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A simplified procedure for seismic risk assessment of masonry school buildings

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ABSTRACT

Seismic risk assessment of school buildings is a problem of particular relevance in Italy, as most of them were not designed using anti-seismic criteria. Seismic risk evaluation of these buildings should account for seismic hazard, structural vulnerability and exposure, the latter being particularly significant. In the last decades, to this aim, many methods have been introduced, which differ from each other by the refinement of the applied methodology of analysis. At national level, in order to provide a contribution to solve this problem, a specific database called “Sistema Nazionale delle Anagrafi dell’Edilizia Scolastica (SNAES)” has been developed, it consisting of a census of all existing school buildings in terms of consistency, degradation state and functionality. In this paper, starting from the existing methods and considering the parameters and the information actually present in the school building files of SNAES, the possibility to adopt a simplified methodology for assessing the seismic risk of masonry schools is analyzed with reference to the school of the Caserta Province.

1 INTRODUCTION

The Italian school building heritage as well as most of the public structures are "historical" and therefore characterized by various issues, in particular related to structural safety in case of earthquake events. From the data emerged by a recent analysis, more than 63% of buildings, in fact, were built before 1975 and often require urgent maintenance (46.8% of the sample) (XIX Rapporto di Legambiente sulla qualità dell’edilizia scolastica, delle strutture e dei servizi, 2018). Moreover, this building heritage does not comply with safety standards imposed by seismic regulations. More than 41% of the school buildings are located in highly prone seismic areas (namely seismic zone 1 and 2). It is highlighted that only 14.2% of all the structures are designed according to seismic criteria and the seismic structural vulnerability has been produced on 32.9% of the sample. Analyzing the funding lines of the last five years, it appears that only 4.4% of the interventions concerned the seismic upgrading or energy efficiency of buildings located in seismic areas, with a consequent estimated timeline that could allow the achievement of security goal for all the school buildings in more than 100 years. This long time, obviously, is not compatible with social needs.

Also for this reason, an instrument called “Sistema Nazionale delle Anagrafi dell’Edilizia Scolastica” (SNAES) has been proposed at national level. It is still incomplete and inaccurate, and therefore unable to provide effective information for the buildings safety. In order to improve such a system, in Regione Campania, a specific research project named “Potenziamento e analisi critica dell’Anagrafe dell’Edilizia Scolastica della Regione Campania” has been developed in 2018 launched, aiming at increasing the dissemination of the tool among provinces and municipalities (De Matteis et al. 2018).

2 THE SCHOOL BUILDING HERITAGE IN THE CASERTA DISTRICT

The school building heritage of the province of Caserta, but the situation is similar at national level, is characterized by various critical issues. It is possible to have a clear picture of the situation by the “Sistema Nazionale delle Anagrafi dell’Edilizia Scolastica” (SNAES), which has been activated on 1st December 2014, although it had already been introduced in 1996 (Norme per l’edilizia scolastica, Legge 11 gennaio 1996, n. 23). It consists in a digital platform, which is continuously updated by filling in appropriate forms information on the functionality and conditions of the building.

Starting from the 780 school buildings located in the territory of Caserta (information reported on the SNAES and updated to October 2018), the sample analyzed in this paper is composed by only 141 school buildings characterized by a masonry structure, which represents about the 18% of the stock of the buildings. A similar analysis has been previously referred to reinforced concrete school buildings and is reported in De Matteis et al. (2018).

Seismic risk evaluation of a building requires the assessment of three fundamental factors: vulnerability, hazard and exposure. Therefore, in the following paper it is investigated the possibility to define a speedy methodology for the seismic risk assessment based on the following main tasks:

1) Identification of the main features of the building to characterize the structural vulnerability;
2) Simplified assessment of exposure and hazard.

3 SEISMIC VULNERABILITY ASSESSMENT

3.1 General

In existing literature, there are specific methods for seismic vulnerability assessment of existing buildings, which can be grouped into two main categories. The first one is characterized by adopting a semi-empirical statistical-observational approach (Zuccaro and Cacace 2007, Zuccaro and Cacace 2015, Dolce et al. 2004), which is essentially based on the detection of building performance especially after significant earthquakes. By observing the behavior of existing buildings, a number of vulnerability factors may be defined, which are differentiated for masonry and reinforced concrete buildings. Starting from these vulnerability factors, taking into account their different influence on the seismic response of the buildings, global indices, based on semi-empirical formulations of vulnerability as function of seismic intensity, can be introduced.

