview of different procedures for the structural analysis of existing buildings.

Type of analysis	Seismic forces distribution	Advantage	Disadvantage
Static linear analysis with lateral forces	Assuming a linear distribution of lateral seismic forces	Easy to use.	Simplified distribution of seismic loads. Time-consuming. FEM modelling.
Dynamic linear analysis with the response spectrum method	Assuming a modal shape distribution of lateral seismic forces	The most frequently used method is easy to use. Realistic evaluation of modal shapes and seismic forces.	Professional level of expertise. Time-consuming. FEM modelling.
Dynamic nonlinear analysis – Time History with accelerograms	Using the PGA accelerograms as input.	Precise calculation of internal forces, stresses and displacements during the timeframe of the selected earthquake.	High level of expertise. A lot of Time-consuming. FEM modelling.
Static nonlinear analysis – Pushover analysis	Assuming an incremental set of lateral static seismic forces to check the performance point for a defined seismicity level	Calculation of the global capacity of the building, taking into account the degradation of strength and stiffness of structural members.	High level of expertise. A lot of Time-consuming. FEM modelling.

FEM can be detailed either using the nonlinear shell and frame elements, but a simpler approach could be the equivalence of the wall piers and spandrels into nonlinear frame equivalent elements and then the conversation of the structural model to an equivalent single degree of freedom system (Fig. 1).

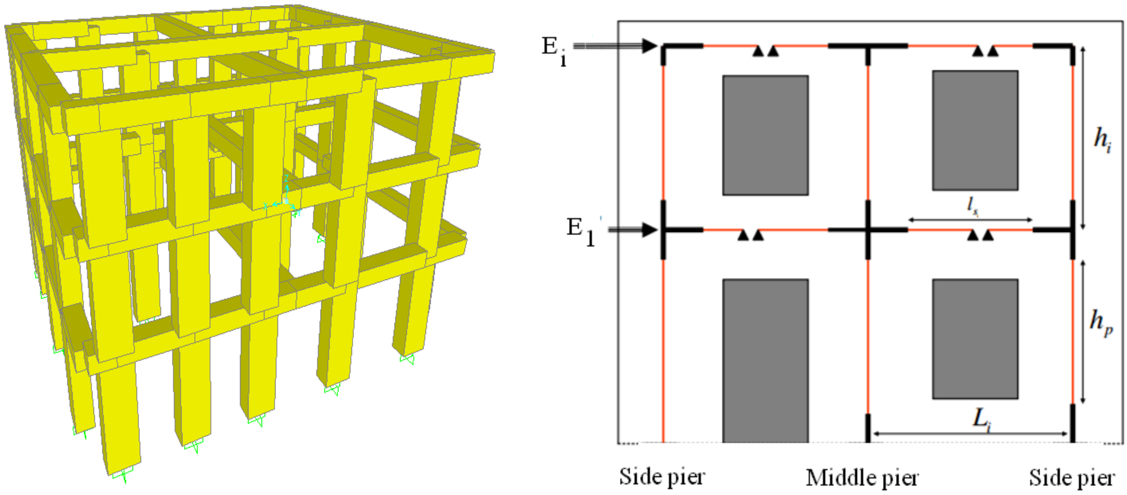


Fig.1 An example of frame equivalent modelling (on the left) and the scheme of equivalation (on the right).

There are a few nonlinear procedures, such as those described in ATC-40 and the N2 method adopted by Eurocode 8 (originally proposed by Fajfar and Fischinger, 1987). The principle of the nonlinear procedures consists of "pushing" the structure with a series of incremental horizontal forces to the yielding point of the structure, registering for every step the relationship between the roof displacement and the base shear (Fig. 2). Plotting this relationship in a two-axis graphic we obtain the so-called "pushover curve" or "capacity curve".

