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# Assessing fragility functions of unreinforced masonry buildings

# Avaliando funções de fragilidade de edifícios de alvenaria sem reforço

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## ABSTRACT

The seismic vulnerability entrenched within the historical urban landscapes of Algeria serves as a poignant reminder of the pressing need for comprehensive risk management strategies, particularly concerning low and medium height unreinforced masonry (URM) structures. These architectural gems, rich in cultural significance, stand as tangible embodiments of Algeria's storied past. However, their susceptibility to seismic disturbances presents an immediate threat, demanding meticulous attention and innovative methodologies for effective risk assessment and mitigation. In a pioneering scholarly pursuit, this research embarks on an ambitious exploration, melding fragility functions and a sophisticated vulnerability index method to unravel the intricate tapestry of seismic risk assessment. Through the lens of fragility functions, the study delves into a nuanced analysis, probabilistically delineating the vulnerabilities entrenched within the complex framework of URM buildings. Furthermore, the meticulous derivation of vulnerability functions via the vulnerability index method enhances the granularity of risk assessment, providing a multifaceted perspective to discern vulnerabilities accurately. Central to this investigation is the Belouizdad district, a microcosm of historical significance nestled within the vibrant metropolis of Algiers. By scrutinizing seismic scenarios spanning a spectrum of intensities (ranging from VII to X), the study orchestrates a symphony of empirical data and analytical prowess, unraveling the potential seismic reverberations poised to impact the district's architectural heritage. In essence, this scholarly endeavor transcends the confines of mere academic pursuit, serving as a guiding light illuminating the path towards tailored seismic reduction policies. It stands as a clarion call to safeguard Algeria's architectural patrimony, fostering resilience amidst the tremors of uncertainty and ensuring the preservation of its cultural legacy for generations to come.

**Keywords:** URM building, seismic action, fragility function, vulnerability index, Damages, GIS.

**RESUMO**

A vulnerabilidade sísmica enraizada na paisagem urbana histórica da Argélia serve como um lembrete comovente da necessidade premente de estratégias abrangentes de gestão de riscos, especialmente em relação às estruturas de alvenaria não reforçada de baixa e média altura (URM). Essas jóias arquitetônicas, ricas em significado cultural, são verdadeiras representações tangíveis do passado marcante da Argélia. No entanto, sua suscetibilidade a distúrbios sísmicos apresenta uma ameaça imediata, exigindo atenção meticulosa e metodologias inovadoras para uma avaliação e mitigação de riscos eficazes. Nesta busca acadêmica pioneira, esta pesquisa embarca em uma exploração ambiciosa, combinando funções de fragilidade e um sofisticado método de índice de vulnerabilidade para desvendar a intrincada tapeçaria da avaliação de riscos sísmicos. Através da lente das funções de fragilidade, o estudo se aprofunda em uma análise sutil, delineando probabilisticamente as vulnerabilidades enraizadas na estrutura complexa dos edifícios de URM. Além disso, a derivação meticulosa de funções de vulnerabilidade através do método de índice de vulnerabilidade aprimora a granularidade da avaliação de riscos, fornecendo uma perspectiva multifacetada para discernir vulnerabilidades com precisão. Central nesta investigação está o distrito de Belouizdad, um microcosmo de significado histórico situado na vibrante metrópole de Argel. Ao examinar cenários sísmicos abrangendo um espectro de intensidades (variando de VII a X), o estudo orquestra uma sinfonia de dados empíricos e habilidades analíticas, desvendando as potenciais reverberações sísmicas prestes a impactar o patrimônio arquitetônico do distrito. Em essência, esta busca acadêmica transcende os limites do mero empenho acadêmico, servindo como uma luz orientadora iluminando o caminho rumo a políticas de redução sísmica adaptadas. Ela se destaca como um chamado claro para salvaguardar o patrimônio arquitetônico da Argélia, promovendo a resiliência em meio às tremulações da incerteza e garantindo a preservação de seu legado cultural para as gerações futuras.

**Palavras-chave:** edificio de alvenaria sem reforço, ação sismica, função de fragilidade, indice de vulnerabilidade, danos, SIG.

## 1 INTRODUCTION

Most of the buildings constructed before the sixties in Algiers and its suburb are typically low and mid-rise multi-storey buildings, made of stone and/or brick masonry walls or infill light steel framing. These buildings were constructed according to construction procedures where seismic regulations were not fully implemented. The main characteristics of masonry buildings are high rigidity, low tensile and shear strength, low ductility and shear capacity. These types of constructions are known to be vulnerable to seismic hazard. This was particularly noted during recent earthquakes that stroke many regions in Algeria such as, Ain-Temouchent in 1999 and Boumerdes in 2003 where post-seismic investigations have shown extensive damages to such structures.

Seismic vulnerability evaluation of existing buildings has become really relevant in the last decades due to the frequent occurrence of earthquakes. It is clear hence that earthquake risk reduction policy should concentrated on masonry structures since they still make up today a very large proportion of the world's existing building stock.

Thus, seismic risk assessments were carried out on populations of buildings to identify the buildings most likely to undergo losses during an earthquake. The results of such studies are important in the mitigation of losses under future seismic events as they allow strengthening intervention and disaster management plans to be drawn up. They are based on the use of vulnerability and fragility curves [1, 2] to assess the mean amount of damage and the damage distribution overall buildings with similar characteristics in relation to the event intensity.

So, vulnerability index methods [3, 4 and 5] were used to classify masonry buildings according to their vulnerability. They allow quick loss estimation of all buildings grouped in the same type. Vulnerability curves are then used to obtain a synthetic result of the mean damage to buildings in a selected territory. In the same context other methods have been developed recently such as the RISK-UE method [6, 7], the Rapid Visual Screening (RVS) [8], the modified vulnerability index [9] and the method given in the ReLUIS Project [10].

Vulnerability functions are generally developed from “Damage Probability Matrices” (DPM) [11, 12 and 13]. They can be also generated from existing vulnerability curves of region using translation method [14]. Several DPM and vulnerability functions were used or developed throughout the world by different authors [15, 16, 17, 18 and 19]. Damage scenarios have been also developed for different cities like Potenza [20, 21], Celano [22], Barcelona [23], Marmara Sea region (Turkey) [24], Granada (Spain) [25] and Istambul [26, 27] using these functions.Likewise, fragility curves are an effective tool for risk assessment of structural systems as they can be used for probabilistic estimation of seismic losses and eventually enables decision-making activities for seismic risk reduction [28]. Fragility curves for unreinforced masonry (URM) structures are currently available from HAZUS [29] but there are subjectively constructed based on expert opinion [30]. Others fragility curves were performed by different authors over the world. Among them, it can be distinguished Risk-Ue project [7], Park et al. [28], Saeidi et al. [31], Rota et al. [32], Illampas and al. [33], Despotaki and al. [34] and Cabrera and al. [35].

The objective of this study is to develop fragility curves for URM buildings using vulnerability curves derived from vulnerability index method and perform seismic scenarios. The district of Belouizdad in the city of Algiers is used as a case study.

## 2 TECHNICS AND METHODS

### 2.1 VULNERABILITY INDEX METHOD

The method consists in attributing a numerical value to each studied building. This number is called "Vulnerability Index (VI)". It is obtained by a sum of value giving the level of vulnerability of the structural and non-structural identified parameters which have an influence on the seismic behavior of the considered building. Similar studies have been conducted for reinforced concrete constructions [40], reinforced masonry structures [41] and steel buildings [42]. In the present study twelve (12) parameters were identified. The level of vulnerability of each parameter referred here as coefficient Ki, is ranged in four classes. Class C1 refers to situation considered conform to Algerian seismic code in use. C2 and C3 refer to situation considered conform to ancient's Algerian codes and C4 refers to unsafe configurations. The Ki values are given in Table 1 and are obtained by a statistical survey, based on Algerian past earthquake data [36-39].