The second category is referred to the adoption of more refined analytical approaches, such as the direct evaluation of seismic capacity of a single building or groups of buildings (Dolce and Moroni 2005, Gattesco et al. 2012). Obviously, even if they are more reliable, they require, however, a more specific knowledge of the construction, including geometrical and mechanical parameters.

In this paper, a simplified method related to the first category (observational based method) has been developed, based only on the data included in the S.N.A.E.S. forms. This methodology has been subdivided into the three main steps described in the following.

3.2 Vulnerability assessment – step 1

The seismic vulnerability of a building is a measure of the possible damage occurred by an earthquake with a predefined seismic intensity. Therefore, it is related to the intrinsic structural capacity of the building itself. With reference to the examined sample made up of 141 masonry school buildings, a preliminary vulnerability assessment was conducted based on a rapid methodology present in the literature, which is based on the use of a classification matrix which considers only two data, namely the structural resisting system and seismicity level (Di Pasquale et al. 2000).

According to this matrix, which represents the first step of the vulnerability assessment, it is possible to assign to each building one among 5 different vulnerability classes, as provided in Figure 1: High (H); Medium-High (MH); Medium (M); Medium-Low (ML); Low (L).

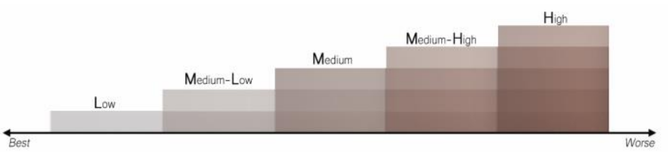

Figure 1. Vulnerability assessment: step 1

In order to account for both the horizontal and vertical structural systems, Table 1 has been assumed to associate the basic vulnerability class to the examined structure for traditional buildings and Table 2 for monumental buildings.

Table 1. Definition of basic seismic vulnerability classes of traditional masonry buildings.

STRUCTURAL HORIZONTAL SYSTEM	STRUCTURAL VERTICAL SYSTEM			
	Mixed masonry - r.c. structures	Sack masonry	Bearing masonry	Tufa masonry
Vaulted structures	MH	M	ML	ML
Wooden slabs	M	MH	M	M
Steel slabs	M	MH	M	M
Reinfoced concrete slabs	M	MH	MH	M

Table 2. Definition of basic seismic vulnerability classes of monumental masonry buildings.

STRUCTURAL HORIZONTAL SYSTEM	STRUCTURAL VERTICAL SYSTEM			
	Mixed masonry - r.c. structures	Sack masonry	Bearing masonry	Tufa masonry
Vaulted structures	MH	M	ML	ML
Wooden slabs	M	MH	M	M
Steel slabs	M	MH	M	M
Reinfoced concrete slabs	M	MH	MH	M

The first matrix shows that the most vulnerable buildings, corresponding to those in the first and second line, are characterized by vaulted structures and wood slabs. It is apparent that the seismic vulnerability of buildings decreases passing from the first column to the last one and from the first line to the last one. This aspect is due to the fact that the last structural vertical and horizontal systems are typically characterized by more accurate technical solutions.

3.3 Vulnerability assessment – step 2

Once basic seismic vulnerability has been assessed by the Table 1 and Table 2, in order to refine the obtained basic classification, additional criteria are considered to either modify or confirm the vulnerability class deduced by Tables 1 and 2. Such additional criteria have been established based on the information included in the SNAES forms (conservation status, designed forces considered at the time of construction and changes that these have undergone over time, number of floors, age of construction, planimetric and elevation regularity,… etc.). For each of these parameters, a specific score is provided. Furthermore, three different intervals have been defined so that the sum of the scores obtained considering all the parameters can determine the effect on the previous vulnerability classification by having:

- a positive class change (increase of vulnerability);
- no class change;
- a negative class change (decrease of vulnerability).