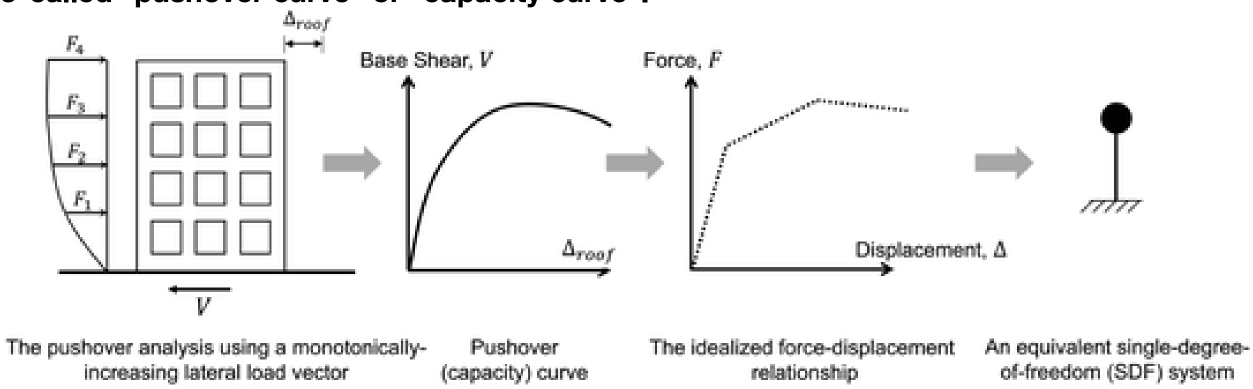


Fig.2 The basic conversion of a detailed structural model into an equivalent SDF system. (source: https://link.springer.com/chapter/10.1007/978-3-319-61914-9)

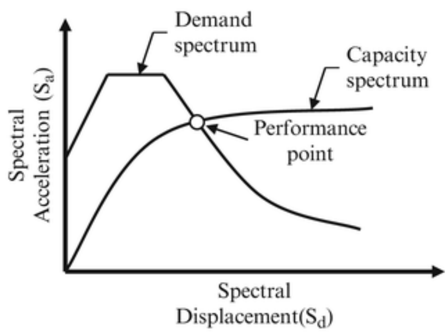


Fig.3 Determination of the Performance Point in the Acceleration-Displacement format.

The capacity curve is compared with the design response spectrum (demand curve) to determine the performance point (the point where the demand meets capacity), see Fig. 3.
Although these methods are the most accurate so far, they do not offer the possibility of quick structural screening or evaluations after large-scale earthquakes or before large-scale projects. In the aftermath of the earthquake of 26 November 2019 in Albania, there were carried thousands of inspections and naked eye screenings, without any numerical evaluation of the seismic risk. On the other hand, the scientific FEMA P-154 procedures were used successfully in 2017 by the authors of this paper, to determine the intervention scale and select the objects to intervene at the Vlora Historic Centre.

ANALYSIS OF VULNERABILITY WITH FEMA P-154 DATA COLLECTION FORM ANALYSIS

Federal Emergency Management Agency FEMA P-154 describes a simple and user-friendly procedure for the calculation of the collapse probability. It is based on the American HAZUS (2017) methodology. The HAZUS-FEMA P-154 methodology processes are three: a. determination of the target displacement for the calculation of a specified damage level, b. determination of the probability of total damage, and c. calculation of the probability of collapse for a determined probability of total damage. FEMA P-154 defines collapse probability as the probability that the building will suffer partial or complete collapse. The procedure for the determination of the collapse probability, in practical terms, consists of selecting score coefficients related to the statistical analysis of fragility curves of 36 different types of buildings. The three processes are shortly given below:

Process 1: Calculation of building's peak response (target displacement) Δ

The method consists of the calculation of the point intersection (performance point or target displacement) of the demand and capacity curves, represented in the Acceleration-Displacement AD format. Fig. 4 describes the logic of the determination of the performance point depending on the given ground acceleration and the building's capacity.

