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Seismic vulnerability assessment of existing buildings in the Tetouan city, northern Morocco

Évaluation de la vulnérabilité sismique des bâtiments existants dans la ville de Tétouan, Nord du Maroc

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Abstract. Tetouan is among the cities in Morocco that are experiencing fairly rapid population and urban growth, and the relationship between urban growth and natural hazards is important. It requires, among other things, the assessment of the seismic vulnerability of existing buildings, which is defined as the degree of damage suffered by a structure for a given seismic intensity. This study addresses the seismic vulnerability of existing buildings in the Tetouan city by adapting the Vulnerability Index Method (VIM), developed in the framework of the European Risk-UE project. First, the typology of the buildings was identified. Second, the vulnerability index for each building was calculated. Finally, a seismic vulnerability map and vulnerability curves of the city were established. The values of the vulnerability index vary between 0.3 and 0.9. The results show that the neighborhoods of the old Medina have a very high vulnerability compared to other areas of the city. Within the framework of earthquake protection, the results constitute a potential guide for the mitigation of seismic risk and the development of earthquake prevention plans.

Keywords: Seismic vulnerability, Risk-UE, Vulnerability Index, Tetouan, Morocco.

Résumé. Tétouan est parmi les villes du Maroc qui connaissent une croissance démographique et urbaine assez rapide, et la relation entre la croissance urbaine et les risques naturels est importante. Elle nécessite, entre autres, l'évaluation de la vulnérabilité sismique des bâtiments existants, laquelle se définie par le degré des dommages subit par une structure pour une intensité sismique donnée. Cette étude traite la vulnérabilité sismique des bâtiments existants dans la ville de Tétouan par l'adaptation de la méthode de l'indice de vulnérabilité (VIM), développée dans le cadre du projet européen Risk-UE. Tous les bâtiments, répartis dans la ville, ont été analysés et classés en fonction de leur typologie, de leurs caractéristiques géométriques et matérielles. D'abord, la typologie des bâtiments a été identifiée, ensuite, l'indice de vulnérabilité de chaque bâtiment a été calculé. Enfin, une carte de vulnérabilité sismique et des courbes de vulnérabilité de la ville ont été établies. Les valeurs de l'indice de vulnérabilité varient entre 0,3 et 0,9. Les résultats montrent que les quartiers de l'ancienne Médina ont une vulnérabilité très élevée par rapport aux autres zones de la ville. Dans le cadre de la protection contre les séismes, les résultats constituent un guide potentiel pour la prise des mesures visant l'atténuation du risque sismique et l'élaboration de plans de prévention des séismes.

Mots-clés : Vulnérabilité sismique, Risk-UE, Indice de vulnérabilité, Tétouan, Maroc.

INTRODUCTION

A terrible earthquake devastated the Agadir city and its region in 1960, the damage toll is catastrophic: more than 12,000 persons died, thousands were injured, more than 75 % of buildings were destroyed, and the extent of damage could be explained by the poor quality of construction. Later, a catastrophic earthquake occurred in Al Hoceima in 2004 in the North of Morocco, the damage is considerable: 629 dead, 926 injured, 15,230 homeless and 2,539 houses collapsed (Cherkaoui & El Hassani 2012, Talhaoui *et al*. 2022).

Seismic vulnerability expresses and measures the level of damage and foreseeable consequences of an earthquake on infrastructure and can be defined as the capacity of a structure to resist given seismic strength. This measure depends on the structural characteristics and their associated deficiencies. Within the framework of the elaboration of strategic prevention plans, the vulnerability analysis aims to develop the knowledge of the existing buildings in a region.

In the last decade, the authorities and the scientific community are increasingly interested in the seismic risk and its impact on society in Morocco. Many buildings that were built before the introduction of seismic standards (RPS 2000, v 2011), represent high seismic risk and in order to avoid disasters at the human and economic levels during a possible earthquake that could strike a region, it is urgent to adopt strategies to mitigate the seismic risk.

On the other side, several studies have been carried out on the conservation of historic buildings of different typologies and the assessment of their seismic vulnerability in Europe (Mouroux *et al.* 2004, Lantada *et al.* 2010) as well as in Morocco (Cherif *et al.* 2017, 2018, 2022), which are a key element to better assess the losses and reduce the economic consequences following the earthquakes.