The selected additional parameters that can influence the vulnerability of the building are the following:

1. Seismic zone; if the building is located in a territory whose seismic classification has changed since it was built, it will be more vulnerable, as it has been designed without taking into account the current earthquake hazard. The actual seismic zone has been considered referring to O.P.C.M. n° 3274/2003.
2. Number of structural storeys; higher buildings are more vulnerable, as they are subjected to seismic amplification at upper storeys.
3. Type of roofing system; this parameter is considered only in terms of morphology (flat, pitched, mixed): in fact, in the SNAES forms, any additional technical information is provided.
4. Type of interventions 1; in this classification are included interventions of: increment of plan, superelevation, restructuring and extraordinary maintenance. Except for the first two, which can lead to an increase of seismic vulnerability if not realized correctly, the structural improvement made by restructuring or maintenance interventions can contribute to reduce the seismic vulnerability.
5. Conservation status of vertical bearing structures and masonry, slabs, stairs and

roofing; the conservation state of structural elements may significantly influence the vulnerability of a building;

6. Age of construction; this parameter reflects the development of construction techniques, according to the technical code requirement, and, starting from a preliminary classification (Calderoni et al. 2017), four different intervals have been defined;
7. Planimetric configuration; each building is classified according to the ratio B/L and to the projections on each side;
8. Altimetric configuration; this parameter takes into account the regularity of stiffness, masses and the distribution of the openings for each storey.

The table was organized in such a way that, for each of the above parameters, 4 different conditions are identified, which are characterized by a different and decreasing effect on seismic vulnerability, passing from class I to class IV. Moreover, for each parameter, a "weight" has been associated to take into account the different importance on the global seismic structural behavior of the building. A summary scheme of the conditions defined for each parameter is provided in Table 3. In such a table, it is clear that buildings characterized by higher vulnerability are those having the above parameters classified in "Class I", while a lower vulnerability is associated to parameters classified in "Class IV".

In order to provide a quantitative measure to the above additional parameters, a specific numerical coefficient has been associated to each vulnerability class, as shown in Table 4. Such numerical coefficients have been assigned in such a way to define numerical intervals that allow to establish a positive or negative class change.

By applying Table 4, the lower and upper limits of the vulnerability parameter (P_V), given by the sum of the products of the coefficients of the "class" column multiplied by the corresponding "weight" are -6,00 and +36,90, respectively.

Such a range has been normalized in order to have a variation range of the vulnerability parameter (P_V) [0; 1]. Within such a range, the parameter P_V should be in the interval (0,29 ÷ 0,45) in order to do not have any variation of vulnerability classes. Therefore, the following situation has been defined (Figure 2):

- If P_V ϵ [*0; 0,29*[the building makes a negative class change (decrease of vulnerability);
- If P_V ϵ [*0,29; 0,45*] the building does not make any vulnerability class change;
- If P_V ϵ]*0,45; 1,00*] the building makes a positive class change (increase of vulnerability).

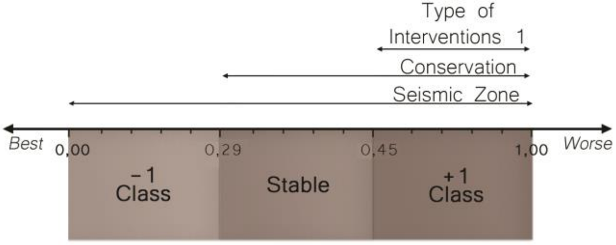

Figure 2. Vulnerability assessment: step 2

3.4 *Vulnerability assessment – step 3*

The vulnerability class obtained in the previous step can be further modified only in presence of structural interventions included in a specific category named “Type of interventions 2”. This parameter contains seismic interventions as: upgrading, improvement and local repair, aimed at increasing the seismic structural capacity and, therefore, reducing the seismic vulnerability. The following assumptions have been made (Figure 3):

- In case of seismic local repair intervention, the building undergoes a class change obtaining a minimum vulnerability class M;
- In case of seismic improvement interventions, the building undergoes a class change obtaining a minimum vulnerability class MB;
- In case of seismic upgrading interventions, the building undergoes a class change obtaining a vulnerability class B.

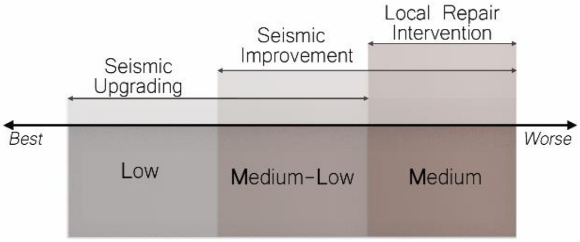

Figure 3. Vulnerability assessment: step 3

Table 3. Vulnerability conditions and weights related to each additional parameter.

