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Rapid Seismic Vulnerability Assessment of Buildings in the Old Algiers

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ABSTRACT

The selection of an appropriate seismic vulnerability method to evaluate buildings stock in urban area depends essentially on the available information. Information about buildings can be obtained essentially from field visual inspection. In this context, rapid visual procedure to collect buildings data can be used to identify vulnerable buildings based their structural characteristics. In this study, which aims to evaluate the seismic vulnerability of existing buildings in the old part of Algiers (Algeria), including Casbah and Bab El Oued areas, buildings data has been collected using rapid visual exterior examination. Then, with the main purpose to evaluate the physical damage and its relationship with the seismic intensity, empirical method using the vulnerability index, previously developed during the European project Risk-UE, is used. Results and conclusions of this work could be useful to define appropriate measures to upgrade seismic performance of existing buildings.

1 Introduction

Large part of existing buildings in Algiers, the capital city of Algeria, is composed of stone masonry structures and reinforced concrete structures designed without seismic measures. Unreinforced masonry buildings are the most predominant type in the old part of Algiers. Some of these old buildings are in a dilapidated state and risk of collapse due to their structural fragilities, deficiencies and lack of maintenance. Therefore, in order to prevent severe damage in this area, in case of future earthquake, it is essential to evaluate buildings seismic vulnerability. Detailed evaluation of all buildings is a long and expensive process, so, simpler methods are more practical to assess rapidly the vulnerability presumption of buildings.

Seismic vulnerability refers to the damage grade suffered by a structure when subjected to a seismic event with a given intensity level [1]. The first attempt to assess vulnerability was that of Whitman et al. (1973) [2], including the concept of damage probability matrix by observing and recording damage caused by the 1971 San Fernando earthquake. Covering

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around 1600 buildings, damage probability matrices (DPM), expressing building damage grade to earthquake intensity were generated. In the 1980's, the GNDT Italian method [3] (Gruppo Nazionale per la Difesadai Terremoti) was created and applied to assess vulnerability by introducing the concept of vulnerability index, based on visual observation and simple structural calculation. Several methodologies developed for seismic vulnerability and risk evaluation [3]-[4]-[5], depend mainly on the number of buildings to evaluate (individual building, group of buildings or urban area), the available information, the project purposes and the type of the results required [6]-[7]-[8]. Vulnerability assessment methods can be classified into two main categories; analytical methods and empirical methods. Calvi et al. [9] divided the various existing methods of vulnerability assessment into three main categories; empirical, analytical and hybrid methods. Empirical methods for the seismic vulnerability assessment of buildings are essentially based on damage observed after earthquakes, while analytical methods are based on the structural analysis using dynamic or simplified model. Hybrid techniques combine two or more different methods.

In case of urban area with a large number of buildings, detailed seismic vulnerability evaluation is not recommended, but can be limited to some specific buildings selected according to their importance[7]-[9]. Methods based on rapid visual examination [10]can be used to evaluate buildings and help to select specific buildings for which a more detailed evaluation is necessary. Most of the seismic vulnerability methods require inventory containing general and structural information of existing buildings. The buildings inventory is achieved from field inspection or by using population census, existing technical documents and plans. Methods based on rapid visual examination do not involve a high level of information of the structure. General and structural information such as; building age, number of levels, structural type, regularity… are collected and recorded on a data collection form (survey form).

This study is carried out to assess vulnerability of ordinary existing buildings in the old part of Algiers, including Casbah and Bab El Oued areas. Firstly, using rapid visual examination, buildings are investigated to identify their characteristics. As a preliminary assessment, buildings are regrouped into structural categories and then classified into vulnerability classes according to European Macroseismic Scale definitions (EMS-98) [11], taking into consideration their structural systems and parameters affecting their vulnerability. In the second step, the expected damage is determined and expressed in relation with the seismic intensity. To achieve this, the vulnerability index method developed in Risk-UE project [12]-[13], is adapted with accordance to the parameters considered in the rapid visual examination.

2 Rapid visual examination; purpose and parameters

The purpose of this procedure is to collect building characteristics and define rapidly the vulnerability without analysing the structure [10].The concept of rapid visual examination was developed by the Federal Emergency Management Agency (FEMA), known as ATC-21[10]. The procedure does not involve a high level of information of the structure, materials used and constructive practice, and it does not require having the plans of the construction. Therefore, the procedure is simple and inexpensive, because it consists only to collect data by external examination of the building. It is worth noting however, that it is sometimes difficult to determine certain criteria or details without access to the interior of the building; such as the vertical continuity, the state of preservation, cracks…In such cases, the inspector goes inside to have more details.