The vulnerability index (eq. 1) is expressed as:

$$VI = \sum_{i=1}^{12} k_i \quad (1)$$

Table 1: Weighting parameters values [36-39]

| Parameter | Coefficient $k_i$ | | | |
|---|---|---|---|---|
| | **C1** | **C2** | **C3** | **C4** |
| 1. Total shear resistance of walls | 0 | 0.05 | 0.12 | 0.21 |
| 2.Plan regularity | 0 | 0.01 | 0.04 | 0.07 |
| 3.Elevation regularity | 0 | 0.01 | 0.04 | 0.07 |
| 4.Walls connection | 0 | 0.03 | 0.07 | 0.10 |
| 5. Walls type | 0 | 0.01 | 0.03 | 0.05 |
| 6. Floor | 0 | 0.01 | 0.03 | 0.05 |
| 7. Roof | 0 | 0.01 | 0.03 | 0.05 |
| 8.Soil conditions | 0 | 0.02 | 0.06 | 0.10 |
| 9.Pounding effect | 0 | 0.01 | 0.04 | 0.07 |
| 10. Modifications | 0 | 0.01 | 0.04 | 0.07 |
| 11. Details | 0 | 0.00 | 0.02 | 0.03 |
| 12.General maintenance conditions | 0 | 0.03 | 0.08 | 0.13 |

Source: Authors.

Three vulnerability classes are proposed (Green, Orange and Red), describing the state of masonry structures. This classification is given in table2 [16, 19].

Table 2: URM masonry structures classification according to the Vulnerability Index

| **Class** | **P1 - Green** | **P2 - Orange** | **P3 - Rouge** |
|---|---|---|---|
| VI | 0.0 – 0.20 | 0.20 – 0.60 | 0.60 – 1.00 |

Source: Authors.

An investigation of URM masonry structures was conducted in the Belouizdad city of Algiers Figure 1. This commune of the capital is located east of Algiers and has an area of 2.16 km² with a population density of 20,394 inhabitants/km². The number of existing masonry buildings is 643 buildings. These are mainly made of stone walls and / or bricks with an average thickness of 60 cm, the floor is mostly vaulted. Let us note that the heritage of the Algerian masonry constructions is old dating from the colonial time between 1830 and 1962. During this period the construction in Algiers knew great evolutions on the urbanistic and architectural plans and evolved according to 4 phases (1830-1854; 1854-1881; 1881-1915; 1915- 1962) [36].

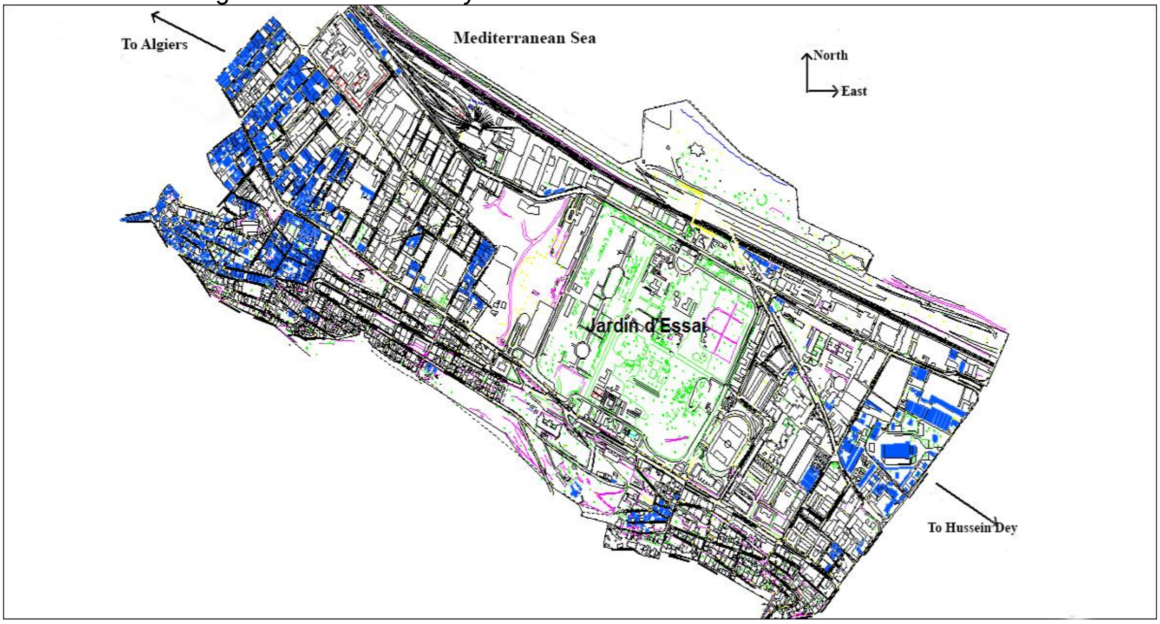
Figure 1: Belouizdad with the sea front - Belouizdad street

Source: Authors.

All the buildings in the municipality were surveyed according to the data sheet developed in [36].

The data thus collected was recorded in a Geographic Information System (GIS). This was done for a better management and representation of the data, as well as for an easier interpretation of the results. A GIS view of the commune is shown in Figure 2.

Figure 2: URM Masonry constructions in the district of Belouizdad




Source: Authors.

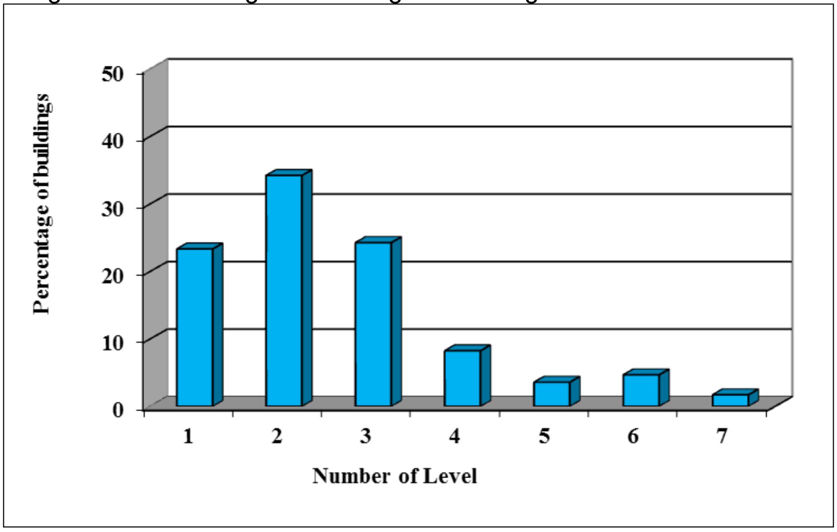
The buildings in the district range from level 1 to level 7. The distribution of these buildings is given in Table 3 and a graph representation is given in Figure 3.

Table 3: Number of buildings according to the amount of floors

| Level | Number of buildings |
|---|---|
| 1 | 150 |
| 2 | 220 |
| 3 | 156 |
| 4 | 53 |
| 5 | 23 |
| 6 | 30 |
| 7 | 11 |

Source: Authors.

Figure 3: Percentage of buildings according to the number of floors




Source: Authors.

It can be seen that the buildings with 2 level are predominant with a percentage of 34.21% of the total number. The ground floor and second floor buildings have comparable percentages of about 20%. This represents more than 70% of the masonry buildings. The other buildings have lower percentages.

In addition, the data relating to the date of construction of the buildings in masonry of the district are not all available. We only have this information is available only for a sample of 138 buildings. These buildings are classified according to the classification given in Table 4 and a graph representation is shown in Figure 4.

Table 4: buildings Classification according to their construction period

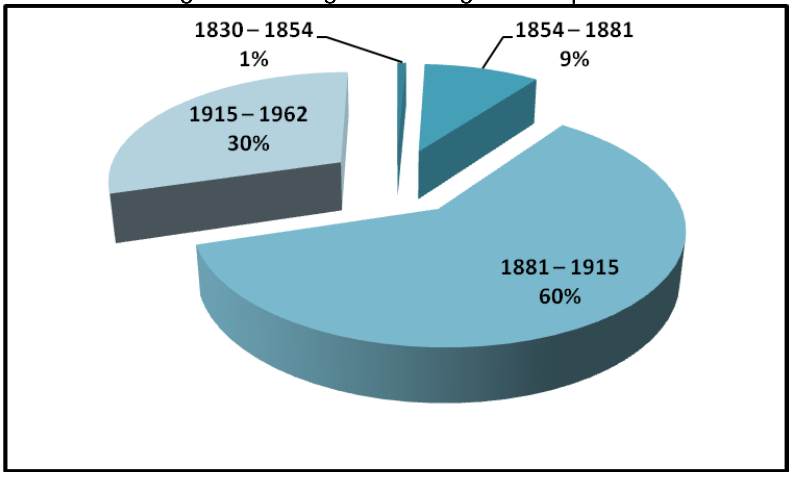
| year | Number of buildings |
|---|---|
| 1830 – 1854 | 1 |
| 1854 – 1881 | 13 |
| 1881 – 1915 | 83 |
| 1915 – 1962 | 41 |

Source: Authors.