Parameter	Vulnerability conditions				Weight
	Class I	Class II	Class III	Class IV	
Seismic zone	Actual seismic zone increases of three classes compared to the classification of the construction period	Actual seismic zone increases of two classes compared to the classification of the construction period	Actual seismic zone increases of one class compared to the classification of the construction period	Actual seismic zone equal to the classification of the construction period	3,00
Number of structural storeys	N.4	N.3	N.2	N.1	1,00
Type of roofing system	Pitched	Mixed	Plane	X	1,00
Type of interventions 1	Enlargement / superelevation	No intervention	Extraordinary maintenance	Renovation	1,00
Conservation status: vertical bearing structures and masonry	Requires total replacement	Requires partial replacement	Requires maintenance	No intervention necessary	0,80
Conservation status: slabs	Requires total replacement	Requires partial replacement	Requires maintenance	No intervention necessary	0,80
Conservation status: stairs	Requires total replacement	Requires partial replacement	Requires maintenance	No intervention necessary	0,80
Conservation status: roof	Requires total replacement	Requires partial replacement	Requires maintenance	No intervention necessary	0,80
Age of construction	Before 1900	From 1901 to 1937	From 1938 to 1960	After 1961	0,50
Planimetric configuration	Irregular [B/L>4]	Almost irregular [all projections >25%]	Almost regular [at least one projection <25%]	Regular [B/L<4]	0,80
Elevation configuration	Irregular stiffness, masses and distribution of openings	Irregular stiffness, masses and regular distribution of openings	Regular stiffness, masses and irregular distribution of openings	Regular stiffness, masses and distribution of openings	0,80

Table 4. Numerical coefficients associated with the vulnerability classes and weights of each parameter.

Parameter	Vulnerability conditions				Weight
	Class I	Class II	Class III	Class IV	
Seismic zone	3	2	1	0	3,00
Number of structural storeys	3	2	1	0	1,00
Type of roofing system	3	2	1	x	1,00
Type of interventions 1	3 (before 2009) 1 (after 2009)	0	-1	-3 (before 2003) -6 (after 2003)	1,00
Conservation status: vertical bearing structures and masonry	3	2	1	0	0,80
Conservation status: slabs	3	2	1	0	0,80
Conservation status: stairs	3	2	1	0	0,80
Conservation status: roof	3	2	1	0	0,80
Age of construction	3	2	1	0	0,50
Planimetric configuration	3	2	1	0	0,80
Elevation configuration	3	2	1	0	0,80

Finally, to define in numerical terms the capacity of the structure for each obtained vulnerability category, Table 5 has been proposed. In such a table the corresponding resisting P.G.A. values (structural capacity) is provided as a function of the determined vulnerability class and of the seismic classification of the territory referring to the year of construction (in the case of a building that was subsequently adapted or improved seismically, it is necessary to refer to the seismic zone relative to the intervention period). Finally, in Table 6 a simple value is associated to each vulnerability class by defining the corresponding vulnerability coefficient C_V.

The proposed method has been applied to determine the vulnerability class of the analyzed stock of 141 masonry school buildings for the district of Caserta. The obtained result is shown in Figure 4. It is apparent that the majority of the analyzed school buildings (43% of the sample) is characterized by a medium-high vulnerability class and 36% by a medium vulnerability class. Only one school building may be identified with a low vulnerability. The remaining part of the sample (20%) is equally subdivided in vulnerability classes H and ML.

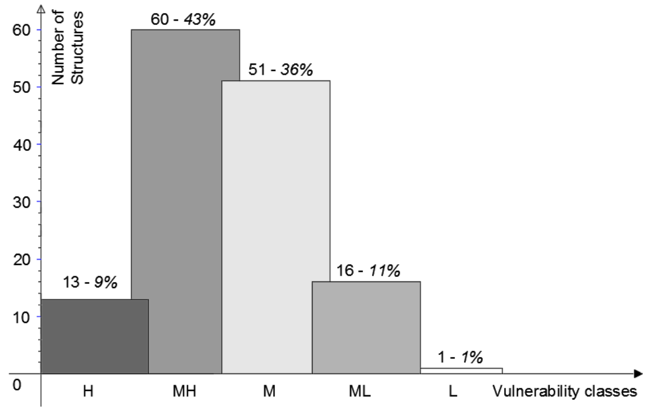

Figure 4. Vulnerability classes determined for the sample of 141 masonry school buildings of the Caserta district.