Once the exterior of the building is examined, information is recorded on the data form and general comments or notes are includes. This process can take about 20 minutes per building. The data processing of inventoried buildings is performed subsequently in order to assign structural categories and vulnerability classes.

The parameters considered in the visual rapid examination are:

- Building address
- Building useçi
- Plan irregularity
- Elevation irregularity
- Position of the building
- General state of preservation
- Other; soil morphology, level of foundations, remarks…

Seismic vulnerability of buildings is not only depending on the structural system type, but also affected by a number of modifier parameters [14]. Parameters 3 to 10are considered as modifiers that can affect the seismic behaviour of the building. Building use parameter distinguishes residential dwelling buildings from office, school and hospital buildings. In the number of stories parameter, three height ranges are considered (low-rise: 1 to 3 stories; mid-rise: 4 to 7 stories; and high-rise (more than 7 stories), so, low-rise building is treated as less vulnerable. The age of the building is related to the publication year of the first Algerian seismic code (1981) [15], thus buildings built before 1981 (pre-code) are treated as seismically vulnerable. Type of structure parameter considers four types (and corresponding subtypes): masonry structure, reinforced concrete structure, steel structure and timber structure. Plan and vertical irregularities describe geometrical irregularities (vertical discontinuities, complex geometry in plan, mass distribution, short columns and open story…) that can affect the behaviour during earthquake. Position of the building (middle, corner, header or separated position, a seismic joint) affects its final vulnerability. Building at the corner or the header of the aggregate are considered as less vulnerable. The state of conservation is assessed by observing the general condition of the building (cracks, damage…).

3 Vulnerability assessment method

3.1 Vulnerability index method

Vulnerability is assessed according to the EMS-98 scale [11]. The scale considers six types of structures for RC buildings and seven for masonry buildings and classify them in six vulnerability classes (A to F), as shown in Table 1. The concept of vulnerability class was introduced by the scale to rank buildings in terms of resistance. The most probable vulnerability classes of RC structures are C, D and E, representing respectively, structures without earthquake resistant design ERD, with moderate level of ERD and with high level of ERD. Masonry building typologies are; unreinforced masonry and reinforced or confined masonry buildings. Vulnerability class A is assigned to the most vulnerable structures, representing the behaviour of the fragile buildings, and vulnerability class F is assigned to buildings with high level of ERD. Vulnerability profile of a building does not only depend on the structure type, modifier parameters can affect the final building vulnerability class [14].

.The vulnerability index method for buildings was originally developed by Benedetti and Petrini in 1984 [16], and used in Italy by the GNDT [3].The vulnerability index V is a score, with an arbitrary numerical value, which qualify conventionally the seismic behaviour of a building. It ranges between 0 and 1; 0 for structures with high earthquake resistance design, and 1 for the most vulnerable structures [1]-[3]-[13].Such methods allow assessing building vulnerability by means of a vulnerability score, through observation of structural and non-structural characteristics. The vulnerability index method version developed in Risk-UE project [12]-[13] is a macroseismic approach that establishes typological classification and groups structures with a similar seismic behaviour according to EMS-98 definitions, then assign a typological vulnerability index V0 as the most probable value. Table 1 shows the vulnerability index values V0 for the EMS-98 building typologies proposed in the Risk-UE project. V0 is the most probable or plausible value and V−/V+, V--/V++ are, respectively, the probable and the less probable vulnerability index ranges. The vulnerability index values were obtained using the Fuzzy Set Theory [13]-[17] and express the pertaining of the buildings to a certain vulnerability class. Each building typology in Table 1 has a probable vulnerability class and a probable vulnerability index, that can be increased or decreased, according to the building parameters able to affect the seismic behaviour, for example ; the state of preservation. The final value of V (V0, V−/V+ or V--/V++) is selected based on personal judgement

As mentioned above, the seismic behaviour of a building does not only depend on the structure type, modifier parameters can influence the final vulnerability index. Therefore, the Risk-UE method suggest to evaluate the vulnerability index as the sum of the most probable value V_0 (typological index) and the scores for all modifiers [1]-[13]. Modifier parameters and scores can be made based on observation of seismic damage during earthquakes, and by proposals made previously or assigned based on expert judgment and experience [3]-[10].Table 2 presents the modifier parameters and their scores adapted for this study based on those proposed by the Risk-UE method.