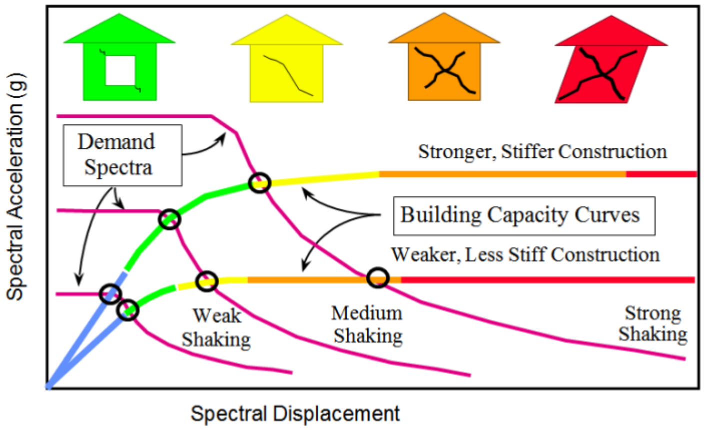


Fig.4 Performance evaluation for different structural types and ground motions.

On the other side, according to Fig. 4, the level of structural damage relates to the location of the Performance Point.

Process 2: Calculation of the Probability of Total Damage P

The HAZUS methodology consists of building fragility curves, which relate the probability of a given level of damage to the maximum spectral response (displacement or acceleration). FEMA P-154 is based on the Complete damage fragility curve, to determine the so-called Basic Scores and Scores Modifiers.

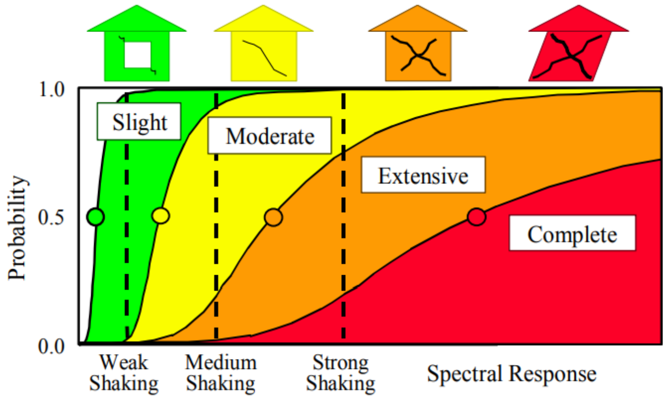


Fig.5 Relationship between the spectral responses and the probability of exceedance of a given level of damage.

Every fragility curve is defined by a median value of the demand parameter (in general spectral displacement) $S_{d,ds}$ that corresponds to the threshold of that damage state and by the total variability associated with that damage state. $S_{d,ds}$ is defined by the multiplication of the story drift ratio, Δd_s, of given damage, building height, H_R , and the ratio of modal parameters, α_2/α_3, where α_2 is the modal height factor and α_3 is the modal shape factor relating maximum-story drift and roof drift.
Median values of fragility curves are obtained by taking into account the results of laboratory testing of simple structural components or complex structural systems, a database of damages from earthquakes, and of course engineering common sense.

The median value of spectral displacement, S_d, of the Complete structural damage state is given by the following expression:

$$S_{d,C} = \Delta_C H_R(\alpha_2/\alpha_3) \quad \textbf{(1)}$$

Lognormal standard deviation values, $\beta_{s,ds}$, take into account the total variability of fragility-curve damage states. The total variability depends on the variability of the capacity curve, the variability of the demand spectrum, and the variability of exceeding the threshold of the damage state (capacity). Uncertainty due to the exceedance of the damage-state threshold is taken independent of the two types of uncertainty. On the other side, demand and capacity curve uncertainties are dependent on the elastic and plastic response of the building.
At this point, taking $S_{d,C}$ and $\beta_{s,C}$ in HAZUS and the peak response, Δ, the probability of complete damage is expressed as:

$$P[Complete\ damage] = \varphi\left[\frac{1}{\beta_{s,C}} ln\left(\frac{\Delta}{S_{d,C}}\right)\right] \quad \textbf{(2)}$$

Process 3: Calculation of the Probability of Collapse

After the calculation of the probability of complete damage, the collapse probability can be determined by multiplying the probability of complete damage with a collapse factor.