4 HAZARD ASSESSMENT

The seismic hazard represents a measure of the destructive power of an earthquake and is linked to the frequency of this aleatory phenomenon, as well as to the geological characteristics of the area in which the event manifests. In this way, the knowledge of the seismic hazard of a site is a fundamental tool to predict the severity of the expected earthquakes.

For the specific study case, the hazard (H) has been defined according to the expected peak ground acceleration (PGA), which has been assumed as the one having a probability of exceedance equal to 10% every 50 years. Such a value, considering that school buildings belong to use class III ("important buildings"), corresponds to an earthquake return period T_R = 712 years. The corresponding PGA value can be determined from the seismic hazard map of the national territory according to the geographic coordinates of each school building. Then, this value may be normalized, considering a maximum of PGA equal to 0.35g, i.e. the maximum value established in NTC2008. Hence, a numerical coefficient (C_H) can be obtained, which represents the hazard of the site where the school building is located.

The proposed method has been applied to determine the vulnerability class of the analyzed stock of 141 masonry school buildings for the district of Caserta (Figure 5). Hazard coefficient values ranging between 0.853 (maximum) and 0.279 (minimum) have been obtained. For the sake of simplicity, the hazard values have been grouped into five different hazard classes according to Table 7.

It is evident that the majority of school buildings, namely 69 buildings corresponding to 49% of the whole sample, are characterized by a Medium Hazard class.

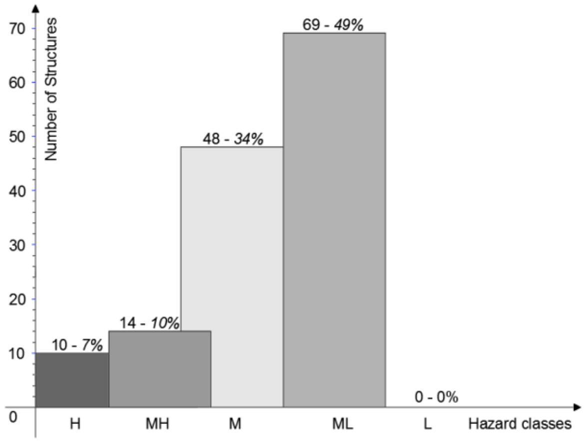

Figure 5. Hazard classes determined for the sample of 141 masonry school buildings of the Caserta district.

5 EXPOSURE ASSESSMENT

Generally, the exposure is associated to the nature, the quality and quantity of the goods exposed to the risk. Therefore, the exposure evaluation translates into the quantification of the number of artefacts (buildings, infrastructures, ect.), of the strategical functions and of the number of personnel that presumably might be involved in the seismic event, as well as in the assessment of their reaction capacity. With reference to the exposure parameter, school buildings are classified as "important buildings", as they are usually subject to considerable crowding (Eurocode 8).

Table 5. Vulnerability classes and related P.G.A. values.

Seismic vulnerability class	H	MH	M	ML	L
Zone 1 (P.G.A.)	0,125	0,150	0,200	0,225	0,250
Zone 2 (P.G.A.)	0,100	0,125	0,150	0,175	0,200
Zone 3 (P.G.A.)	0,050	0,075	0,100	0,125	0,150
Zone 4 (P.G.A.)	0,025	0,030	0,035	0,040	0,050

Table 6. Vulnerability coefficients C_V.

Vulnerability class	H	MH	M	ML	L
Vulnerability coefficient C_V [-]	0,90	0,70	0,50	0,30	0,10

Table 7. Hazard classes and hazard coefficient C_H.

Hazard class	H	MH	M	ML	L
Hazard coefficient C_H [-]	$C_H > 0,80$	$0,60 < C_H \leq 0,80$	$0,40 < C_H \leq 0,60$	$0,20 < C_H \leq 0,40$	$C_H \leq 0,20$

Table 8: School index.

Type of school	Is [-]
Preschool	1,0
Primary school	0,80
Secondary school – grade I	0,70
Secondary school – grade II	0,60
Comprehensive institute	0,85

Table 9: Density index.

N_U/S_{TOT}	I_D [-]
$N_U/S_{TOT} < 0,08$	0,75
$0,08 \leq N_U/S_{TOT} < 0,16$	0,85
$0,16 \leq N_U/S_{TOT} < 0,24$	0,90
$0,24 \leq N_U/S_{TOT} < 0,32$	0,95
$N_U/S_{TOT} \geq 0,32$	1,00

Table 10: Floor number index.