3.2 Damage assessment

The expected damage that may occur when buildings are subjected to a specified earthquake can be assessed in terms of mean damage μ_D using an analytical function (Eq. (1)) [17]. The mean damage is expressed as a function of the assessed vulnerability and the macroseismic intensity. The ductility index Q in Eq. 1, defines the ratio of increase in the damage with intensity [1]-[17].It was evaluated considering the building typology and its constructive features. Resulting from the macroseimic approach, for buildings designed without ductile behaviour (unreinforced masonry and RC frame structures), Q takes a value of 2.3[1]-[17].

$$\mu_D = 2.5\left[1+\tanh\left(\frac{I+6.25V-13.1}{Q}\right)\right] \tag{1}$$

Where I is the macroseimic intensity, V is the vulnerability index and Q and the ductility index.

Table 1 - Vulnerability classes and index values for masonry and RC building typologies (Risk-UE project).

	Building typologies	Vulnerability classes						Vulnerability indices				
		A	B	C	D	E	F	V^{--}	V^{-}	V_0	V^{+}	V^{++}
Masonry	M1: Rubble stone, fieldstone	■						0.62	0.81	0.873	0.98	1.02
	M2: Adobe (earth brick)	■	▒					0.62	0.687	0.84	0.98	1.02
	M3: Simple stone	░	■					0.46	0.65	0.74	0.83	1.02
	M4: Massive stone		▒	■	░			0.3	0.49	0.616	0.793	0.86
	M5: Unreinforced with manufactured	░	■	░				0.46	0.65	0.74	0.83	1.02
	M6: Stone unreinforced with RC floors		▒	■	░			0.3	0.49	0.616	0.79	0.86
	M7: Reinforced or confined			░	■	▒		0.14	0.33	0.451	0.633	0.7
Reinforced Concrete	RC1: RC frame without ERD	░	▒	■				0.3	0.49	0.644	0.8	1.02
	RC2: RC frame with moderate ERD		░	▒	■	▒		0.14	0.33	0.484	0.64	0.86
	RC3 : RC frame with high ERD			░	▒	■	▒	-0.02	0.17	0.324	0.48	0.7
	RC4: Shear walls without ERD		░	■	▒			0.3	0.367	0.544	0.67	0.86
	RC5 : Shear walls with moderate ERD			░	■			0.14	0.21	0.384	0.51	0.7
	RC6 : Shear walls with high ERD				░	■	▒	-0.02	0.047	0.224	0.35	0.54
■	Most probable	▒	Probable	░	Less probable			ERD: earthquake resistant design				

Building typologies and corresponding vulnerability classes (A to F) according to EMS-98 and vulnerability index values evaluated by the Risk-UE method (macroseismic approach) [13]. V_0 is the most probable value and V^{-} /V^{+} and V^{--} /V^{++} are, respectively, the probable and less probable vulnerability index ranges.

Table 2 - Vulnerability modifiers parameters and scores.

Vulnerability modifiers		Scores for masonry	Score for RC Pre-code
Number of floors	Low-rise	-0.02	-0.02
	Med-rise	0	0
	High-rise	+0.04	+0.08
Plan irregularity	Geometry and Mass distribution	+0.04	+0.04
Vertical irregularity	Geometry and Mass distribution	+0.04	+0.04
Aggregate position	Middle	-0.04	+0.04 (insufficient aseismic joint)
	Corner	+0.04	
	Header	+0.06	
Soil morphology	Slope	+0.02	+0.02
	Escarpment	+0.04	+0.04
Conservation state	Good	-0.04	-0.04
	Bad (fragilities, bad conservation state, non-structural elements)	+0.04	+0.04

Scores for modifier factors for masonry and RC buildings pre-code (built before the introduction of the Algerian seismic code in 1981) adapted from those of the Risk-UE method [13].

4 Vulnerability assessment in the study area

4.1 Buildings in the old part of Algiers

According to the official statistics of 2018 [18], the city of Algiers accounted about 2 million inhabitants with an average density of 11000 inhabitants per km². Dense and old buildings stock, narrow streets and rugged topography characterize its urban situation. In addition, Algiers is located in zone III (zone of high seismicity) according to the seismic code RPA 99 version 2003 [19], and taking into account its historical seismicity, the most frequent EMS-intensities expected for the city are VII, VIII and IX [20]-[21]

Fig.1 shows the limits of the study area, covering two areas of Bab El Oued and Casbah, extended over 2.29 km². The most representative buildings in this area are masonry buildings built prior to 1960, as shown in Fig. 2 and Fig. 3. Masonry buildings are two to six stories height, made mostly of stone walls and wooden floor slabs, and openings of considerable size and number. Reinforced concrete buildings are few and mostly built in the period of 1950-1960 as shown in Fig. 3.