It can be noticed that for the period from 1830 to 1854, there is only a very small percentage of buildings because there are not many buildings left from this period which coincides with the beginning of the colonial period and the end of the Ottoman period.

During the second phase (1854-1881), there was a revival of construction, because it was the beginning of the development of the territory during the colonial period. There are a number of 13 buildings.

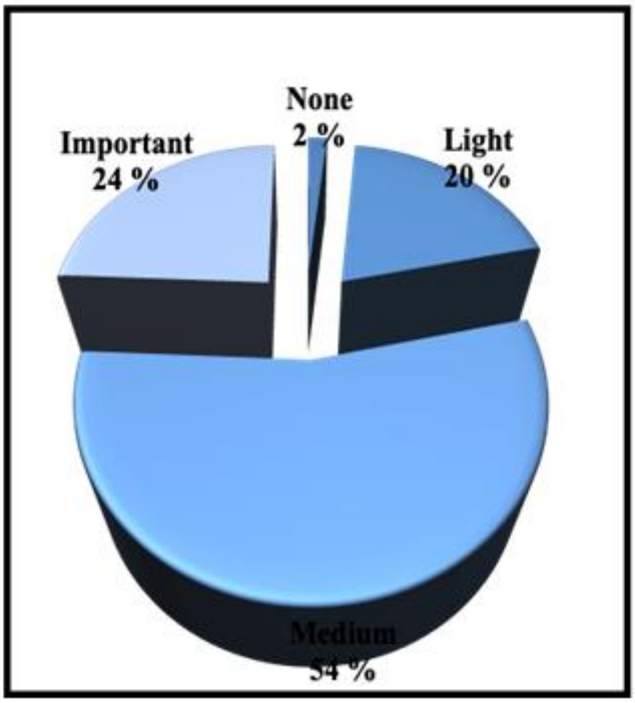
Figure 4: Percentage of buildings according to their period of construction.




Source: Authors.

The peak in the number of buildings constructed was reached during the third phase (1881-1915) with 83 buildings representing 60.14% of the total number. We can see the expansion of the height of the buildings up to level 7 is observed. This is due to the French legislation of 1884, which allows for the retreat of the roof with steep slopes, to gain two floors. During the fourth phase (1915-1962), a decline in the number of buildings built (41 buildings) compared to the previous period is noted, this is due to the emergence of the technique of construction in reinforced concrete from 1930. Note that very few of the buildings analyzed have not undergone any modification of their original state (2%). More than half of the buildings have undergone average transformations, while the percentage of the constructions having accused important modification are around 20%.

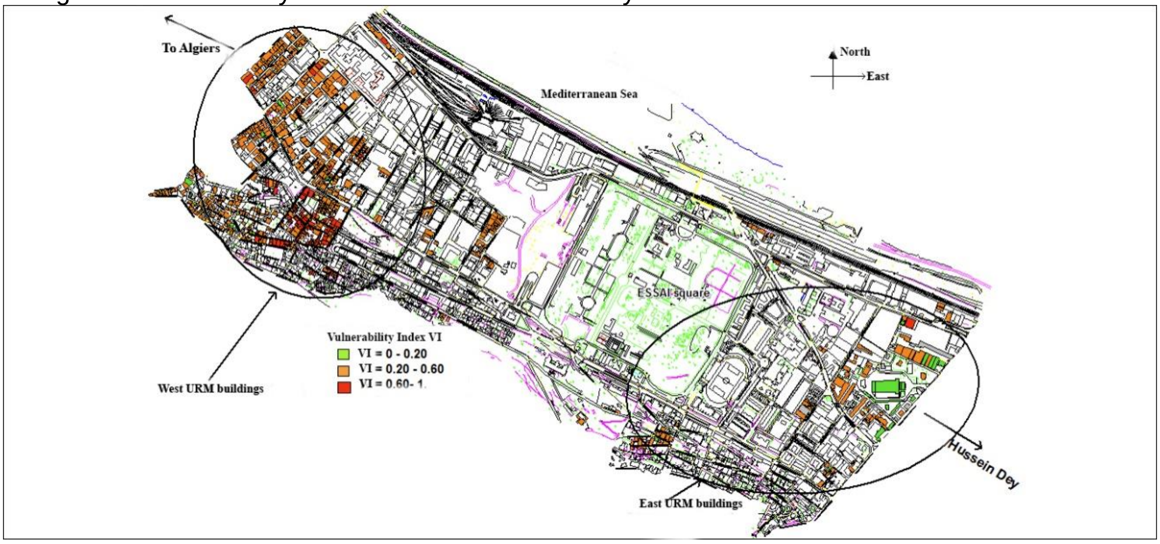
Figure 5: Distribution of buildings according to the parameter 'modifications'




Source: Authors.

The survey allowed the calculation of the vulnerability index of URM masonry structures, according to the vulnerability index method. The results obtained are represented on GIS (Figure 6).

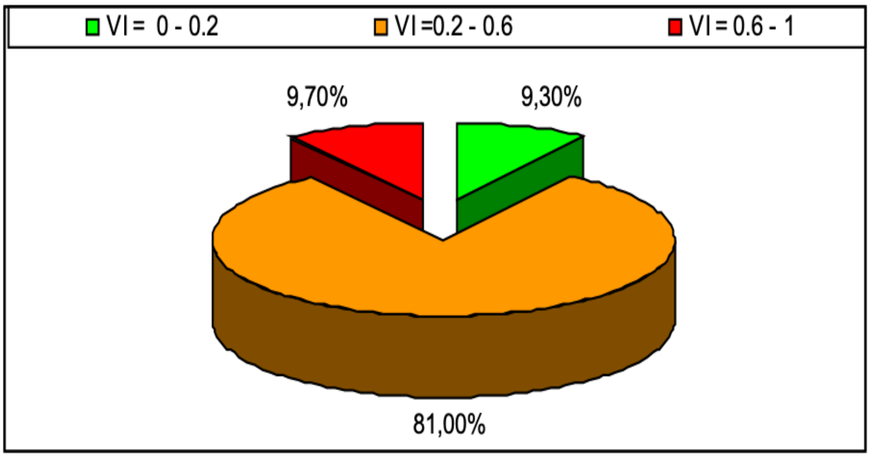
Figure 6: Vulnerability distribution of URM Masonry constructions in the district of Belouizdad




Source: Authors.

The results of the study show that about 80% of masonry buildings in the town of Belouizdad have an average seismic quality. Indeed, the vulnerability indices for 508 buildings are between 0.20 and 0.60 which reflects an average vulnerability of the latter and nearly 10% of buildings are very vulnerable to seismic action see Figure 7.

Figure 7: Distribution of the seismic vulnerability of buildings in the municipality



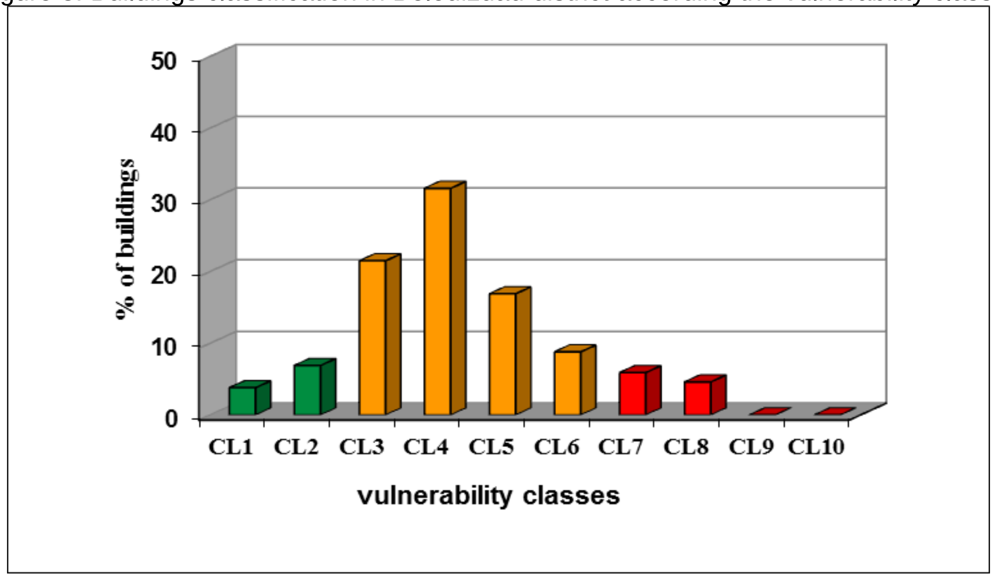

Source: Authors.