$P[\text{COL}] = P[\text{COL} \mid \text{Complete Damage}] \times P[\text{COL} \mid \text{Complete Damage}]$ **(3)**

where: $P[\text{COL} \mid \text{Complete Damage}] = \text{Collapse factor}$

HAZUS methodology provides collapse different factors for all Model Building Types. It is obvious that the collapse factor is small for building types, which do not have significant risks of collapse, and larger for building types, which are at higher collapse risk, e.g. unreinforced masonry.

ANALYSIS OF RISK ASSESSMENT WITH THE SIMPLIFIED METHODOLOGY (DÌAZ FUENTES, 2016; D'AMATO ET AL., 2018) – WITH THE APPLICATION OF THE PRINCIPLE OF VIRTUAL WORK FOR THE CALCULATION OF THE SEISMIC VULNERABILITY

Recently, D. Fuentes has proposed a simple methodology based on a three-step procedure (2016), for the seismic evaluation of historical churches, which is extended and proposed to residential buildings as the purpose of the study. Each of the steps (namely Tool 1, 2 and 3) consists of the determination of score coefficients related to Hazard (H), Vulnerability (V), and Economical Value (E). Then the coefficients can be multiplied to find the Seismic Risk by the expression 4 (UNDRO 1979, FEMA 2004):

$\text{R} = \text{H} \times \text{V} \times \text{E}$ **(4)**

Each of the Tools is described shortly below; however, in addition to the three Tools, two more processes are proposed by the authors of this article in order to express the seismic risk as a collapse probability, comparable with the FEMA 154 outputs.

Tool 1: Determination of the Economical Value/ Exposure towards risks

Expresses the cultural value from both the economical and historical viewpoint. In this study, the parameter E was assumed as one; for consistency, the same value has been applied when using FEMA 154 rapid screening procedure. Therefore, equation (4) becomes:

$\text{R} = \text{H} \times \text{V}$ **(5)**

Tool 2: Calculation of the hazard with the principle of virtual work

Hazard is defined as what level of an earthquake (or any other natural event) is expected due to potential future seismic events (plus possible other major forces). Since the determination of hazard means the evaluation of the potential and gravity of the buildings to damage, it is necessary the identification of possible damage mechanisms, which in terms of masonry structures are related to the loss of equilibrium of masonry panels. For this purpose, the Principle of Virtual Work has been used throughout history for the analysis of rigid bodies and statics. This principle states that: "when a rigid body that is in dynamic equilibrium is subject to virtual compatible displacements, the total virtual work of all external forces and moments is zero; and contrarily if the total virtual work of all external forces and moments acting on a rigid body is zero then the body is in dynamic equilibrium". For the identification of failure mechanisms (vulnerability), the method FaMIVE (Failure Mechanisms Identification for Vulnerability Evaluation) was developed (D' Ayala and Speranza 2004), Fig. 6. This method depicts the possible failure mechanisms of load-bearing walls of masonry buildings, including partition walls.