Fig. 1 –Limits of the study area (Satellite image captured by Google earth)

Casbah and Bab El Oued are the oldest districts of Algiers. Casbah has an area of 1.08 km² and more than 36700 inhabitants. The district contains the historical quarter classified as having world heritage status by the United Nations Educational Scientific and Cultural Organization UNESCO. Bab El Oued was constructed entirely between 1870 and 1954. It has an area of 1.21 km² and more than 61600 inhabitants. Unreinforced stone masonry buildings still represent a great part of buildings in this part of the city. However, buildings vary in architecture, dimensions, materials, design and construction procedure. In Casbah, earth was widely used as the main construction material during the Ottoman period. Buildings structural elements are of earth, adobe walls or dried earth bricks with wooden floor slabs. According to the EMS-98 scale classification [11] these buildings are treated as vulnerability class A. Residential dwelling buildings frequently contain a commercial ground floor and apartments above (Fig. 2). For this category of buildings, situated in the lower part of Casbah and in Bab El Oued, the predominant structural system is composed of load bearing external stone masonry walls and wooden floor slabs [22]-[23]. Some of these buildings have a regular structural layout with thick external walls distributed in both directions. Floors and roofs are made of wood, sometimes of stone or brick vaults in the first ground floor.

Fig. 2- Buildings in the old part of Algiers, (a) Masonry buildings in Bab El Oued (1870-1950), (b) Narrow streets and stairs between buildings in Casbah (1840-1854.)

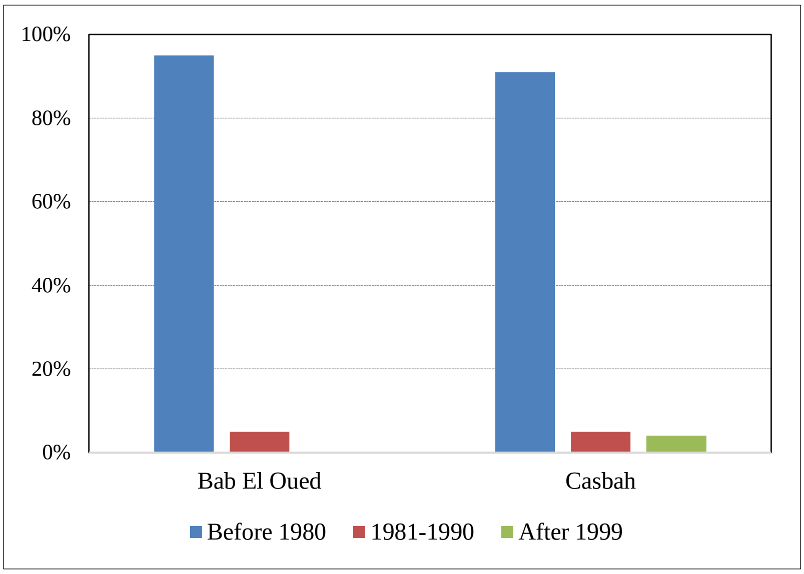


Fig. 3–Distribution of buildings in Casbah and Bab El Oued districts according to the construction period (Source: National Centre for Earthquake Engineering Research CGS)

4.2 Buildings inventory and damage assessment

The inventory was established using rapid visual inspection. It gathers buildings information recorded in each data form. Since full treatment of the buildings was not possible, arbitrary itineraries within each area were selected. For each building of the 1370 investigated buildings in the two surveyed areas of Bab El Oued and Casbah, and accordingly to the collected data form, each building is classified into a seismic category (structural type) with similar characteristics in terms of seismic performance (masonry, reinforced concrete, steel or wood). Then, corresponding subcategories are defined, e.g. adobe, simple stone … for masonry structures, and RC frame without ERD, RC frame with moderate ERD… for reinforced concrete structures. Final vulnerability class is assigned taken into account the structural type and the modifier parameters according to Table 1.

Using statistical processing of data, results indicate that: 83.3% of the investigated buildings are residential masonry buildings built before 1960, and 5.6% are residential RC buildings built before 1980 without ERD. According to EMS-98 definitions and modifier parameters analysis, about 97% of the investigated buildings are vulnerability classes A and B, with respectively 56% and 41%. Vulnerability class C represents 3% of the entire investigated buildings as shown in Fig. 4 and Fig. 5.