The present study will assess the seismic vulnerability of existing buildings by adapting and applying the vulnerability index method developed in the European project Risk-UE (Milutinovic & Trendafiloski 2003). However, the existing buildings in the study area are determined through a visit of the districts to identified, located, photographed, and briefly characterized buildings from their structure characterization. As a result, an assessment of seismic vulnerability of existing buildings in earthquake-prone region is a crucial step for earthquake protection and mitigating risk in the city. In the present research, we evaluate the vulnerability index map and the vulnerability curves through the vulnerability index approach for developing urban planning.

STUDY AREA

Geological and tectonic setting

The Rif chain, located in northern Morocco, is a part of the Alpine system of the Western Mediterranean. Towards the north, it is extended in the Betic Cordilleras in southern Spain. From a structural point of view, the Rif is subdivided into three domains; from the interior to the exterior of the chain, we find the internal domain, the flysch domain, and the external domain (Michard 1976, Suter 1980).

The geology of the urban center of Tetouan (Fig. 1) and its surroundings is characterized from east to west by a stack of west-verging thrust sheets that thrust the internal domain into the flysch domain and the external domain. The internal domain outcrops in the East with Ghomarides metamorphic terrains that carry the tectonic scales of the external limestone ridge of Jbel Dersa (northern Tetouan). The Flysch domain is represented by the Beni Ider groundwater in the west and the Predorsalian along the Martil valley.

From a lithological point of view, the city of Tetouan is built on very varied lithological units; the old Medina is built on travertine's that rest on soft marl and or sandy marl, on both sides of the Oued Martil are developed ancient alluvium in the form of terraces at the foot of which we find current Quaternary alluvium (Fig. 1). Massive carbonate rocks mainly form the reliefs, by alternating units (sandstone, marl, and semi-rock).

The major structural events explaining the main tectonic features of the region can be summarized in the tectonic history of the Tetouan cluse, which began in the Oligocene with a NE-SW distensional phase, mainly responsible for the early collapse of the Alboran Sea and the first episodes of the opening of the Tetouan Cluse (Benmakhlouf 1990). In the Aquitano-Burdigalian period, a synsedimentary distensive phase occurs, which is responsible for the actual genesis of the Tetouan Cluse as a graben in the center of the Inner Rif limited by two horsts to the south and north (Benmakhlouf & Chalouan 1994). Subsequently, a N-S compressive phase accentuated the collapse of the Tetouan Cluse, leading to the formation of a syncline, at the level of the cluse that separates two anticlines at Beni Bousera in the south and Beni Mzala in the north. This last phase is followed by a compressive period E-W, which is at the origin of the birth of longitudinal folds, thrust, back thrust, and detachments (Benmakhlouf 1990, Benmakhlouf & Chalouan 1994). These deformations were guided by the Tetouan Cluse, which was open at that time. As the nappes advanced westward, parallel faults appeared at the level of the Tetouan cluse, whose dexterous play accompanied retrocharges in the Haouz chain and thrust in the limestone ridge south of Tetouan (Benmakhlouf 1990, Benmakhlouf & Chalouan 1994).

The end of the Miocene was characterized by a distension phase marked by normal faults that affected the entire Internal Rif. It is responsible for the maximum collapse of the Alboran Sea and the E-W early Pliocene gulfs already open (Tetouan Cluse), which receive the Pliocene deposits (Benmakhlouf & Chalouan 1994). Note that during the Pliocene, the paleogeography of the Cluse, as well as that of the Martil plain, shows a thickening of the sandy marls from the periphery to the center. During the Quaternary Pontian, the Betic-Rifan-Kabyle arc was subject to distensive deformation materialized by vertical movements (Maurer 1968, Chalouan 1986) responsible, in the Tetouan Cluse, for the heightening of Quaternary deposits to altitudes beyond hundreds of meters.

Basin geometry of the Tetouan plain

The lithological presentation has been exploited to construct the longitudinal and transverse geological crosse-section in the Tetouan-Martil Basin (Fig. 2). The first section oriented NE-SW (Fig. 2a), whose the lithology is regular over a depth of about 60 m. The Pliocene substratum is formed by marl deposits with a depth of 40 m. Above this geological substratum, the layers of conglomerates are founded and overlaid by Quaternary material deposits. The second section oriented N-S (Fig. 2b), shows an asymmetrical sedimentation in Tetouan plain caused by the normal fault of Tetouan Cluse (Benmakhlouf 1990, Benmakhlouf & Chalouan 1994) and by the important dynamics of Oued Martil (Stitou 2002). Although, the deposits of the Quaternary layers become deeper in the sudden town to the other side and the contact of the plain with the "Dorsale Calcaire" are mainly indicated by travertine deposits in the N part.