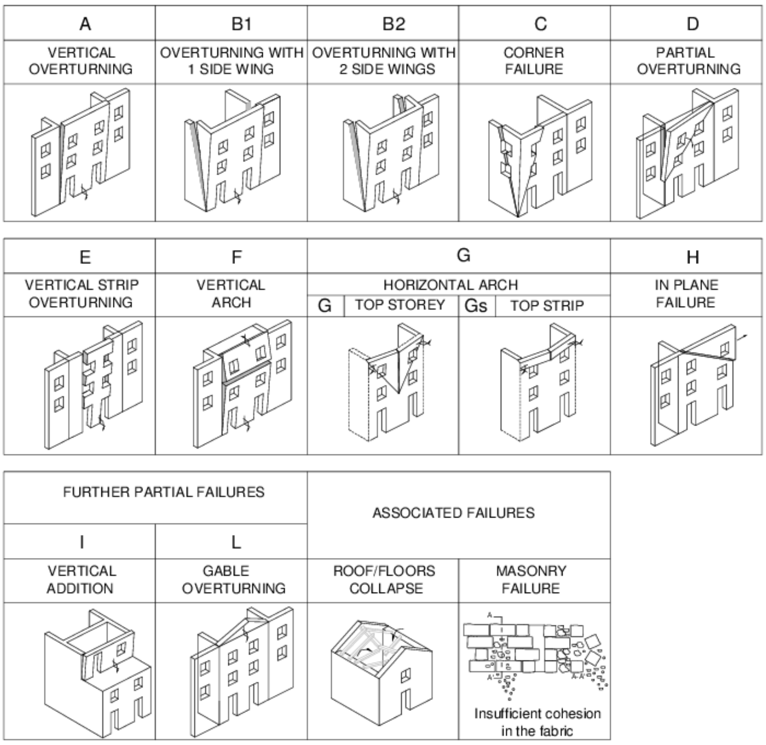


Fig.6 FaMIVE failure collapse mechanisms (D' Ayala and Speranza 2003).

The Italian code NTC 2018, describes an algorithm to check the out-of-plane overturning, as a factor which contributes to the total collapse of the building. The algorithm given below is a 6-steps procedure based on FaMIVE, which takes into account the formation of hinges at each storey level.

Step 1: Calculation of the collapse factor

$$\sum_i^n M_{S.i} = \sum_i \alpha \cdot M_{R.i} \qquad \textbf{(6.1)}$$

$$\alpha = \frac{M_{S.1}+M_{S.2}-M_{R.3}}{M_{R.1}+M_{R.2}} \qquad \textbf{(6.2)}$$

Step 2: Calculation of virtual displacements

Assuming a linear deflection of the wall against overturning (as a rigid body), a unit displacement is applied to the top of the wall. As a result, we can get the proportional relative virtual displacements for any horizontal load.

$$\delta_1 : H_{tot} = \delta_i : H_i \qquad \textbf{(6.3)}$$

$$\delta_1 = \frac{1 \cdot H_1}{H_{tot}} \qquad \textbf{(6.4)}$$

Step 3: Calculation of the participating mass

$$M^* = \frac{[\sum_i P_i \cdot \delta_i]^2}{g \cdot \sum_i (P_i \cdot \delta_i^2)} \qquad \textbf{(6.5)}$$

Step 4: Calculation of the participating mass ratio

$$e^* = \frac{g \cdot M^*}{\sum_i (P_i)} \qquad \textbf{(6.6)}$$

Step 5: Calculation of spectral acceleration

$$a^* = \frac{\alpha \cdot g}{e^*} \quad \textbf{(6.7)}$$

Step 6: Ultimate Limit State check against overturning

The following equation should be satisfied, for the overturning not to happen.

$$a^* \geq \frac{\alpha_g \cdot g \cdot S}{q} \cdot \left[1 + 1.5 \cdot \frac{Z}{H_{tot}}\right] \quad \textbf{(6.8)}$$

Z – is the level of weights (mass centre), and which is calculated as follows:

$$Z' = \frac{\sum_i P_i \cdot Z_i}{\sum_i P_i} \quad \textbf{(6.9)}$$

i – is the number of storeys above hinged level, and

Z_i – is the vertical distance of the i-force from the hinged storey

$$Z = \sum_j H_j + Z' \quad \textbf{(6.10)}$$

j – is the number of stories below the hinged storey

H- is the height of j-storey

a_g – unit less peak ground acceleration.

S – Soil amplification factor

q - is the behaviour Factor of the structure

It is obvious that the possible damages resulting from the application of the 6-steps procedure produce the Collapse or non-collapse results, for a given Peak Ground Acceleration a_g of the site. However, the Collapse situation should be carefully judged with the engineering common sense if it falls in the Middle Damage or Catastrophic Damage area of the Hazard Evaluation Chart below (Tab. 2).

Tab. 2 Hazard Evaluation Chart: Determination of coefficients of the seismic hazard hi.