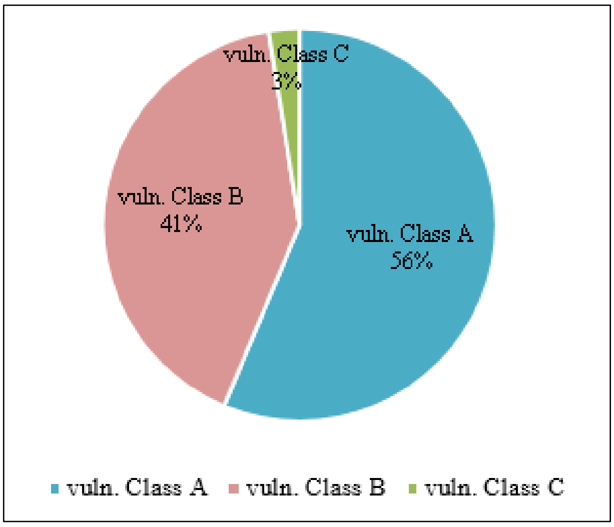


Fig. 4 - Distribution of buildings vulnerability classes according to EMS-98

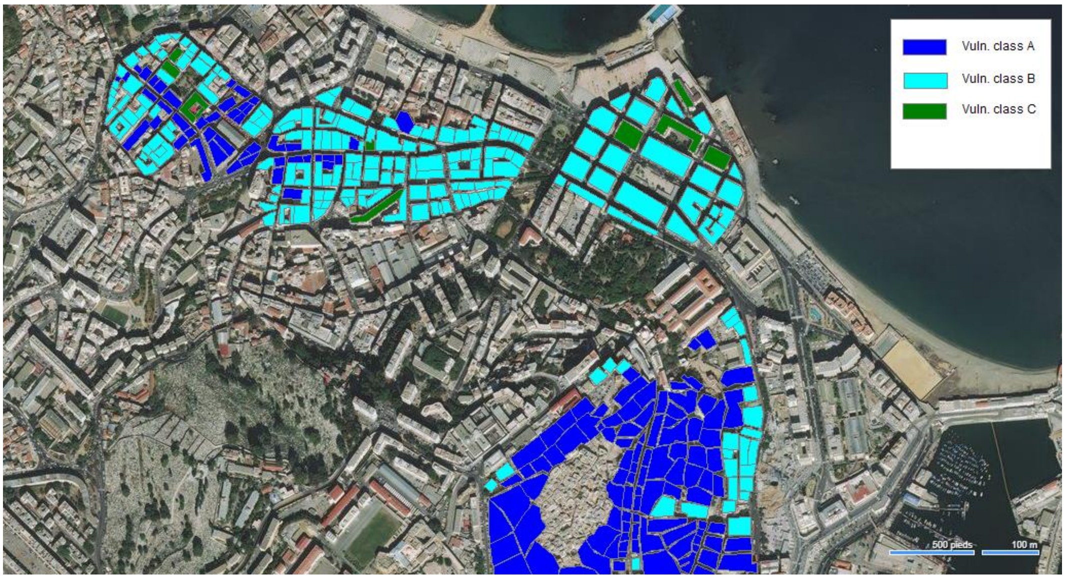


Fig. 5–Distribution of building vulnerability class within the study area

Figs. 6-(a) and 6-(b) show the distribution of the mean damage grade μ_D within each area, considering earthquake intensities I(EMS)=VIII and I(EMS)=IX corresponding to the strongest historically-felt earthquakes experienced in Algiers region. The mean damage grade μ_D is obtained using Eq. (1) as a function of the vulnerability index V and the intensity I. Once the vulnerability class is attributed to each building, using external characteristics, the probable vulnerability index $V_0$is assigned according to Table 1. By examining modifier parameters that can affect the building vulnerability, scores are evaluated and assigned according to Table 2. The final vulnerability value V is calculated as the sum of the probable vulnerability index V_0 and the scores of all parameters. Results indicate that the mean damage grade μ_D ranges between 1.5 and 3.5 for I(EMS)=VIII, which corresponds to moderate damage state (D_2) and substantial to heavy damage state according to Table 3[24]. Moreover, for I(EMS)=IX, the mean damage value μ_D ranges between 2.5 and 4.5 for the entire area, which corresponds to substantial (D_3) to very heavy damage state (D_4) (see Fig.6).

(a) (b)

Fig.6–Mean damage grade distribution in the study area (a) for I(EMS)=VIII, (b) I(EMS)=IX.

As shown in Fig.5, in Casbah the most preponderant vulnerability class is A, while in Bab El Oued is class B. Thus, buildings in Casbah are the most vulnerable. In terms of damage distribution (Fig.6), difference is shown for intensity I(EMS)=VIII, buildings in Bab El Oued will suffer moderate damage grade, while in Casbah buildings will undergo substantial to heavy damage. However, for seismic intensity I(EMS)=IX, buildings will suffer substantial to very heavy damage grade in both districts. Therefore, this part of the capital city can be identified as the most vulnerable to earthquakes.