Thus about 90% of the heritage of the commune of Belouizdad is vulnerable and requires intervention for strengthening or replacement. These results can be explained by the age of construction, poor maintenance of buildings and modifications to structures, which considerably increase their vulnerability.

## 2.2 VULNERABILITY FUNCTION

The methodology given by Huo and al. in [14] allows the translation of buildings vulnerability functions from city to city by systematically considering the differences in buildings design codes in the reference and target city. So, Algiers (Algeria) vulnerability functions of URM buildings were deduced from those obtained for Friuli (Italy), an area which has same kind of masonry structuresand quite same geological conditions. They are function on the Mercally Modified Intensity (MMI) versus the Mean Damage Ratio (MDR) in percentage. These curves depend on the vulnerability index of the considered building. This vulnerability index (VI) is set varying from zero (no damage) to one (collapse). A step of 0.1 is taken in order to finely represent the vulnerability of masonry constructions in the district of Belouizdad. Ten vulnerability classes were considered. This step has been also considered to get closer to the classes of vulnerability adopted by Benedetti [4] to establish the matrix of probability of damage (DPM) after the earthquake of Friuli in 1976. Note that it is on the basis of this DPM that we have made the translation of the Italian curves to the Algerian curves while based on the seismic codes of the two countrieswas performed. Figure 8 shows the distribution of masonry buildings according to the classes of vulnerability. The ten classes of vulnerability CL1(VI=0.-0.1), CL2(VI=0.1-0.2), CL3(VI=0.2-0.3), ...,CL9(VI=0.8-0.9) and CL10(VI=0.9-1) are respectively representative of buildings with a decreasing seismic quality

Figure 8: Buildings classification in Belouizdad district according the vulnerability classes




Source: Authors.

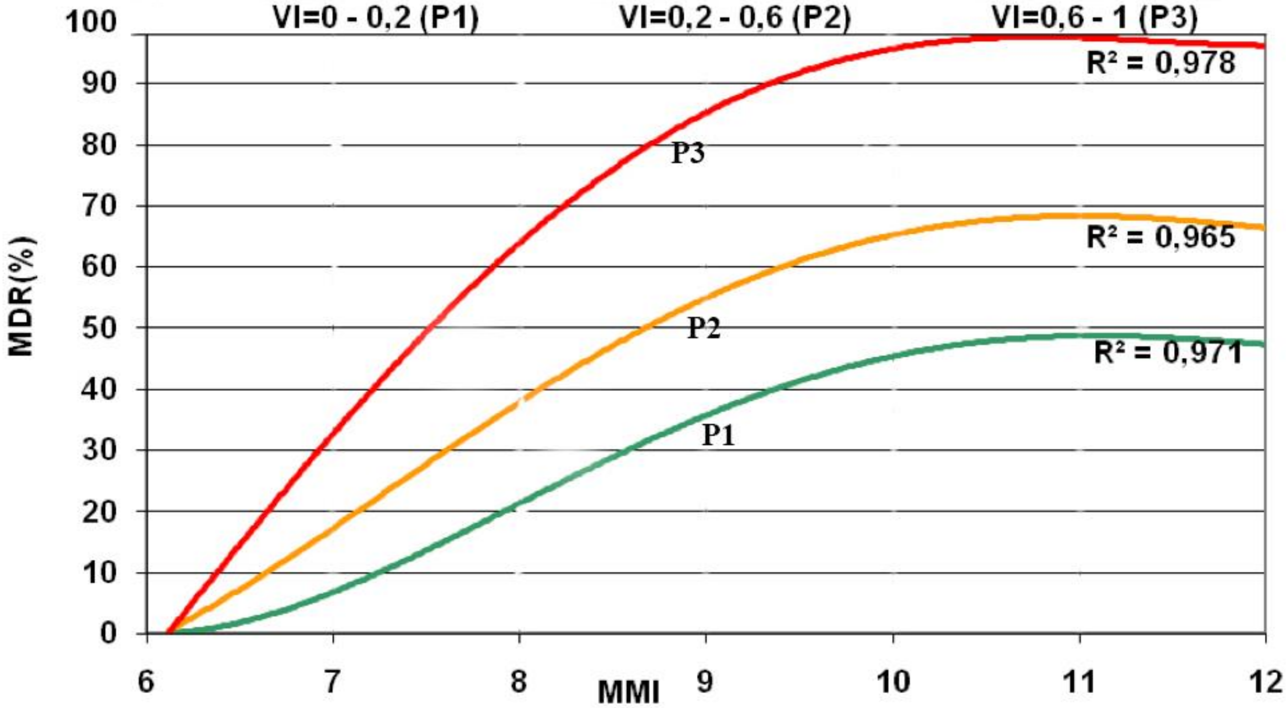
Thus classes CL1 and CL2 represent buildings with a low seismic vulnerability.

Classes CL3 to CL6 represent buildings with a medium seismic vulnerability.

Finally, classes CL9 and CL10 represent constructions with a high seismic vulnerability.

We represent in Figure 9 the Algerian vulnerability curves [36, 37] obtained for the 10 classes of buildings. The translation of the reference curves to the target curves is obtained by a shift along theaxis of MMI intensity equal to 0.12 and a rotation MDR variable from one curve to another.

Figure 9 – Algerian vulnerability curves for URM buildings [36, 37]




Source: Authors.

The analytical representation of the vulnerability curves allows the link between the mean damage ratio (MDR), the intensity and the vulnerability index (VI). These analytical functions are obtained byinterpolation of established vulnerability curves and were integrated into a geographic information system (GIS) to perform seismic scenarios.

To each vulnerability class, (VI = 0.2 for P1, VI = 0.6 for P2 and VI = 1 for P3), a relation damage rate/seismic intensity is associated, the following analytical functions equations (2 and 3) are proposed:

$$MDR(VI, I) = (-3.65VI - 0.56)[I + 1.52Ln(VI) - 15.77][I + 0.11Ln(VI) - 6.11] I = 6.3, 11 \quad (2)$$

$$MDR(VI,12)=MDR(VI,11) \quad (3)$$

## 2.3 FRAGILITY CURVES ASSESSMENT

Fragility curves provide the probability of reaching or exceeding a given damage state as a function of the intensity of the seismic event. Usually they are modeled by lognormal functions. A very important point is that fragility curves clearly take into account that not all buildings of the same type will suffer the same level of damage for a given event intensity [43].

### 2.3.1 Damage Level

To link the MDR given by the developed vulnerability curves to the damage level, the definitions given by Park and Ang in [43] are used. These definitions are summarized in Table 5 and will be used to build fragility functions.

Table 5: Limit states damage [43].