Number of storeys	N_f [-]
1	0,60
2	0,75
3	0,85
4	0,95
≥5	1,00

Table 11. Exposure classes and exposure coefficient C_E.

Exposure class	H	MH	M	ML	L
Exposure coefficient C_E [-]	$C_E > 0,80$	$0,60 < C_E \leq 0,80$	$0,40 < C_E \leq 0,60$	$0,20 < C_E \leq 0,40$	$C_E \leq 0,20$

Table 12. Seismic risk classes.

Risk class	H	MH	M	ML	L
Risk coefficient R [-]	$R > 0,80$	$0,60 < R \leq 0,80$	$0,40 < R \leq 0,60$	$0,20 < R \leq 0,40$	$R \leq 0,20$

The exposure is related to a functional component and another one linked to the users, in particular it can be assumed that the exposure coefficient (C_E) is obtained as a product of two indices, namely the user index (I_U) and the function index (I_F) (Ferrini 1998, Polidoro 2010). It is significant to note that while the function index (I_F) is obtained from qualitative considerations on the functions performed in the building under consideration, the user index (I_U) is provided by quantitative data concerning the users and number of operators in the buildings. In the specific study case, referring only to school buildings, it seems reasonable to assume that exposure is not dependent on the function index. The user index (I_F) is, in turn, function of the behavioural capacity of the users present in the building, the period of use of the building, the building crowding index and the storeys number.

Summarizing, the exposure coefficient (C_E) can be determined by the following symbolic equation:

$$C_E = Is \cdot I_D \cdot I_P \qquad (1)$$

where:

- I_S is the index that takes account the behavioural ability of users, that is related to the reaction capacity, dependent mainly on the age of students, physical conditions and freedom of movement, and also on the period of use of the school building, which is simply the number of weekly hours during which users attend the school activities (Table 8).
- I_D is the user density that is a function of the ratio between the user number (N_U) and the total area of the various levels of the building (S_{TOT}). For each value of this ratio is possible to associate a given coefficient, as shown in Table 9.
- I_P is the index relative to the number of storeys, since it is related to the evacuation easiness, without taking into account the characteristics of the users; it is defined according to Table 10.

For the sake of simplicity, the exposure risk values have been grouped into five different exposure classes according to Table 11.

The proposed method has been applied to determine the seismic risk of the analyzed stock of 141 masonry school buildings for the district of Caserta (Figure 6) excluding structures that host gyms, canteens and administrative spaces and the structures presently not used.

It is evident that the majority of school buildings, namely 115 buildings corresponding to

82% of the whole sample, is characterized by a Medium Hazard class.

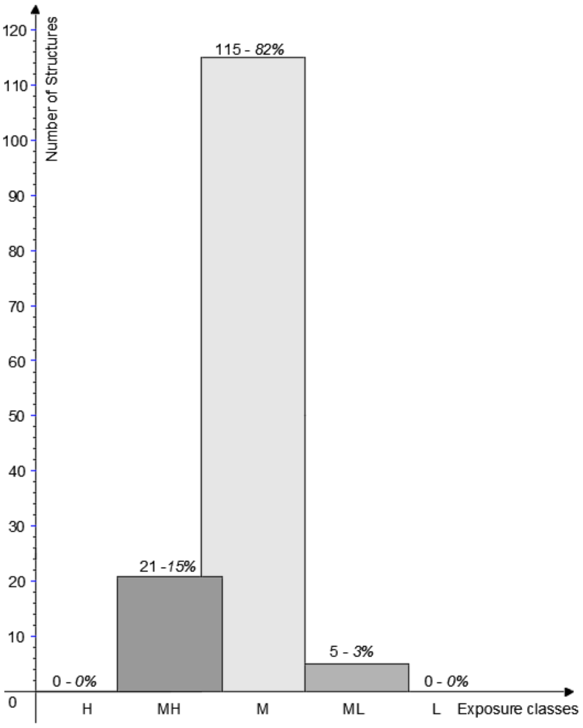

Figure 6. Seismic exposure determined for the sample of 141 masonry school buildings of the Caserta district.

