A Simplified Procedure for Seismic Risk Assessment of Existing Italian School Buildings

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Abstract. Seismic risk assessment of school building heritage is a relevant topic in Italy, as most of them were built several years ago and were not designed using anti-seismic criteria. In addition, a large portion of existing school structures is characterized by a bad state of conservation, mainly due to the lack of maintenance and structure deterioration. Seismic risk evaluation of these buildings has to take into account the combination of seismic hazard, structural vulnerability and exposure considering the mainly characteristics. 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 tool to solve this problem, a specific database called "Sistema Nazionale delle Anagrafi dell'Edilizia Scolastica (SNAES)", which consists of a census of the entire school building heritage, has been developed. Such database contains many parameters related to the 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, a simplified and fast methodology for assessing the seismic risk of both masonry and reinforced concrete schools is provided. This procedure can be applied to a large number of structures and in this paper it is analyzed with reference to a sample of school buildings located in the Caserta Province.

Keywords: Risk assessment · School buildings · Seismic vulnerability · Seismic exposure · Seismic hazard

1 Introduction

The Italian school building heritage is constituted by many public "historical" structures, which may be characterized by inadequate structural safety in case of seismic events. From the data emerged by a recent analysis, more than 63% of the relevant 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, the instrument called "Sistema Nazionale delle Anagrafi dell'Edilizia Scolastica" (SNAES) has been proposed in Italy. 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, De Matteis and Bencivenga 2019).

2   The School Building Heritage in the Caserta District

The school building heritage of the province of Caserta, similarly to the 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). This system has been activated on 1st December 2014, despite 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 781 school buildings located in the territory of Caserta (information reported on the SNAES and updated to November 2019), the sample analyzed in this paper, corresponding to the 27% of the stock, is composed by 211 school buildings: in particular 141 school are characterized by a masonry structure and the remaining 70 are reinforced concrete buildings.

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

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

3   Seismic Vulnerability Assessment

3.1   General

In the 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 single or groups of buildings (Dolce and Moroni 2005, Gattesco et al. 2012). Obviously, even though it is more reliable, such a method requires a more specific knowledge of the structure, 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 structure 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 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 corresponding to the vertical and horizontal structural system (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 Fig. 1: High (H); Medium-High (MH); Medium (M); Medium-Low (ML); Low (L).
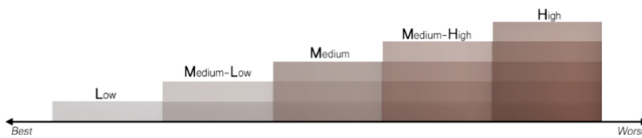

Fig. 1. Vulnerability assessment: step 1

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.

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.

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	H	H	H	H
Wooden slabs	H	H	MH	MH
Steel slabs	MH	MH	M	M
Reinforced concrete slabs	M	MH	M	ML
Other	M	MH	M	ML

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
Reinforced concrete slabs	M	MH	MH	M

Table 3. Definition of basic seismic vulnerability classes of reinforced concrete buildings

Structural resisting system	Vertical loads designed (Zone 4)	Low seismic forces designed (Zone 3)	Medium seismic forces designed (Zone 2)	High seismic forces designed (Zone 1)
Frames – columns and high beams, with light cladding	H	MH	MH	M
Frames – columns and high beams, with heavy cladding	MH (M)	M (ML)	ML	ML
Walls	ML	L	L	L

Similarly to this procedure, for the sample of 70 reinforced concrete buildings, a matrix (Table 3) that considers two data only, namely the structural resisting system and seismicity level has been proposed.