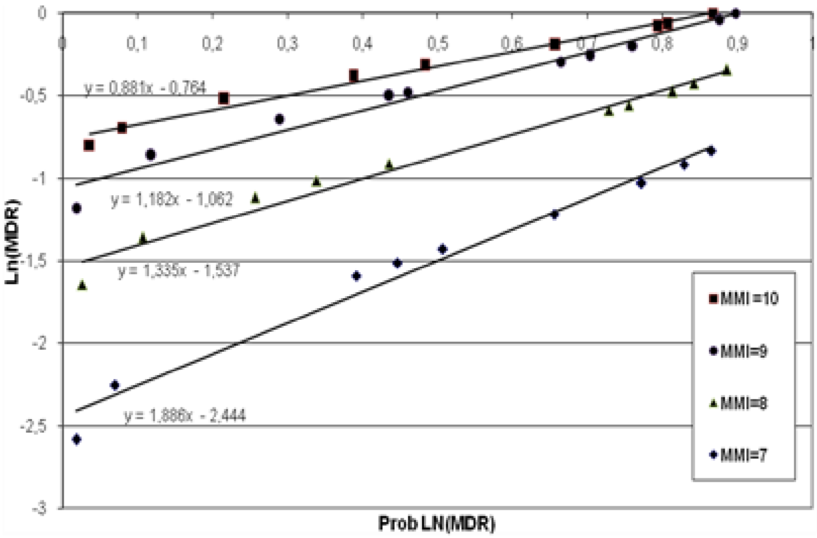
| Damage categories | Damage level |
|---|---|
| Negligible | Non-structural = 0.01 – 0.1 |
| Minor | Light structural damage = 0.1 – 0.2 |
| Moderate | Moderate structural damage = 0.2 – 0.5 |
| Severe | Severe structural damage = 0.5 – 0.85 |
| Collapse | Collapse = 0.85 – 1. |

Source: Williams and Sexsmith, 1985

### 2.3.2 Damage Measure and Performance Level

Defining a measure for quantifying the buildings seismic damage is the first important step of fragility analysis. In the case of URM buildings, FEMA 356 defined three performance levels and HAZUS [29] defined four limit states (Slight damage, moderate damage, extensive damage and collapse damage). In this study the limit states defined by Park and Ang. are adopted and the fragility curves are developed accordingly. Figure11 shows the mean damage ratio (MDR) distribution for URM structures for different earthquake intensity levels. According to Park et al. [28], a log-normal distribution for the statistical description of the building response is a reasonable assumption. The log-normal mean ($\mu_{\ln D}$) and the standard deviation ($\sigma_{\ln D}$), necessary to describe the log-normal distribution, can be estimated from the log-normal probability plot of the data points (Figure 10).

Figure 10: Log-normal fitting of fragility




Source: Authors.

The log-normal mean and the standard deviation are estimated from the y-intercept and the slope of the fitted line respectively. The log-normal parameters for description of fragility curves are given in Table 6.

Table 6: Log-normal parameters

| MMI | $\mu_{\ln D}$ | $\sigma_{\ln D}$ |
|---|---|---|
| 7 | -2.444 | 1.886 |
| 8 | -1.537 | 1.335 |
| 9 | -1.062 | 1.182 |
| 10 | -0.764 | 0.881 |

Source: Authors.

The variance of MMI 7 is higher than that of MMI 10 for instance, as the slope of MMI 7 is steeper than that of MMI 10.

## 3 RESULTS AND DISCUSSION

### 3.1 CONSTRUCTION OF FRAGILITY CURVES

The probability of exceedance of the different limit states damage (None Damage = 0.01, Light Damage = 0.1, Moderate Damage = 0.2, Sever Damage = 0.5, Collapse = 0.85) of the structure can then be calculated using the obtained log-normal parameters as given in Eq. (4) where Φ(.) denotes standard normal cumulative distribution function (CDF).

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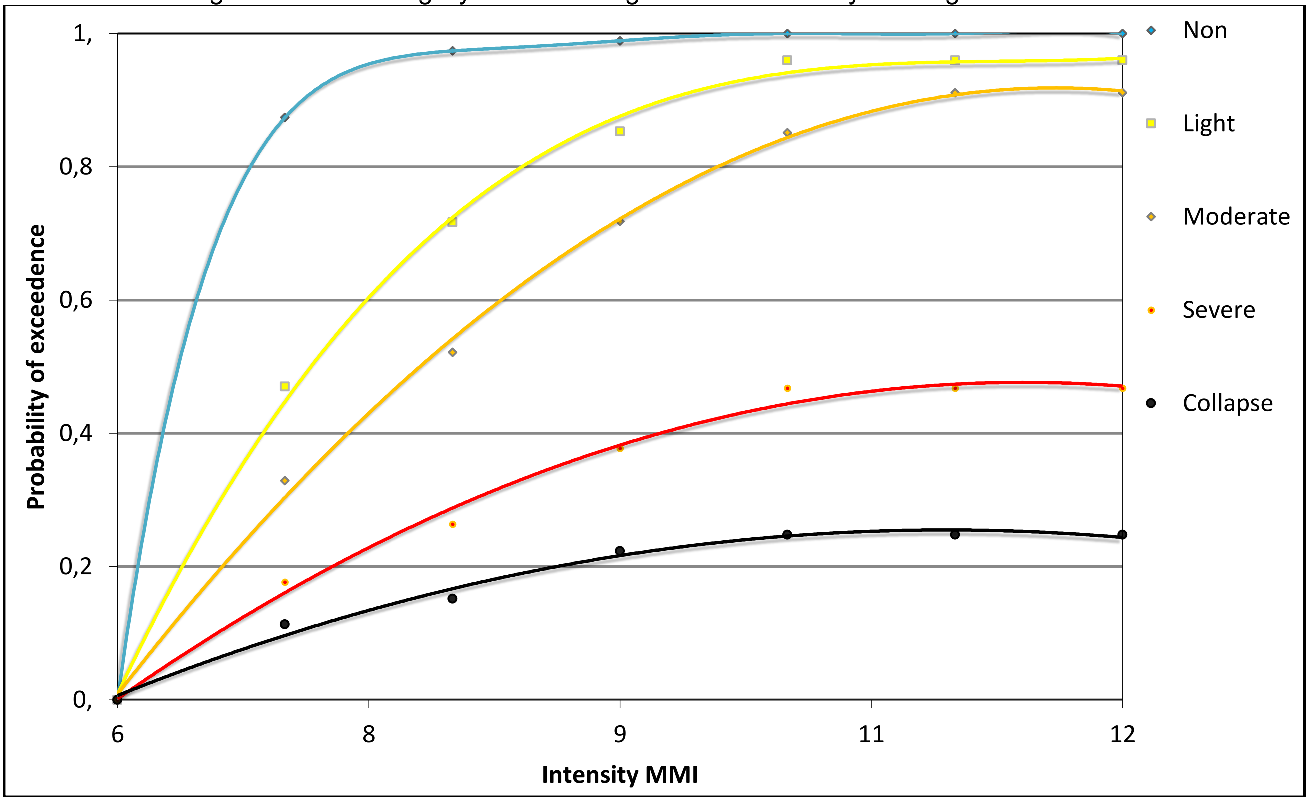
$$P(D > D_{limstate}/I) = 1 - \Phi\left(\frac{ln(D_{limstate}) - \mu_{lnD}}{\sigma_{lnD}}\right) \qquad (4)$$

The fragility curves of URM (Figure 10) structures corresponding to different limit states can then be generated by plotting the seismic level in term of MMI and the probability of exceeding limit state.

Figure 11: Fitted fragility curves for Algiers URM masonry buildings




Source: Authors.

Figure 11 shows, for instance, for an earthquake of intensity 10, the probability of exceeding a damage state “collapse” is 25%, it is 50% for the damage state “severe” and it is 100% for the state no damage.

## 3.2 FRAGILITY CURVES VALIDATION

Within the framework of the European program RISK-UE, the LM1 method has been developed to assess the seismic vulnerability of structures in Europe. It is a method based on the correlation between the macroseismic intensity and the observed damage of past earthquakes (DPM) deduced from the European Macroseismic Scale (EMS-98).

The LM1 method distinguishes between the state of no damage (None), and five levels of damage designated as slight, moderate, significant, very significant and destruction. The Building Classification Matrix (BCM) defines 23 main structural classes in Europe grouped according to 1) structural system and 2) building material.

The LM1 method is used to define the vulnerability classes, the vulnerability index and to develop relevant damage probability matrices (DPM).

The vulnerability index is introduced to represent and quantify the membership of a building to a certain vulnerability class. The value of the vulnerability index is between 0 and 1 allowing to quantify in a conventional way the behavior of the construction.The LM1 method defines a semi-empirical function allowing to correlate the average damage level $\mu_D$ with the macroseismic intensity I and the vulnerability index VI

The present work deals with unreinforced masonry constructions (URM), the majority of constructions encountered in Algeria are made of stone and / or brick and whose floors are in vaults corresponding to categories M1.2 and M3.3 in the classification of RISK-EU. The vulnerability indexes for these categories are indicated in Table 7.