Socio-economic background

The city of Tetouan which is the subject of this work, is an old city founded in the 15th century, it is constituted by the urban perimeter of the city of Tetouan to which is attached a coastal urban fringe formed by the communes of Martil, M'diq and Fnideq. The urban population is both its capacity for development and an issue in terms of territorial planning, quality of life, environmental protection, and finally in case of major disasters. Thus, the urban fabric has experienced anarchic growth at an accelerated pace, which make this urban population face huge damage from the strength of earthquake, stability, erosion, flooding, etc.

According to the General Census of Population and Housing (RGPH 2014) report, the city of Tetouan has 380,787 inhabitants and 92,606 households with an average annual increase rate of 2.91%. While, housing, are the first elements to be taken into account in the analysis of risk or more precisely seismic risk. Therefore, it is necessary to assess the seismic vulnerability of existing buildings in the city of Tetouan. However, the province of Tetouan is characterized by a significant economic activity, located mainly in the Tetouan city and coastal tourist centers. It covers various fields such as commerce, industry and fishing. Agricultural and pastoral activity are represented in the rest of the sector.

SEISMIC HAZARD

A seismic hazard is the possibility of a given site or region experiencing an earthquake. The evaluation of the hazard is the first step in the prevention of seismic risk. It requires the delimitation of "seismic zones", which are generally active faults that can generate future damaging earthquakes (Nicol *et al*. 2016). The identification of these zones on a global scale is relatively easy because the earthquakes are located on narrow bands at the plate boundaries. At the scale of a region, the delimitation of these source zones is complicated and imprecise, because the seismicity becomes diffuse, this is mainly due to localization errors, especially for historical earthquakes (Cherkaoui 1991).