Parameters		**Damage gravity**		
Sporadic events		Absence of damage	Middle damage	Catastrophic damage
	Earthquake and tsunami threat	0	0.2	0.4
	Landslides	0	0.15	0.25
	Volcanic threat	0	0.2	0.4
	Hydro-methodological threat	0	0.15	0.25
	Chemical-technological threat	0	0.15	0.25
	Forest fires	0	0.15	0.25
Continuous events	Erosion threat	0	0.05	0.1
	Physical stress or threat	0	0.05	0.1
	Air pollution	0	0.01	0.05
	Socio-organizational threat	0	0.01	0.05
	Demographic decline	0	0.01	0.05

After selecting the Hazard coefficients, the H value is then calculated as:

$$H = \sum_i h_i \quad \textbf{(7)}$$

Tool 3: Calculation of the seismic Vulnerability

The vulnerability of a structure is defined as a numerical evaluation of possible damages to the structure for a given hazard level. The vulnerability is associated only with the seismic activity, in contrast to Hazard, which is not limited only to seismicity, but even to other natural forces.

Table 3 Vulnerability Evaluation Chart: Determination of the vulnerability coefficients.

	Parameters	Class (v_i)				Weight p_i
		A	B	C	D	
1	Position of the building and foundations	0	1.35	6.73	12.12	0.75
2	In-plane configuration	0	1.35	6.73	12.12	0.50
3	In-elevation configuration	0	1.35	6.73	12.12	1.00
4	Distance among walls	0	1.35	6.73	12.12	0.25
5	Non-structural elements	0	1.35	6.73	12.12	0.25
6	Resistant system type and organization	0	1.35	6.73	12.12	1.50
7	Resistant system quality	0	1.35	6.73	12.12	0.25
8	Floors	0	1.35	6.73	12.12	1.00
9	Roofs	0	1.35	6.73	12.12	1.00
10	Conservation state	0	1.35	6.73	12.12	1.00
11	Environmental alterations	0	1.35	6.73	12.12	0.25
12	Construction system negative alterations	0	1.35	6.73	12.12	0.25
13	Fire vulnerability	0	1.35	6.73	12.12	0.25

As it can be noted, structures are divided into four categories having different scores and weights for the calculation of V with the formula:

$$V = \sum_i v_i \times p_i \qquad \textbf{(8)}$$

Process 4: Calculation of the seismic Risk

After the evaluation of H and V, the formula can be used to evaluate the seismic risk However, Diaz Fuentes (2016) and D'Amato et. al. (2018) proposed that the expression should be modified to have a resulting score higher than 1. Therefore, the expression is modified to:

$$\mathrm{R} = (\mathrm{H} + 1) \times \mathrm{V} \qquad \textbf{(9)}$$

Process 5: Calculation of the collapse probability

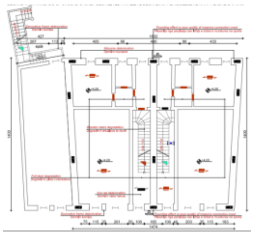
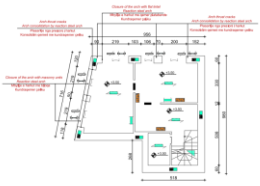
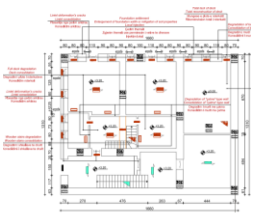
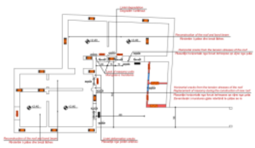
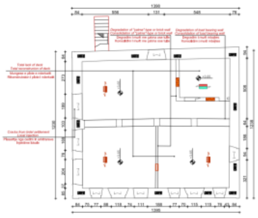
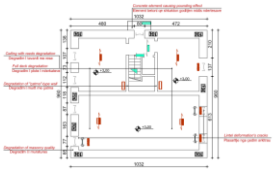
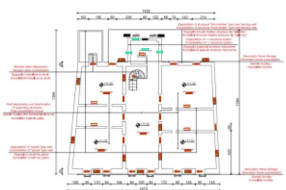
After the evaluation of the Hazard H and Vulnerability V, the seismic Risk can be associated with the probability of collapse as the ratio between the actual calculated seismic Risk to the maximum value of Risk. Therefore, we can write the expression:

$$P[\mathrm{COL}] = R/R_{max} \qquad \textbf{(10)}$$

ANALYSIS OF THE ACCURACY OF THE TWO METHODS

The authors of this paper have been part of the structural consolidation project of the objects located in the Vlora Historic Centre. Both methods were applied for the preliminary selection of the buildings, which would have undergone structural consolidation, with the intention of getting the most accurate evaluation. We have assumed the unit value of E=1 for both methods. Tab. 4 is given a short structural description for each of the objects, for a better understanding of the performed vulnerability assessment.