Table 3 - Mean damage value intervals and damage states

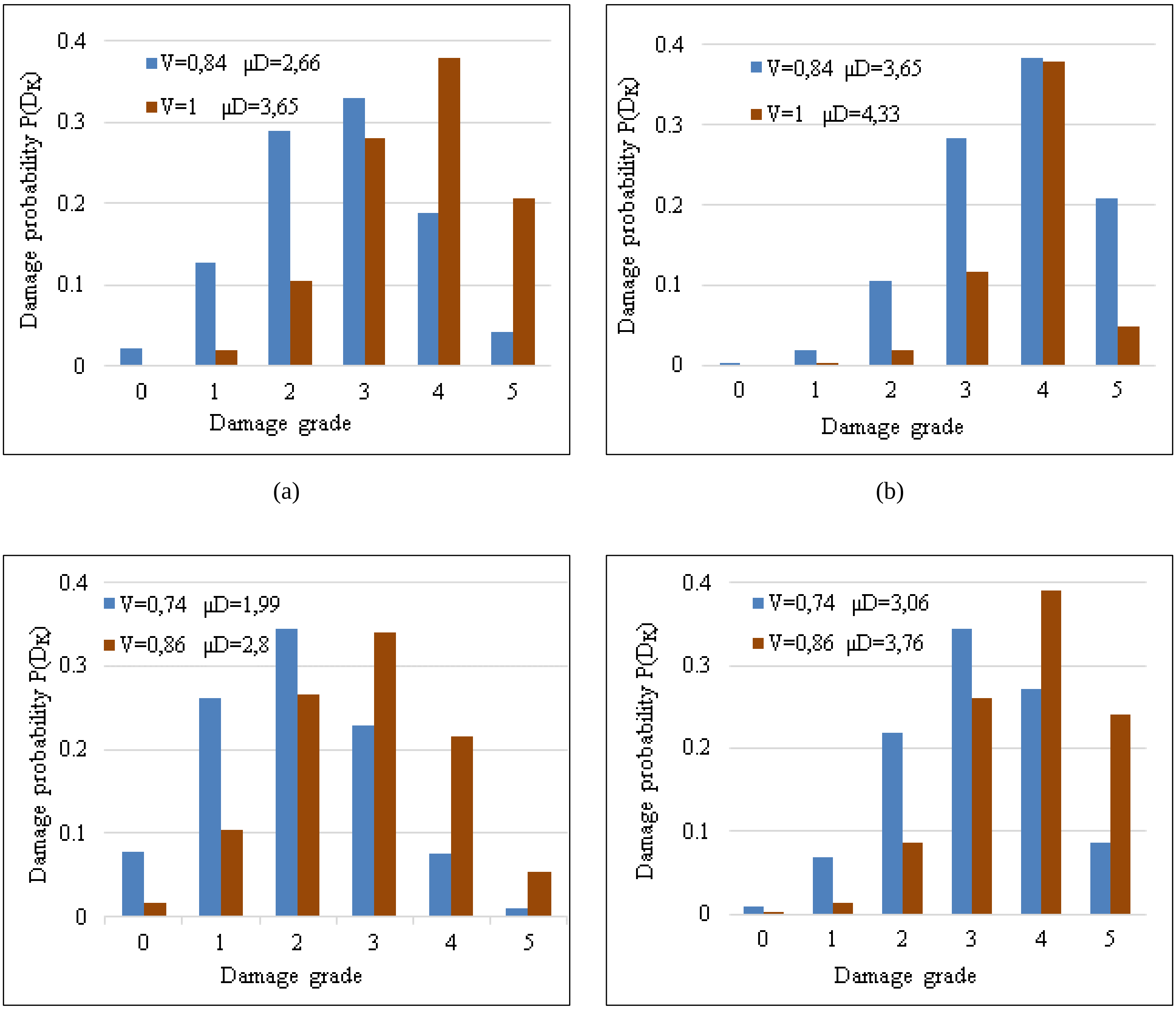
Mean damage intervals	Most probable damage state
0.0 - 0.5	None
0.5-1.5	Slight (D1)
1.5-2.5	Moderate (D2)
2.5 - 3.5	Substantial to heavy (D3)
3.5 - 4.5	Very heavy (D4
4.5 – 5.0	Destruction (D5)

Mean damage value intervals ($0 \leq \mu_D \leq 5$) [24] are appropriate for mapping damage distributions; each interval corresponds to a damage grade (state) as defined by the EMS-98 [11].