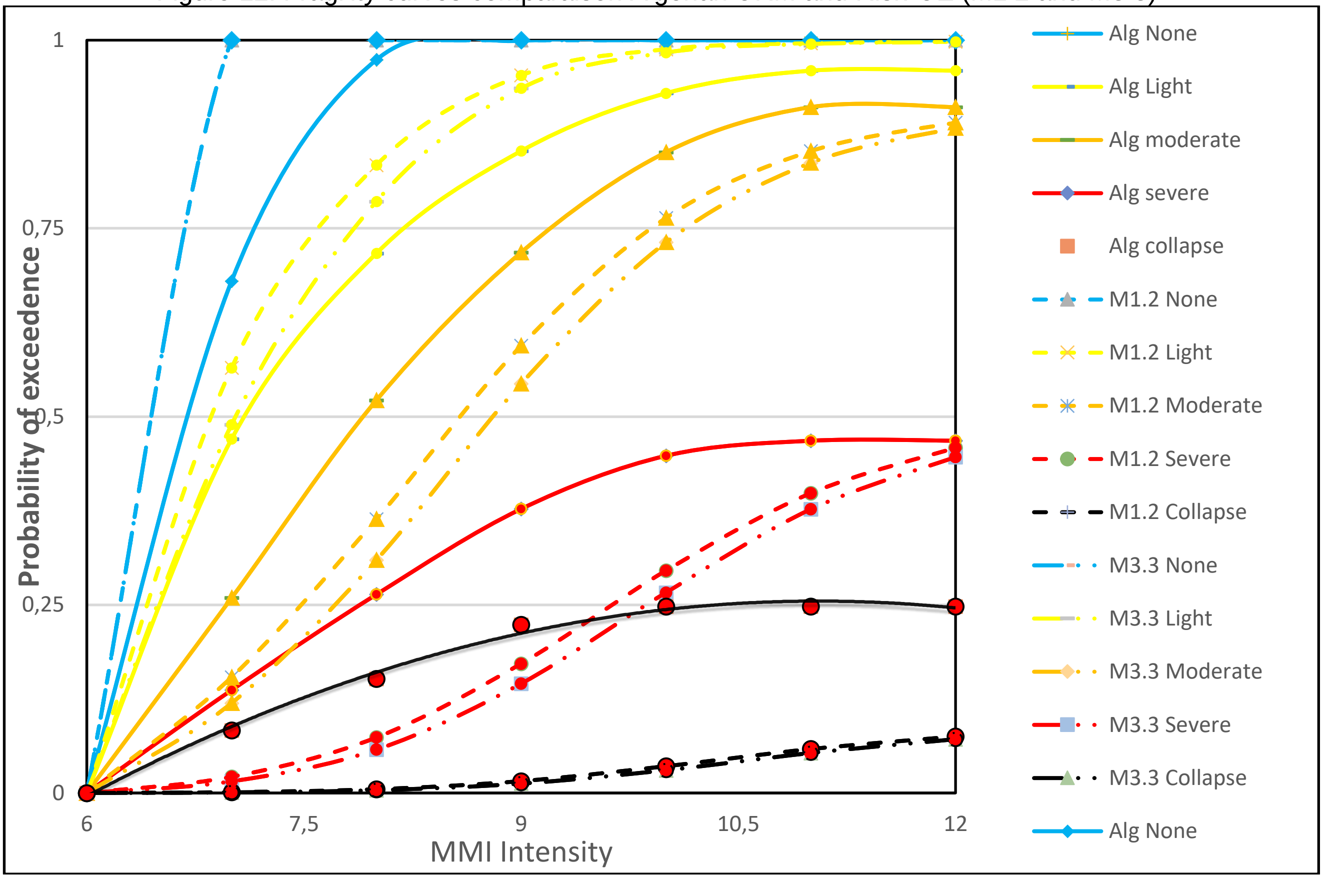
Table 7: Risk-UE Mean vulnerability index

| **Building typology** | **Mean VI** |
|---|---|
| URM M1.2, Risk-UE | 0.74 |
| URM M 3.3, Risk -UE | 0.70 |

Source: Authors.

In the same graph (Figure 13), the Algerian fragility curves (using log-normal distribution) and Risk-UE fragility curves (using beta probability density function) are plotted.

Figure 12: Fragility curves comparaison Algerian URM and Risk-UE (M1.2 and M3.3)




Source: Authors.

Algerian fragility curves are upper the Risk-UE curves for Moderate, severe and collapse damage states. The fragility curves plotted for the Algerian context are similar to those developed by the Risk-UE project for the two types of unreinforced masonry M1.2 and M3.3 (Figure 13). The average deviations for each damage level are presented in Table 8.

This situation can be explain by the use of different function to develop the fragility curves (log-normal distribution for Algerian functions and beta probability density for Risk-UE). As can be seen, the curves developed are more conservative than the one developed by RISK-UE. This is justified by the lack of maintenance and the intensive use of constructions due to the overpopulation in Algeria.

## 3.3 SEISMIC SENARIOS

Seismic scenarios of different MMI intensities (VII to X) are performed for the district of Belouizdad using fragility curves for Algiers URM masonry buildingsdeveloped above and the analytical functions (eq. 2 and 3) which are implemented in a GIS tool to perform seismic scenarios The damage distributions

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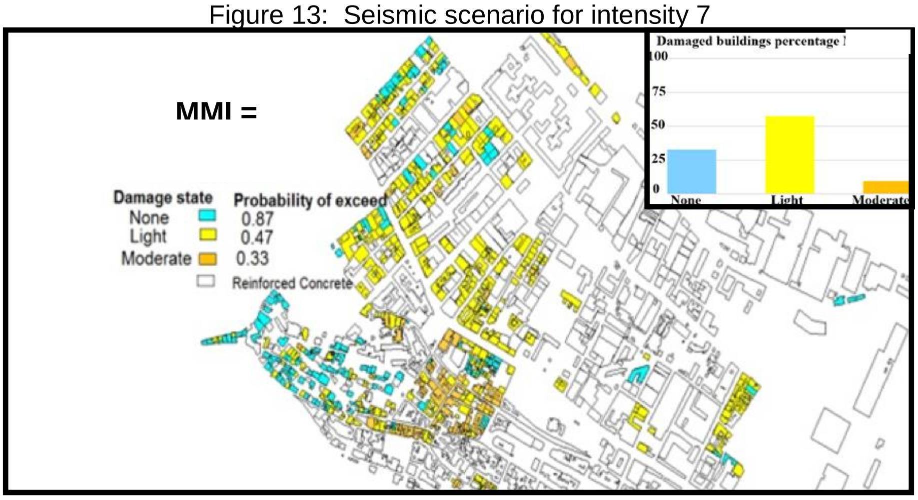
for 645 URM buildings for the district are given in Fig. 14, 15, 16 and 17.

Table 8: Percentage of the average deviation between Algerian URM - Risk-UE

| Damage level | % of Average Deviation | |
|---|---|---|
| | **Algerian URM / M3.3, Risk-UE** | **Algerian URM / M1.2, Risk-UE** |
| **None** | 17.12 | 17.12 |
| **Light** | 27.13 | 27.46 |
| **Moderate** | 29.00 | 29.30 |
| **Severe** | 16.15 | 16.17 |
| **Collapse** | 8.86 | 8.96 |

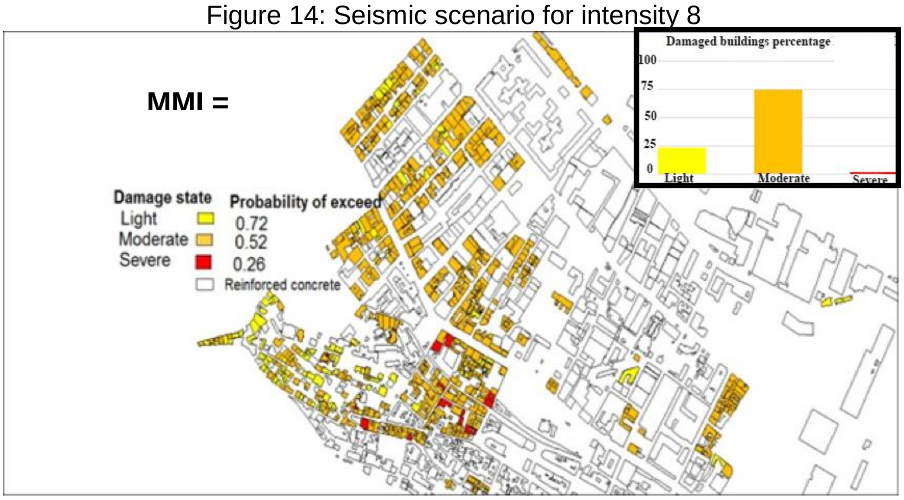
Source: Authors.