Tab. 4 Description of the building assessed with the two methods.

Object Code	Photography	Drawing plan	Structural description
B.O.2			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Good Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O. 6			No. of stories: 2 Plan irregularity: Yes Height irregularity: No Past damage from earthquakes: No Conservation state: Good Rigid Diaphragms: Yes Existing tie rods: No Past structural restoration: Yes
B.O.10			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: Conservation state: Very bad Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.12			No. of stories: 1 Plan irregularity: Yes Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.13			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Very bad Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.17			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.31			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No

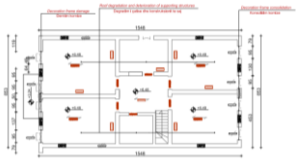
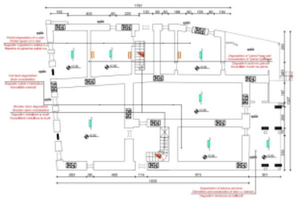
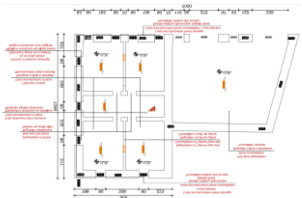
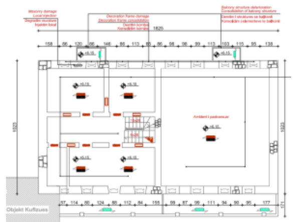
B.O.32			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.34			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.41			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: No Conservation state: Poor Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No
B.O.43			No. of stories: 3 Plan irregularity: No Height irregularity: No Past damage from earthquakes: Conservation state: Good Rigid Diaphragms: No Existing tie rods: No Past structural restoration: No

Table 5 Determination of the vulnerability coefficients.

Code of the object as per the Masterplan of Vlora Historic Ensemble	**Probability of collapse for the Maximum Considered Earthquake MCE**			
	Probability of partial/total collapse as per FEMA P-154 Data Collection Form – Probability 2% in 50 years ($a_{g,R}$=0.52g)	**Probability of partial/total collapse calculated with the Simplified Method PVW, 2% in 50 years ($a_{g,R}$=0.52g)**		
		Vulnerability Score	Hazard Score	Risk Probability
B.O.2	31%	34.61	0.82	20%
B.O. 6	12%	24.91	0.82	14%
B.O.10	63%	47.79	1.02	31%
B.O.12	63%	49.81	1.10	33%
B.O.13	50%	43.75	1.12	30%
B.O.17	25%	43.75	0.82	26%
B.O.31	27%	44.42	1.02	29%
B.O.32	26%	44.42	1.02	29%
B.O.34	40%	44.42	1.02	29%
B.O.41	63%	47.11	0.92	27%
B.O.43	31%	47.11	0.82	21%

Tab. 5, gives an overview of the calculated probability of collapse of 11 buildings, for a very rare earthquake, the Maximum Considered Earthquake (MCE) has a probability of exceedance of 2% in

50 years (or a return period of 1000 years for buildings of cultural heritage importance). It is obvious that the probabilities of collapse determined with FEMA are almost equal to (B.O.6, B.O.7, B.O.17, B.O. 31, B.O. 32) or higher (B.O.2, B.O. 10, B.O. 12, B.O. 13, B.O. 34, B.O. 41, B.O.43) than those determined with the Simplified Methodology.
Tab. 5 results are presented also in Fig.7, where it can be clearly seen that the difference is larger for the object coded B.O.10, B.O.12, B.O.13 and B.O.41. The common of all these objects is the lack of a roof and damage to floors and retaining walls due to rainwater penetration. The conservation state of the building shows that there is an underestimation of the vulnerability coefficients related to the conservation state.
Fig.7 is presented the comparison between the Risks and Vulnerability scores of the Simplified Methodology.