The vulnerability index assessment requires detailed information of buildings characteristics, while the process used to collect data based on rapid visual examination of buildings does not allow obtaining detailed information of the interior of the buildings. As mentioned previously, the final vulnerability value V is calculated as the sum of the probable vulnerability index V0 and the scores of all parameters. For example; for a typical mid-rise masonry building located in Casbah, made of earth brick, with irregular plan shape and bad state of conservation; the probable vulnerability class is A, V0=0.84 (Table 1), the modifier parameter scores are +0.02 and +0.04 (Table 2), so the final vulnerability index is V=0.84+0.02+0.04=0.9. Accordingly, for investigated buildings classified within vulnerability class A, the resulting value of V varies from 0.84 to 1, for buildings vulnerability class B, V varies from 0.74 to 0.86 and for buildings vulnerability class C, V varies from 0.64 to 0.72.

For each vulnerability class, the damage described by the EMS-98 scale for each degree of intensity may be reported in terms of damage probability matrix, expressing the probability $P(D_K)$ that the damage grades are reached by the buildings.

Using the binomial distribution with one parameter; μ_D, the probability $P(D_K)$ of having a damage grade, during a seismic event is obtained for intensities I(EMS)=VIII and I(EMS)=IX as shown in Fig.7.Damage histograms (Fig.7) show a gradual increase of the damage probability with the intensity for both vulnerability classes A and B. The damage probability increase also with the mean damage value μ_D, which is function of the vulnerability index V. Higher vulnerability index means greater probability of having substantial to very heavy damage.



(a) (b)

(c) (d)

Fig. 7. Damage probability $P(D_K)$ distribution histograms (a) Class A, I(EMS)=VIII, (b) Class A, I(EMS)=IX, (c) Class B, I(EMS)=VIII, (d) Class B, I(EMS)=IX

The results show that the buildings stock in Casbah and Bab El Oued areas has an average vulnerability class A and B, and the expected damage, corresponding to substantial to very heavy damage, will cover the major part of surveyed area for a macroseismic intensity I(EMS)=IX. These vulnerability results depend on the building information assessed and the method to adapt this information into vulnerability values [25]. As previously noted, uncertainty in vulnerability is due to various elements, essentially the rapid visual inspection where building interior details are neglected. In fact, in some cases of masonry buildings, determining exact structural type is very uncertain when using exterior visual examination only. Assigning vulnerability ranges to the probable values considering modifier parameters is also a source uncertainty because it depends of personal opinion of building inspectors.

5 Conclusion

The seismic vulnerability assessment for current buildings in the old part of Algiers was performed using a rapid visual examination and an evaluation method based on the EMS-98 definitions. Vulnerability classes were assigned to buildings depending essentially on the type of structure. The vulnerability was performed by means of damage assessment and vulnerability index considering modifier parameters.

Results lead to the conclusion that the building stock in the old part of Algiers is vulnerable and in case of moderate to strong earthquake, damage will cover most the area, since many old fragile buildings with deficient seismic quality are concentrated in this area. Poor behaviour of unreinforced stone masonry buildings, that show highest expected vulnerability, is due to their heavy weight, poor conservation condition and probably to the manner in which the walls have been built, connected and anchored at the floor levels. Therefore, the results obtained correlate well with the built characteristics.

Empirical methods for vulnerability evaluation based on field observation require less information about the structure, which can be collected by a rapid visual examination. Despite some elements of uncertainty in the process, it remains more practical in case of urban area evaluation. Therefore, vulnerability results depend on the data assessed, the evaluation method applied and the personal judgment of building inspectors.

The evaluation of existing buildings in urban area is an important step in vulnerability and risk assessment projects. Evaluation of seismic damage is essential to decide on appropriate measures to undertake in order reduce seismic vulnerability and risk, by improving buildings seismic performance.

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REFERENCES

[1]- A.H. Barbat, S. Lagomarsino, L.G. Pujades, Vulnerability assessment of dwelling building. In Assessing and managing earthquake risk. Geotechnical, Geological and Earthquake Engineering book series. Springer, Dordrecht, 2006, pp.115-134. doi:10.1007/978-1-4020-3608-8

[2]- R. V. Whitman, J.W. Reed, S.T. Hong, Earthquake damage probability matrices. In: Proceeding of the Fifth World Conference on Earthquake Engineering, Rome, 1973, pp.2531–2540.

[3]- GNDT: Gruppo Nazionale per la Difesadai Terremoti, Scheda di esposizione e vulnerabilità e di rilevamentodanni di primo livello e secondo livello (muratura e cementoarmato), Roma, 1994.

[4]- ATC, Seismic evaluation and retrofit of concrete buildings. Applied Technology Council, California, 1996.

[5]- HAZUS, Earthquake loss estimation methodology technical manual. National Institute of Building Sciences, Federal Emergency Management Agency (FEMA), Washington, DC, 1999.