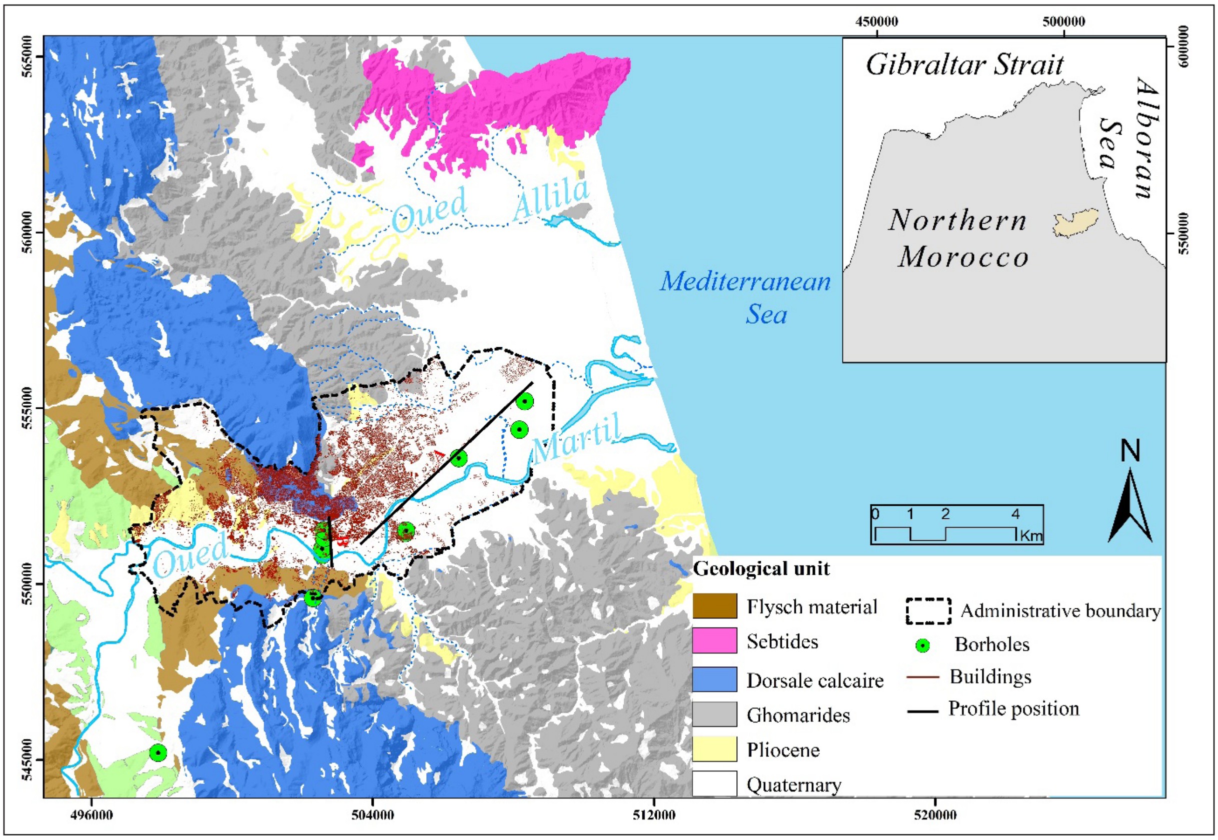

Figure 1. Geological map of the study area (based on the geological map of Tetouan-Ras-Mazari, 1:50,000 scale).

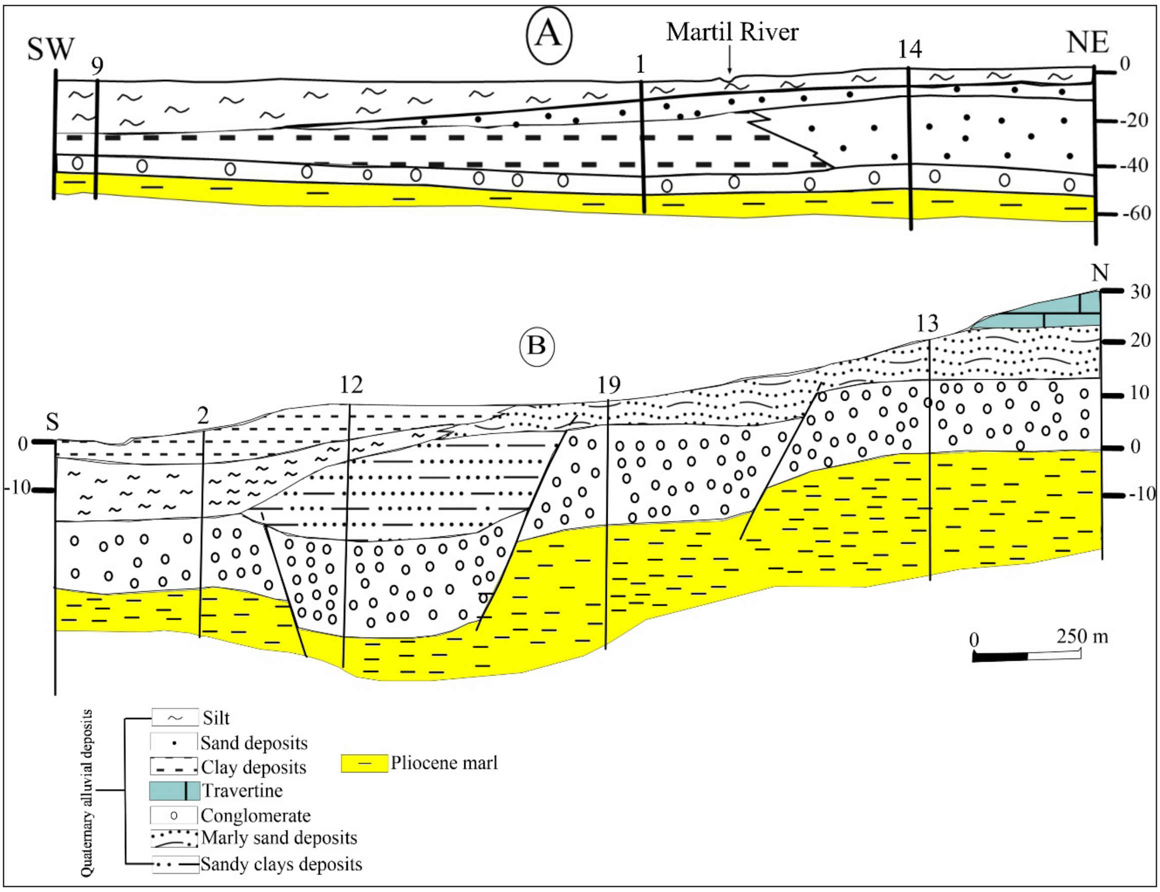

Figure 2. Geological cross sections of the Tetouan plain interpreted from core-drilling data (Ahniche 1997, modified). The location of each section is shown in figure 1.