3.3 Vulnerability Assessment – Step 2

Once basic seismic vulnerability has been assessed by Tables 1, 2 and 3, in order to refine the obtained basic classification, additional criteria are considered to either modify or confirm the vulnerability class deduced by Tables 1, 2 and 3. Such additional criteria have been established considering 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:

– 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. In Tables 4 and 5 is indicated +3, +2, +1, +0 stand for buildings located in seismic zones actually increased of three, two, one or zero classes. Furthermore >2003 indicates schools realized or designed after the new classification.
– Number of structural storeys; higher buildings are more vulnerable, as they are subjected to seismic amplification at upper storeys and larger forces at lower storeys.
– 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 not provided.
– Type of interventions 1; in this classification are included interventions of: enlargement, superelevation (EN./S.E.), restructuring (RE.) and extraordinary maintenance (E.M.). Except for the first two, which can increase the seismic vulnerability if not realized correctly, the structural improvement provided by restructuring or maintenance interventions can contribute to reduce the seismic vulnerability.
– 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. In Table 4 and 5, T.R. and P.R. indicate that buildings need total and partial replacement respectively, O.M. stands for ordinary maintenance and N.I. express that no interventions are necessary.

– 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;
– Planimetric configuration; each building is classified according to the ratio B/L and to the projections on each side;
– 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 4 and in Table 5 for masonry structures and reinforced concrete buildings, respectively. In such tables, it is evident 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 6 for masonry structures and in Table 7 for reinforced concrete buildings. 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 6 and 7, 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 between −6,00 and +36,90 for masonry buildings and from −6,70 to +28,20 for reinforced concrete structures.

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, for masonry buildings the parameter P_V should be in the interval (0,29 ÷ 0,45) in order to do not have any variation of vulnerability classes; similarly the interval (0,18 ÷ 0,27) is valid for reinforced concrete school buildings.

Therefore, for masonry structures the following situation has been defined (Fig. 2):

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

As in the previous case, for reinforced concrete buildings the following classification has been provided too (Fig. 3):

– If P_V ϵ [0; 0,18[the building has a negative class change (decrease of vulnerability);
– If P_V ϵ [0,18; 0,27] the building has not any vulnerability class change;
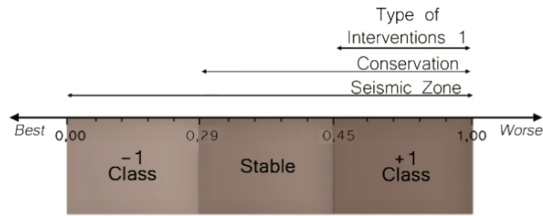– If P_V ϵ]0,27; 1,00] the building has a positive class change (increase of vulnerability).

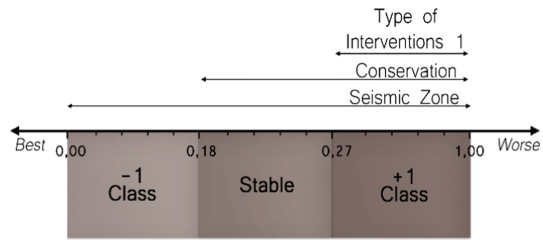**Fig. 2.** Vulnerability assessment: step 2 (masonry structures)

Fig. 3. Vulnerability assessment: step 2 (r.c. buildings)

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 includes 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 (Fig. 4):

– 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 ML;
– In case of seismic upgrading interventions, the building undergoes a class change obtaining a vulnerability class L.
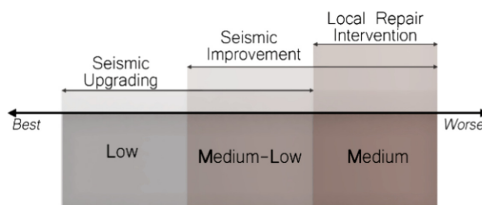

Fig. 4. Vulnerability assessment: step 3

Table 4. Vulnerability conditions and weights related to each additional parameter (for masonry structures)

Parameter	Vulnerability conditions				Weight
	Class I	Class II	Class III	Class IV	
Seismic zone	+3	+2	+1	+0	3,00
Number of 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	EN./S.E.	N.I.	E.M.	R.E	1,00
Conservation status: vertical bearing structures and masonry	T.R.	P.R.	O.M.	N.I.	0,80
Conservation status: slabs	T.R.	P.R.	O.M.	N.I.	0,80
Conservation status: stairs	T.R.	P.R.	O.M.	N.I.	0,80
Conservation status: roof	T.R.	P.R.	O.M.	N.I.	0,80
Age of construction	<1900	1901 ÷ 1937	1938 ÷ 1960	>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 5. Vulnerability conditions and weights related to each additional parameter (for r.c. buildings)