6 SEISMIC RISK ASSESSMENT

Once the numerical values of the various factors concurring to define seismic vulnerability, hazard and exposure have been obtained, the seismic risk (R) can be consequently evaluated by combining the above coefficients C_V, C_P, C_E. As an homogeneous class of buildings is considered, in order to emphasise the differences among the buildings, a simplified additive model can be applied to combine the above risk factors rather than a combination model based on their product; then, to account for the different importance of the above three coefficients, a weight equal to 0,4 has been assigned to the vulnerability coefficient C_V, while a weight equal to 0,3 has been considered for the other two coefficients C_H and C_E.

Therefore, the seismic risk R is evaluated by applying the following combination formula:

$$R = 0{,}4 \cdot C_V + 0{,}3 \cdot C_H + 0{,}3 \cdot C_E \qquad (2)$$

For the sake of simplicity, the seismic risk values can be grouped into five different hazard classes according to Table 11. The proposed method has been applied to determine the seismic risk of the analyzed stock of 141 masonry school buildings for the district of Caserta (Figure 7) excluding structures that host gyms, canteens and administrative spaces and also other buildings which presently are not used.

The obtained value ranges between a minimum of 0,330 to a maximum of 0,722. The school building representative of the greatest seismic risk is located in seismic zone 1, characterized by a high seismic action, a medium-high vulnerability and exposure: in fact it hosts a preschool with a medium user density. The school building characterized by the lowest seismic risk is located in seismic zone 2, built in the last fifteen years and therefore characterized by low features of vulnerability and medium characteristics of exposure and hazard.

For the sake of synthesis, the results got by the above application have been grouped defining five different classes of seismic risk (Table 12). The results obtained from this classification are shown in Figure 7. The majority of the analyzed school buildings, namely 100 school buildings corresponding to 71% of the whole sample, is classified M; 23% of the school buildings present a medium seismic risk class MH; only 9 school building structures can be classified in the ML class.

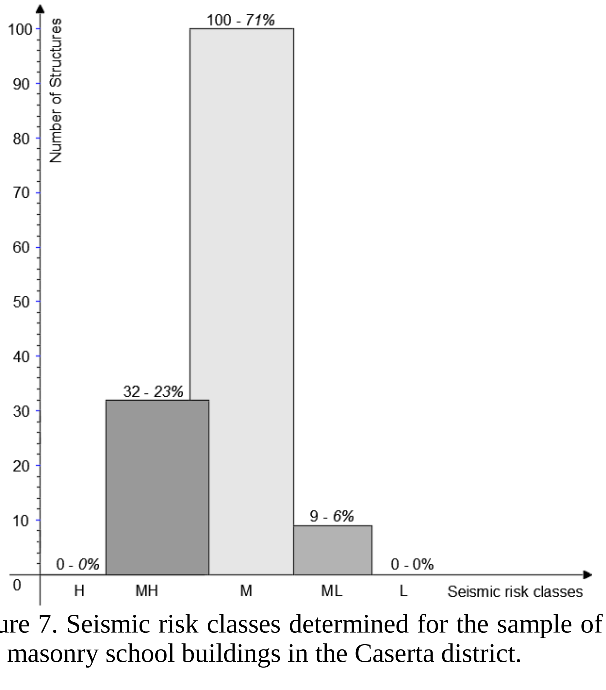

Figure 7. Seismic risk classes determined for the sample of 141 masonry school buildings in the Caserta district.

7 CONCLUSION

In this paper, a simplified method to define seismic vulnerability, seismic hazard and exposure of masonry school buildings has been proposed. It is based on the structural and typological parameters which are present in the “Sistema Nazionale delle Anagrafi dell’Edilizia Scolastica” (SNAES). Starting from a value of seismic vulnerability provided by a preliminary matrix that depends only on the vertical and horizontal structural systems, using additional specific parameters taken from the existing database, it is possible to define specific vulnerability classes.

In order to prove the actual possibility of application of such a methodology, it has been applied to evaluate the seismic risk of the school building heritage of the province of Caserta. Therefore, starting from the 780 schools of the Caserta district (information reported on the SNAES and updated to October 2018), a stock of buildings composed by 141 masonry schools has been analyzed.

The obtained results show that the five classes of vulnerability are not homogeneously represented by these buildings. In fact, the majority of the analyzed schools (43% of the sample) is characterized by a medium-high vulnerability class, 36% are classifiable in the medium class and only one building may be identified with a low vulnerability. The remaining part of the sample (20%) is equally subdivided in the remaining two vulnerability classes. Analogously, in terms of seismic risk, which accounts also for seismic hazard and exposure, 71% of the whole sample of the analyzed schools have been classified with a Medium seismic risk, while 23% with a Medium-High seismic risk, while only 9 school building structures are characterized by a Medium-Low seismic risk class.