Figure 13: Seismic scenario for intensity 7



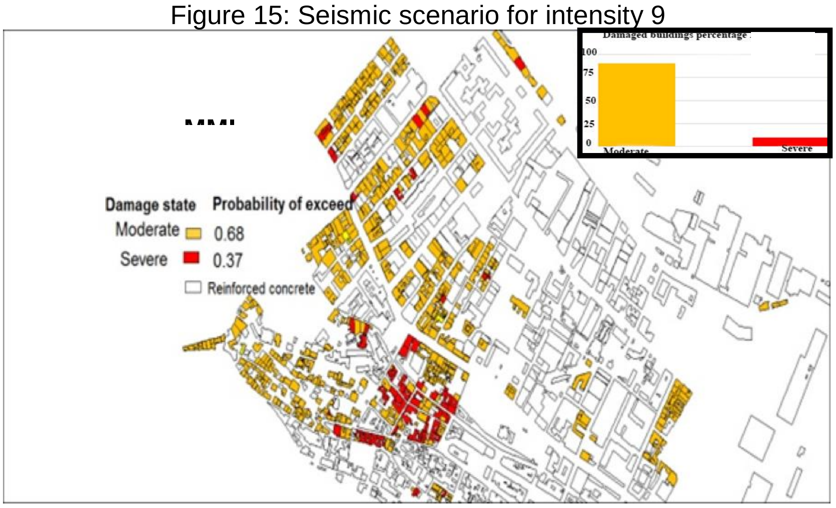

Source: Authors.

Figure 14: Seismic scenario for intensity 8



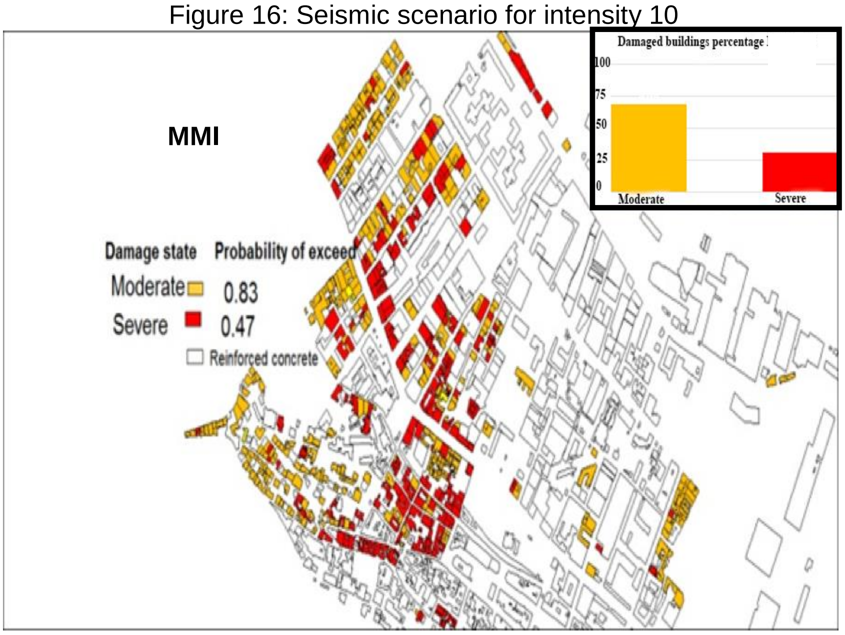

Source: Authors.

Figure 15: Seismic scenario for intensity 9




Source: Authors.

Figure 16: Seismic scenario for intensity 10




Source: Authors.

From fragility curves developed for Algiers URM, It appears that, the probability of exceeding a given limit state increase with the seismic intensity. According to seismic code, the inelastic behavior of URM buildings starts at about MMI equal to VII and several structural damage are observed at about MMI 10. So, the analyzed buildings have more than 30% probability of exceeding the moderate damage state and around 18% probability of exceeding the severe damage state for MMI VII. For MMI X, these buildings have more than 80% probability of exceeding the moderate damage state and more than 40% probability of exceeding the severe damage state. Even for low seismic intensity (between VII and VIII), the damage state "collapse", has a significant probability of exceedance (more than 10%). So, it can be derived, that Algiers URM structures have low seismic performance; this is due to the fact that most of the structures are designed without consideration of seismic loadings.

Regarding the seismic scenarios for intensity VII, 58 % of the buildings stocks present a light damage state with 0.47 probability of excedance. Only 9 % of the buildings expected a moderate damage state. 33 % of buildings have no damage with 0.87 probability of exceeding this damage state.

For the seismic scenario of the intensity VIII, the probability of exceeding moderate damage state is 0.52 with a rate of 75 %. Moreover, rates of masonry buildings of 23 % are expected to suffer a light damage with 0.72 probability of exceedance. Only 2 % of buildings stocks suffer a severe damage with 0.26 probability of exceedance.

The results show that for seismic scenario MMI IX, the majority of masonry buildings (90 %) expected a moderate damage state with the probability of exceedance of 0.68. Only 10 % suffer severe damage.

Regarding the last seismic scenario of intensity X, the probability of exceeding severe damage state is 0.47 representing 31% of the analyzed buildings. The probability of exceeding moderate damage state is of 0.83 for 69% of URM masonry constructions of the Belouizdad district. Therefore, the obtained results are in accordance with the vulnerability of the URM buildings of the Belouizdad district.

## 4 CONCLUSION

In conclusion, the derived fragility curves for unreinforced low and mid-rise masonry buildings in Algiers represent a significant leap forward in the city's seismic risk assessment. This research sheds light on the vulnerability inherent in Algiers' URM building stock, emphasizing the urgent need for proactive seismic mitigation strategies. Unlike traditional vulnerability curves, which offer a generalized assessment of mean damage across a region, fragility curves provide a more nuanced understanding of damage distribution. This precision allows policymakers to pinpoint the most vulnerable buildings and tailor interventions for strengthening, ultimately fostering a more resilient urban landscape with reduced risks of earthquake-related casualties and economic losses.

From an academic perspective, this research contributes substantially to the evolving body of knowledge surrounding URM building seismic behavior. The developed vulnerability functions serve as a foundation for future refinement, particularly as more data on local construction practices and material properties becomes available. Moreover, the investigation of cost-effective retrofitting techniques tailored to the unique context of Algiers holds promise as a valuable contribution to the field. By exploring innovative retrofitting strategies, researchers can enhance the resilience of URM buildings, ensuring their longevity and safety in the face of seismic events.

By bridging the gap between seismic risk assessment and practical mitigation strategies, this research empowers policymakers and engineers to safeguard the lives and livelihoods of Algiers' residents. However, it is important to acknowledge the limitations of this study, including the reliance on estimated parameters due to the absence of detailed building inventories. This underscores the necessity for ongoing data collection efforts and collaborative endeavors among stakeholders. Together, researchers, policymakers, and engineers can work towards ensuring a safer and more resilient future for Algiers and other cities grappling with significant URM building stocks.

## REFERENCES

M. Dolce, A. Kappos, A. Masi, G. Penelis, and M. Vona, Vulnerability assessment and earthquake damage scenarios of the building stock of Potenza (Southern Italy) using Italian and Greek methodologies,Engineering Structures28 (2006) 357–371.

S.M. Senel, and A.H.Kayhan, Fragility based damage assessment in existing precast industrial building: Acase study for Turkey, Structural Engineering and Mechanics. 34(1) (2010) 39-60.

D. Benedetti, and V. Petrini, On the seismic vulnerability of masonry buildings: proposal of year procedure evaluation, The Industry of Constr. 18 (1984) 66-78.