Parameter	Vulnerability conditions				Weight
	Class I	Class II	Class III	Class IV	
Seismic zone	+2	+1	+0	>2003	3,00
Number of storeys	N.4	N.3	N.2	N.1	0,50
Type of roofing system	Pitched	Mixed	Plane	X	0,30
Type of interventions 1	EN./S.E.	N.I.	EM	RE	1,00
Conservation status: vertical bearing structures and masonry	T.R.	P.R.	O.M.	N.I.	0,90
Conservation status: slabs	T.R.	P.R.	O.M.	N.I.	0,90
Conservation status: stairs	T.R.	P.R.	O.M.	N.I.	0,90
Conservation status: roof	T.R.	P.R.	O.M.	N.I.	0,90

Table 6. Numerical coefficients associated with the vulnerability classes and weights of each parameter (for masonry structures)

Parameter	Vulnerability conditions				Weight
	Class I	Class II	Class III	Class IV	
Seismic zone	3	2	1	0	3,00
Number of storeys	3	2	1	0	1,00
Type of roofing system	3	2	1	x	1,00
Type of interventions 1	3 (<2009)	0	−1	−3 (<2003)	1,00
	1 (>2009)			−6 (>2003)	
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

Furthermore, to define in numerical terms the capacity of the structure for each obtained vulnerability category, Table 8 has been proposed. In such a table the corresponding resisting P.G.A. values (structural capacity) are provided as a function of the determined vulnerability class and of the seismic classification of the territory referring to the year of construction. It should be noted that 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.

Table 7. Numerical coefficients associated with the vulnerability classes and weights of each parameter (for r.c. buildings)

Parameter	Vulnerability conditions			
	Class I	Class II	Class III	Class IV
Seismic zone	3	2	1	0
Number of structural storeys	3	2	1	0
Type of roofing system	3	2	1	x
Type of interventions 1	3 (before 2009)	0	−1	−3 (before 2003)
	1 (after 2009)			−6 (after 2003)
Conservation status: vertical bearing structures and masonry	3	2	1	0
Conservation status: slabs	3	2	1	0
Conservation status: stairs	3	2	1	0
Conservation status: roof	3	2	1	0

Table 8. 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

Finally, in Table 9 a simple value is associated to each vulnerability class by defining the corresponding vulnerability coefficient C_V.

Table 9. 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

3.5 Application to School Buildings of Caserta District

The proposed method has been applied to determine the vulnerability class of the analyzed stock of 211 school buildings for the district of Caserta. The obtained result is shown in Fig. 5. It is evident that the majority of the analyzed school buildings (34% of the sample) is characterized by a medium-high vulnerability class and 29% by a medium

vulnerability class. Only two school buildings may be identified with a low vulnerability. Furthermore the 25% of the sample is representative of the vulnerability class H and the remaining part of the sample (11%) corresponds to the class ML.
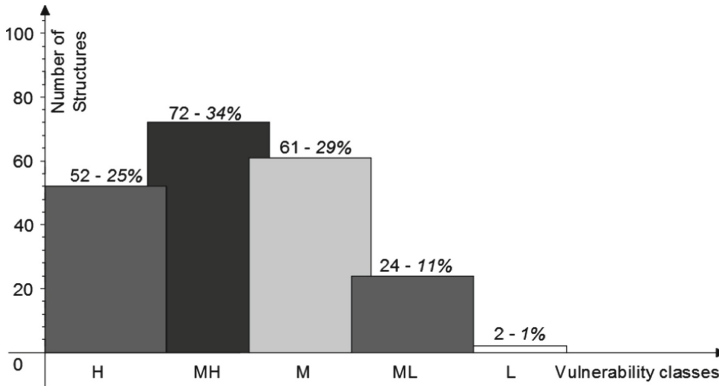

Fig. 5. Vulnerability classes determined for the sample of 211 school buildings of the Caserta district.