In the whole, the obtained results confirm that the school building heritage present many critical issues that should be solved in order to mitigate seismic risk. The proposed simplified methodology, which is similar to the one already developed for reinforced concrete school buildings (De Matteis et al. 2018), seems to represent a useful tool to categorize the seismic risk of schools at large territorial scale in order to define effective intervention priorities.

REFERENCES

Calderoni, Sandoli A., Cordasco E.A., 2017. Valutazione speditiva della vulnerabilita' sismica dei centri urbani italiani: classificazione tipologica strutturale degli edifici esistenti in muratura ed in c.a. *Structural 210 – marzo/aprile 2017 – paper 09 – ISSN 2282-3794.* DOI 10.12917/Stru210.09.

D.M. 14 gennaio 2008. Norme tecniche per le costruzioni, Consiglio Superiore dei Lavori Pubblici, Gazzetta Ufficiale della Repubblica Italiana.

De Matteis G., Bencivenga P., Guarino F., Nola C., 2018. A simplified analysis for seismic risk assessment of reinforced concrete school buildings. *World Heritage and Knowledge. Le Vie dei Mercanti - XVI International Forum*. June 14-16. Naples, IT.

Di Pasquale G., Dolce M., Martinelli A., 2000. Censimento di vulnerabilità a campione dell’edilizia corrente dei centri abitati nelle Regioni Abruzzo, Basilicata, Calabria, Campania, Molise, Puglia e Sicilia Roma, 2000.

Dolce A., Masi A., Moroni C., Liberatore D., Laterza M., Ponzo F., Cacosso A., D’Alessandro G., Faggella M., Gigliotti R., Perillo G., Samela L., Santarsiero G., Spera G., Suanno P., Vona, 2204. Valutazione della vulnerabilità sismica di edifici scolastici della Provincia di Potenza. *XI Congresso Anidis*. January 24-29, Genova, IT.

Dolce M., C. Moroni C. 2005. La valutazione della vulnerabilità e del rischio sismico degli edifici pubblici mediante le procedure VC (vulnerabilità c.a.) e VM (vulnerabilità muratura), *Atti del Dipartimento di Strutture, Geotecnica, Geologia Applicata all’Ingegneria della Università della Basilicata, Vol. 4*.

Eurocode 8, Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings, 2005.

Ferrini M., 1998. Progetto terremoto in Garfagnana e Lunigiana. Un modello di calcolo per la determinazione di un indice di esposizione di edifici pubblici strategici.

Gattesco N., Franceschinis R., Zornini F, 2012. Stima della vulnerabilità sismica delle strutture in c.a. mediante procedura semplificata. *XV Convegno ANIDIS*. June 30 – July 4. Padova, IT.

Legambiente, 2008. Ecosistema scuola - XIX Rapporto di Legambiente sulla qualità dell’edilizia scolastica, delle strutture e dei servizi.

Norme per l’edilizia scolastica, Legge 11 gennaio 1996, n. 23.

Ordinanza 3274 della Presidenza del Consiglio dei Ministri, 2003. Primi elementi in materia di criteri generali per la classificazione sismica del territorio nazionale e di normative tecniche per le costruzioni in zona sismica.

Ordinanza 3519 del Presidente del Consiglio dei Ministri 2006. Criteri generali per l’individuazione delle zone sismiche e per la formazione e l’aggiornamento degli elenchi delle stesse zone.

Polidoro B., La valutazione della vulnerabilità sismica: il caso di Pettino (AQ), 2010. Tesi di Laurea Magistrale in Ingegneria Strutturale e Geotecnica, Università degli Studi di Napoli "Federico II".

Zuccaro G., Cacace F, 2007. Proposta per una procedura di valutazione semplificata di rischio sismico a scala nazionale dell'edilizia scolastica. *Proceedings of National Congress of Italian National Association of Earthquake Engineering*. 2007, Pisa, IT.

Zuccaro G., Cacace F., 2015. Seismic vulnerability assessment based on typological characteristics. The first level procedure SAVE. *Soil Dynamics and Earthquake Engineering*, 2015.