Seismic hazard assessment studies in Morocco have shown that the highest values for north Morocco, expressed in centennial intensity (values likely to be exceeded once every hundred years), values between VI and VII MSK, are located in the western Rif, due to its proximity to oceanic earthquakes, and in the central Rif in the Al Hoceima region (Cherkaoui 1991, Cherkaoui & Asebriy 2003). In another study (Tadili 1991) where the values of seismic hazard are expressed in values of ground acceleration (which is one of the parameters of interest to civil engineers) corresponding to a 90% probability of not being exceeded for a period of 100 years, the highest values are 26% g for the region of Al Hoceima and 22% g at the level of Tangier peninsula.

On the other hand, the centennial intensity values can be converted into ground acceleration values using empirical relationships. While selecting the attenuation functions for this study, the attenuation functions of Ambraseys *et al.* (2005) and Akkar & Bommer (2010) have been considered. The attenuation functions of Ambraseys *et al.* (2005) are selected since they are the most preferred and commonly used for earthquake hazard models for Europe and the Middle East, while those of Akkar & Bommer (2010) are selected because they are the most recent (World Bank 2012).

The relationships established by Ambraseys (1985) and Ambraseys *et al.* (2005) describe the attenuation of horizontal ground motion as a function of earthquake magnitude and distance, in addition to the maximum horizontal acceleration of the ground.

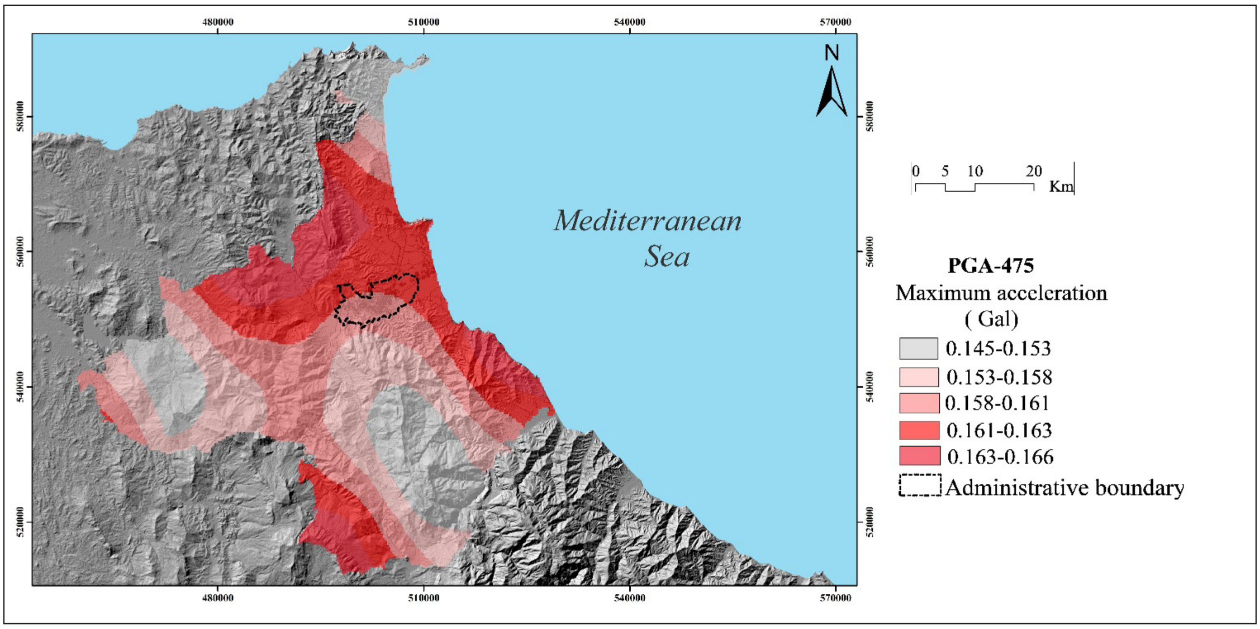

Figure 3. Maximum horizontal ground acceleration calculated for the Tetouan city and neighbouring regions with the laws of Ambraseys *et al*. (2005).