[6]- R. Vicente, H. Varum, J.A.R. Mendes da Silva, Seismic vulnerability assessment of buildings in the old city centre of Coimbra. In: Proceedings of the international conference 250th anniversary of the 1755 Lisbon earthquake, Lisbon, 2005, pp. 206–213.

[7]- R. Vicente, S. Parodi, S. Lagomarsino, H. Varum, J.A.R. Mendes Silva, Seismic vulnerability and risk assessment: case study of the historic city centre of Coimbra, Portugal. Bull. Earthq. Eng. 9 (2011) 1067–1096. doi:10.1007/s10518-010-9233-3

[8]- A. H. Barbat, M. L. Carreño, L. G. Pujades, N. Lantada, O. D. Cardona, M. C. Murulanda, Seismic vulnerability and risk evaluation methods for urban areas. A review with application to a pilot area. Struct. Infrastruct. Eng. 6(1–2) (2010)17–38. doi:10.1080/15732470802663763

[9]- G. M. Calvi, R. Pinho, G. Magenes, J. J. Bommer, L. F. Restrepo-Vélez, H. Crowley, Development of seismic vulnerability assessment methodologies over the past 30 years. ISET J. Earthq. Technol. 43(3) (2006)75-104.

[10]- ATC-21, Rapid visual screening of building for potential seismic hazards: a handbook. Applied Technology Council, FEMA 145, Redwood city, California, 1988.

[11]- G. Grünthal, European Macroseismic Scale EMS-98. Cahier du Centre Européen de Géodynamique et de Séismologie, vol. 15, Luxembourg, 1998.

[12]- Z. V. Milutinoviç, G. S. Trendafiloski,WP04: Vulnerability of current buildings handbook. RISK-UE project: an advanced approach to earthquake risk scenarios with applications to different European towns. Contract No. EVK4-CT-2000-00014, Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje, 2003.

[13]- S. Giovinazzi, S. Lagomarsino, AMacroseismic Method for the Vulnerability Assessment of Buildings. In: Proceedings of the 13th World Conference on Earthquake Engineering, Vancouver, 2004, pp. 1-6.

[14]- S. Martinez-Cuevas, Urban modifiers of seismic vulnerability aimed at Urban Zoning Regulations. Bull. Earthq. Eng. 15 (2017)4719–4750. doi:10.1007/s10518-017-0162-2

[15]- CTC, Règles parasismiques Algeriennes RPA81. Algiers, 1981.

[16]- D. Benedetti, V. Petrini, Sulla vulnerabilitasismica di edifici in muratura: unmetodo di valutazione. A method for evaluating the seismic vulnerability of masonry buildings. L'industria delle Construzioni. 149(1984) 66–78.

[17]- S. Lagomarsino, S. Giovinazzi, Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bull. Earthq. Eng. 4(4) (2006) 415-443. doi:10.1007/s10518-006-9024-z

[18]- ONS, Recensement Général de l'Habitat et de la Population 2018. Office National des Statistiques, 2018.

[19]- DTR/B-C 2-48-2003, Algerian seismic code RPA2003. National Center for Applied Research in Earthquake Engineering (CGS), 2003.

[20]- M. S. Boughacha, M. Ouyed, A.Ayadi, H. Benhallou, Seismicity and seismic hazard mapping of northern Algeria: Map of Maximum Calculated Intensities (MCI). J. Seismol. 8(1) (2004)1-10. doi:10.1023/B:JOSE.0000009513.11031.43

[21]- M. Hamdache, J. A.Peláez, A.Talbi, C.A. López Casado, A unified catalog of main earthquakes for northern Algeria from A.D. 856 to 2008. Seismol. Res. Lett. 81(5) (2010)732-739. doi:10.1785/gssrl.81.5.732

[22]- M. N. Farsi, F. Lazzali, Y. Ait-Meziane, Stone masonry apartment buildings. Report 75, World Housing Encyclopedia, EERI, 2002.

[23]- F. Lazzali, S. Bedaoui, Seismic Performance of masonry buildings in Algeria. In Issue of International Conference on Construction and Building Materials, Paris, 2012, pp. 397-401.

[24]- N. Lantada, J. Irizarry, A. H.Barbat, X.Goula, A. Roca, T.Susagna, L.G. Pujades, Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE vulnerability index method. Bull. Earthq. Eng. 8(2010) 201–229. doi:10.1007/s10518-009-9148-z

[25]- S. Steimen, D. Fäh, D. Giardini, M. Bertogg, S. Tschudi, Reliability of Building Inventories in Seismic Prone Regions. Bull. Earthq. Eng. 2(2004) 361–388. doi:10.1007/s10518-004-3806-y