4   Hazard Assessment

4.1   The Proposed Method

The seismic hazard represents a measure of the destructive capacity 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.

4.2   Application to School Buildings of Caserta District

The proposed method has been applied to determine the vulnerability class of the analyzed stock of 211 school buildings for the district of Caserta (Fig. 6). Hazard coefficient values ranging between 0.853 (maximum) and 0.279 (minimum) have been obtained.

Table 10. Hazard classes and hazard coefficient C_H.

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

For the sake of simplicity, the hazard values have been grouped into five different hazard classes according to Table 10.

It is evident that the majority of school buildings, namely 185 buildings corresponding to 86% of the whole sample, are equally subdivided in vulnerability classes M and ML.
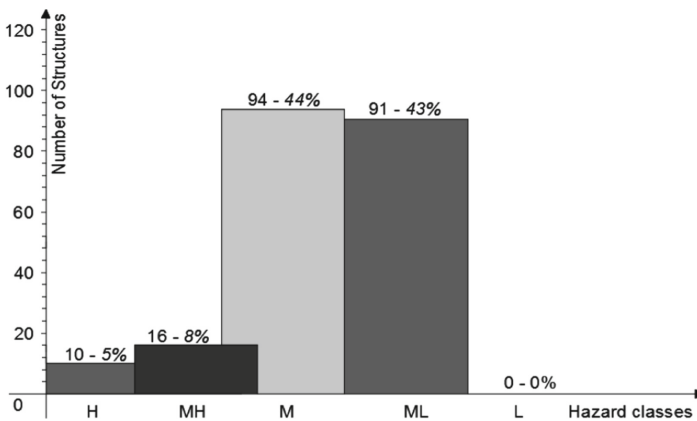

Fig. 6. Hazard classes determined for the sample of 211 school buildings of the Caserta district.

5 Exposure Assessment

5.1 The Proposed Method

Generally, the exposure is associated to the nature, the quality and quantity of the goods exposed to the risk. Therefore, the exposure takes into account the quantification of the number of artefacts (buildings, infrastructures, etc.), of the strategical functions and of the number of personnel that presumably might be involved in the seismic event, in relation to their reaction ability. With reference to the exposure parameter, school buildings are classified as "important buildings", as they are usually subject to considerable crowding (Eurocode 8, 2005).

The exposure is generally related to a functional and a user component: 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 analyzed structure, 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, depending on the behavioral capacity of the users into the building, the period of use of the structure, the building crowding index and the storeys number.

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

$$C_E = Is \cdot I_D \cdot I_P \tag{1}$$

where:

- I_S is the index that takes into account the behavioral 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 11).
- 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 floors of the building (S_{TOT}). For each value of this ratio is possible to associate a given coefficient, as shown in Table 12.

Table 11. 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 12. 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 13. Floor number index.

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

– 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 13.

For the sake of simplicity, the exposure risk values have been grouped into five different exposure classes according to Table 14.

Table 14. Exposure classes and exposure coefficient C_E.