D. Benedetti, G. Benzoni and M.A. Parisi, Seismic vulnerability and risk evaluation for old urban nuclei, Earth.Eng. and Struc. Dyn. 16 (1988) 183-201.

M. Bensaibi, F. Djaalali, I. Belheouane, O. Amellal and N. Yousfi, Seismic vulnerability index method: Algerian case studies. In: 8th International Conference on Urban Earthquake Engineering. (2011) Tokyo, Japan.

S. Giovinazzi, S. Lagomarsino and A. Penna, Seismic Risk Scenarios: Typological and Mechanical Approach in Vulnerability Assessment, Geophysical Research Abstract. 5 (2003) 09910.

Risk-UE, An advanced approach to earthquake risks scenarios with to applications different European towns, WP4: Vulnerability of current buildings. Evk4-ct-2000-00014, (2003).

T. Srikanth, R.P. Kumar, A.P. Singh, B.K. Rastogi and S. Kumar, Earthquake vulnerability assessment of existing buildings in Gandhidham and Adipur cities Kachchh, Gujarat (India), European.Journal of Scientific Research. 41 (3) (2003). 336-353.

R. Vicente, S. Parodi, S. Lagomarsino, H. Varum, D.A. Mendes and J.A.R. Silva, Seismic vulnerability assessment, damage scenarios and loss estimation case study of the old city centre of Coimbra Portugal. In: 14th Wold Conference on Earthquake Engineering. (2008) Beijing, China.

S. Lagomarsino and G. Magenes, Evaluation and reduction of the vulnerability of masonry buildings. The state of Earthquake Engineering Research in Italy: the ReLUIS-DPC 2005-2008 Project. G. Manfredi and M. Dolce (eds), 1-50 (2009).

F. Braga, M. Dolce and O. Liberator, A statistical study one damaged buildings review of the Msk-76 scale,. In: Proceedings of the Seventh European Conference one Earthquake Engineering. (1982).Athens, Greece.

Coburn and R. Spence, Earthquake Protection. Chichester, Great Britain: John Wiley and Sons (1992).

S.W. Cole, Y. Xu and P.W. Burton, Seismic hazard and risk in Shanghai and estimation of expected building damage, Soil Dyn. and Earthq. Eng. 28 (2008) 778–794.

J.R. Huo, R.S. Lawson and N.G. Kishi, Translation of earthquake vulnerability functions. In: Eleventh European Conference on Earthquake Engineerin. (1998) Balkema.

R.V. Whitman, J.W. Reed and S.T. Hong, Earthquake damage probability matrices. In: Proceedings of the Fifth World Conference on Earthquake Engineering. (1974) 25-31, Rome, Italy.

ATC-13, Earthquake damage evaluation data for California.ATC-13. Applied Technology Council. Redwood city, California, (1985).

S. Lagomasino and S. Giovinazzi, Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings, Bul. of Earthq. Eng. 4 (2006) 415-443.

M. Rota, A. Penna and G. Magenes, A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analyses, Eng. Struc. 32, (2010) 1312-1323.

L.C. Pagnini, R. Vicente, S. Lagomarsino and H. Varum, A mechanical model for the seismic vulnerability assessment of old masonry buildings, Earthquake and Structures. 2(1) (2011) 25-42.

M. Dolce, A. Masi, M. Marino and M. Vona, Earthquake damage scenarios of Potenza town (Southern Italy) including site effects, Bul. of Earthq. Eng. 1(1) (2003) 115–40.

M. Dolce, A. Kappos, A. Masi, A, G, Penelis and M. Vona, Vulnerability assessment and earthquake damage scenarios of the building stock of Potenza (Southern Italy) using Italian and Greek methodologies, Eng. Struc. 28 (2006) 357–371.

Martinelli, G. Cifani, G. Cialone, L. Corazza, A. Petracca and G. Petrucci, Building vulnerability assessment and damage scenarios in Celano (Italy) using a quick survey data-based methodology, Soil Dyn. and Earthq. Eng. 28(2008) 875– 889.

A.H. Barbat, L.G. Pujades and N. Lantada, Seismic damage evaluation in urban areas using the capacity spectrum method: Application to Barcelona, Soil Dyn. and Earthq. Eng. 28 (2008) 851–865.

Ansal, A. Kurkulus and G. Tonuk, Seismic Microzonation and earthquake damage scenarios for urban areas, Soil Dynamic and Earthquake Engineering. 30 (2010) 1319-1328.

L.F. Vida, M. Feriche, A. Ruiz and A. Ontiveros, Seismic vulnerability assessment of traditional unreinforced masonry buildings. The case of Granada city (Spain). In: Ninth International Workshop on Seismic Microzoning Risk Reduction. (2010) Cuernavaca, México.

Ansal, G. Akinci, M. Cultrera, V. Erdik and G. Pessin, Loss estimat in Istambul based on deterministic earthquake scenario, Soil Dynamic and Earthquake Engineering. 29(4) (2009) 699-709.

M. Erdik, K. Sesetyan, M.B. Demircioglu, U. Hancilar and C. Zulfikar, Rapid earthquake loss assessment after damaging earthquakes, Soil Dynamic and Earthquake Engineering. 31 (2011) 247–266.

J. Park, P. Towashiraporn, J.I. Craigm and B.J. Goodno, Seismic fragility analysis of low-rise unreinforced masonry structures, Journal of Engineering Stuctures. 31 (2009) 125-137.

NIBS-National Institute of building Sciences, HAZUS 99 Earthquake Loss Estimation Methodology, Technical manual. Washington, DC.

Y.K. Wen, B.E. Ellingwood, D. Veneziano and J. Bracci,Uncertainty modeling in earthquake engineering, Mid-America Earthquake Center Poject FD-2 Report (2003).

Saeidi, O. Deck and T. Verdel, Developpment of building vulnerability functions in subsidence regions from empirical methods, Journal of Engineering Stuctures. 31 (2009) 2275-2286.

M. Rota, A. Penna and G. Magenes, A methodology for deriving analytical fragility curves for masonry buildings based on stochastic nonlinear analysis, Journal of Engineering Structures. 32 (2010) 1312-1323.

R. Illampas, N. Kyriakides and D.C. Charmpis, Seismic Fragility Assessment of Traditional Adobe Masonry Buildings with Limited Stiffness. In: 16th European Conference on Earthquake Engineering. (2018) Greece.

V Despotaki Silva, S. Lagomarsino, I. Pavlova, J. Torres, Evaluation Of Seismic Risk On Unesco Designated Cultural Heritage Sites In Europe. In: 16th European Conference on Earthquake Engineering. (2018) Greece.

T. Cabrera1, G. Boulicaul, T. Hube, H.S. María, Empirical Fragility Curves For Masonry Houses Using Data From Two Earthquakes In Chile. In: 16th European Conference on Earthquake Engineering. (2018) Greece.

F. Djaalali, Détermination Des Courbes De Vulnérabilité Pour Le Bâti en Maçonnerie de la Capitale Alger (Algérie), D. Thesis. National School of Built and Ground Works Engineering, Algiers, Algeria (2013).

F. Djaalali, M. Bensaibi and N. Bourahla, Evaluation of the vulnerability index for unreinforced masonry structures, Applied Mechanics and Materials. 166-169 (2012) 1387-1390.

F. Djaalali, M. Bensaibi and N. Bourahla, Vulnerabilité sismique des structures en maçonnerie application à la ville d'Alger, Algérie Equipement. 49 (2011) 2-10.

F. Djaalali, M. Bensaibi and N. Bourahla and L. Davene, Vulnerability curves for masonry constructions Algiers case stud, Structural Engineering and Mechanics. 42(5) (2012) 609-629.

F. I. Belheouane and M. Bensaibi, Seismic vulnerability index for reinforced concrete construction in Algeria, Advanced Science Letter. 13 (2012) 364-368.

N. Yousfi and M. Bensaibi, Weighting assessment of vulnerability index parameters for reinforced masonry structures, Structural Engineering International. 27(1) (2012) 79-87.

O. Amellal and M. Bensaibi, Parametric study of the seismic vulnerability of steel structures and their vulnerability curves, Journal of Materials and Engineering Structures, (2020).

M.S. Williams and R.G. Sexsmith, Seismic damage indices for concrete structures A state-of-the-Art, Earthquake Spectra. 11(2) (1985) 319-349.