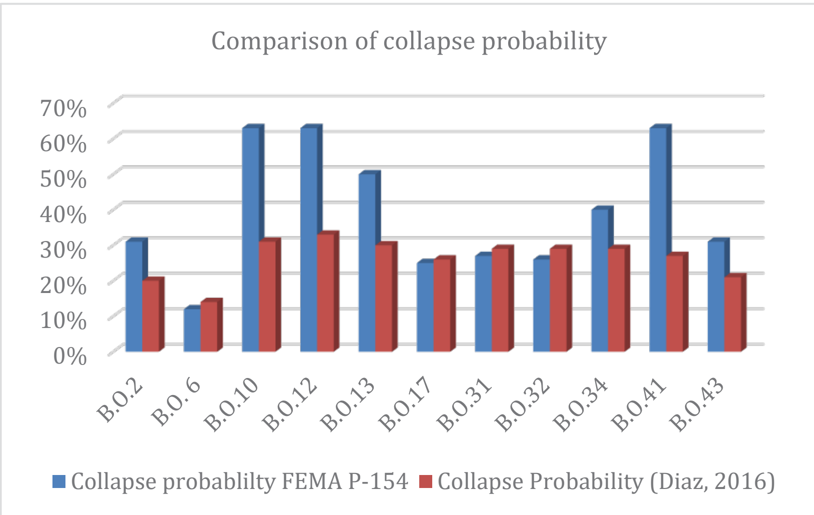


Fig.7 Comparison of collapse probabilities of FEMA P-154 and Simplified Methodology (Diaz, 2016).

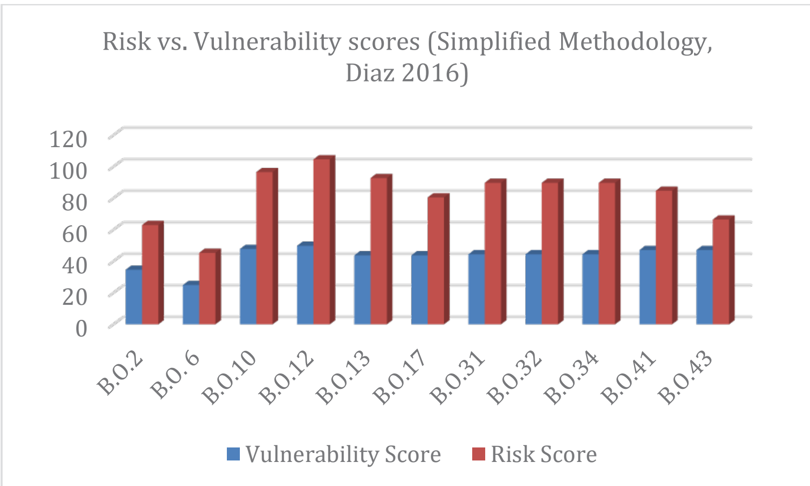


Fig.8 reveals how the vulnerability parameters affect the Risk score, compared to the Vulnerability score, which depends mainly on the damage gravity due to sporadic events.

CONCLUSIONS

Both methods are very helpful tools in the hand of designers, especially in the first steps of design. FEMA P-154 provides higher values of collapse probabilities for heavier damaged buildings. The

Simplified Method (Diaz, 2016) is more time consuming and requires the help of the application of the principle of Virtual works, in comparison to FEMA which just follows scoring with coefficients. However, the two methods can be successfully applied not only in large-scale projects but also in individual buildings and procedures are independent of the building size or type.
Even though the results are accurate for the preliminary evaluation of the buildings under consideration, a further detailed structural analysis should follow. In addition to the conventional linear or nonlinear analysis described above, a procedure intended to be used for the quick estimation and calibration of the results of this study is the methodology SPO2IDA, which consists of the application of the incremental dynamic analysis IDA in SDOF systems, and then building of the fragility curves to determine the seismic risk.

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