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

5.2 Application to School Buildings of Caserta District

The proposed method has been applied to determine the seismic risk of the analyzed stock of 211 school buildings for the district of Caserta (Fig. 7). It is noticeable that the majority of school buildings, namely 173 buildings corresponding to 82% of the whole sample, is characterized by a Medium Hazard class.
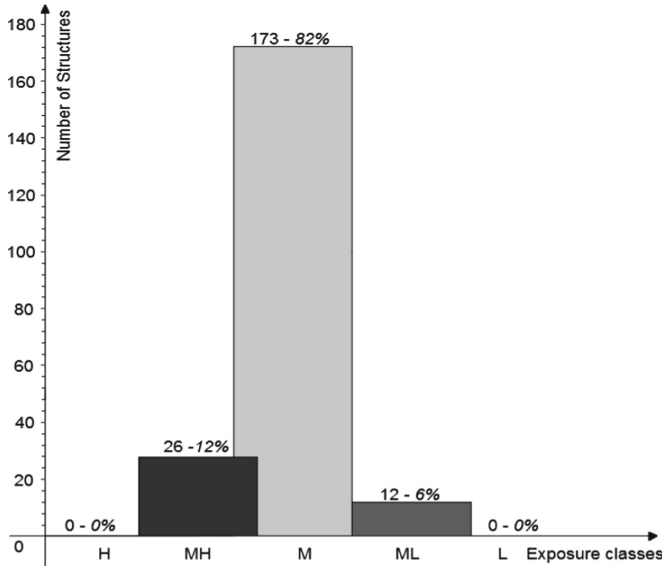
Fig. 7. Seismic exposure determined for the sample of 211school buildings of the Caserta district.

6 Seismic Risk Assessment

6.1 The Proposed Method

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 highlight 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:

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

For the sake of synthesis, the results got by the above application have been grouped defining five different classes of seismic risk (Table 15).

6.2 Application to School Buildings of Caserta District

The proposed method has been applied to determine the seismic risk of the analyzed stock of 211 school buildings for the district of Caserta and the results are shown in Fig. 8. The obtained values range between a minimum of 0,33 to a maximum of 0,72.

Table 15. Seismic risk classes

Risk class	H	MH	M	ML	L
Risk coefficient R [–]	R > 0,80	0,60 < R ≤ 0,80	0,40 < R ≤ 0,60	0,20 < R ≤ 0,40	R ≤ 0,20

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.
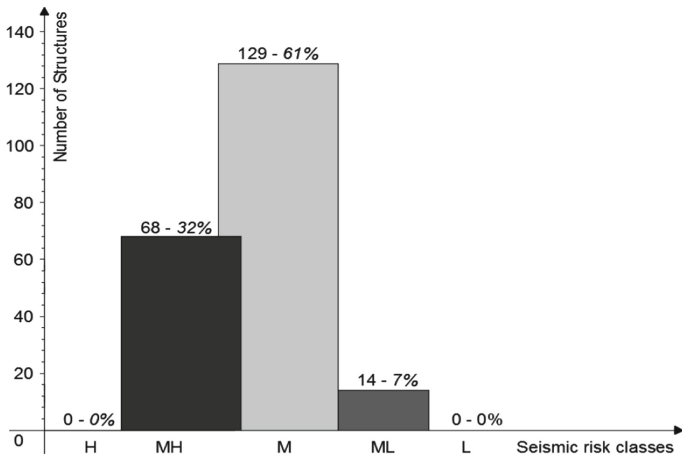

Fig. 8. Seismic risk classes determined for the sample of 211 school buildings in the Caserta district.

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. Furthermore, the majority of the analyzed school buildings, namely 129 school buildings corresponding to 61% of the whole sample, is classified M; 32% of the school buildings present a medium seismic risk class MH; only 14 school building structures can be classified in the ML class.

7 Conclusions

In this paper, a simplified method to define seismic vulnerability, seismic hazard and exposure of masonry and reinforced concrete school buildings has been proposed. It is based on the structural and typological parameters which are included in the "Sistema Nazionale delle Anagrafi dell'Edilizia Scolastica" (SNAES). Starting from a seismic vulnerability value 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 781 schools of the Caserta district (information reported on the SNAES and updated to November 2019), a stock of buildings composed by 211 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 (34% of the sample) is characterized by a medium-high vulnerability class, 29% are classifiable in the medium class and only two buildings may be identified with a low vulnerability. Furthermore the 25% of the sample is representative of the vulnerability class H and the remaining part of the sample (11%) corresponds to the class ML. Analogously, in terms of seismic risk, which accounts also for seismic hazard and exposure, 61% of the whole sample of the analyzed schools have been classified with a Medium seismic risk, while 32% with a Medium-High seismic risk, while only 14 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 seems to represent a useful tool to categorize the seismic risk of schools at large territorial scale in order to define effective intervention priorities.

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