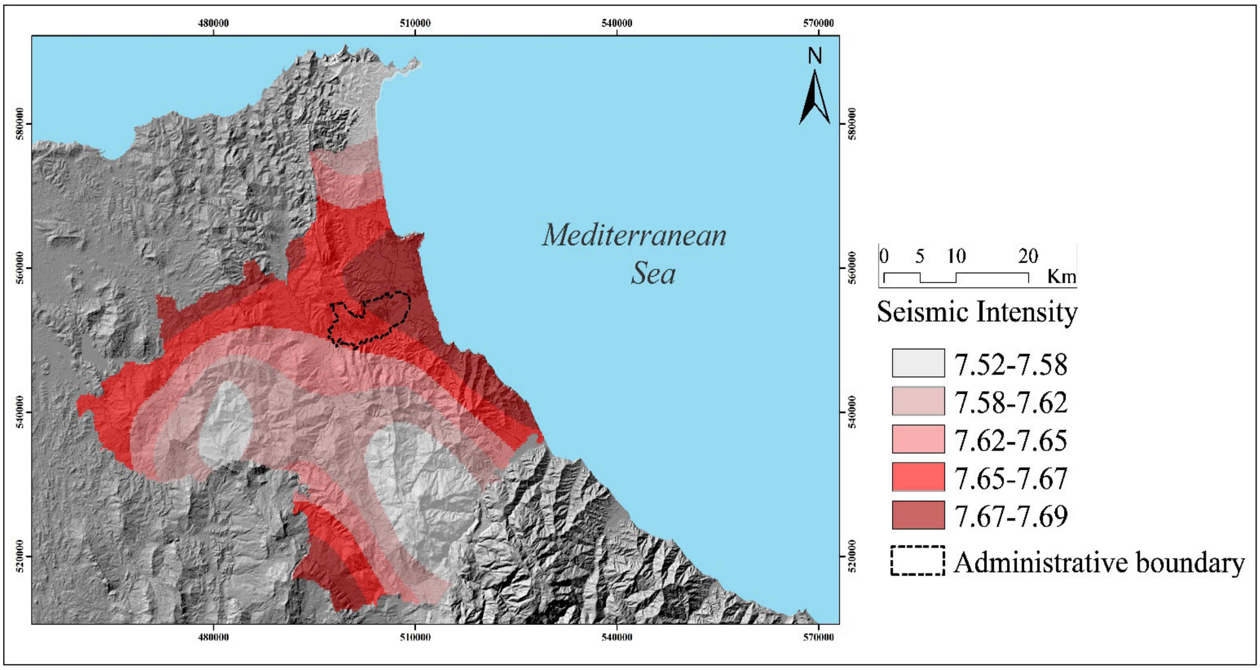

Figure 4. Maximum intensities calculated in the province of Tetouan by probabilistic approach.

Composite probabilistic risk values in terms of PGA (Peak Ground Acceleration) were calculated from all potential events and probabilistic seismic hazard analysis map for a return period of 475 years, and then generated for the province of Tetouan as shown in Figure 3. The probabilistic analysis also had to be calculated in the form of a macroseismic intensity (Fig. 4) to allow the application of level 1 (methodology defined in the section assessment of the vulnerability of existing buildings). For this, the seismic intensity calculated from VII to VIII is probably at the level of the Tetouan regions (Table 1).

Table 1. European Macroseismic Scale 1998 (Grünthal 1998).

EMS Intensity	Definition	Description of typical observed effects (abstracted)
I	**Not felt**	Not felt
II	**Scarcely felt**	Felt only by very few individual people at rest in houses
III	**Weak**	Felt indoors by a few people. People at rest feel a swaying or light trembling.
IV	**Largely observed**	Felt indoors by many people, outdoors by very few. A few people are awakened. Windows, doors and dishes rattle.
V	**Strong**	Felt indoors by most, outdoors by few. Many sleeping people awake. A few are frightened. Buildings tremble throughout. Hanging objects swing considerably. Small objects are shifted. Doors and windows swing open or shut.
VI	**Slightly damaging**	Many people are frightened and run outdoors. Some objects fall. Many houses suffer slight non-structural damage like hair-line cracks and fall of small pieces of plaster.
VII	**Damaging**	Most people are frightened and run outdoors. Furniture is shifted and objects fall from shelves in large numbers. Many well-built ordinary buildings suffer moderate damage: small cracks in walls, fall of plaster, parts of chimneys fall down, older buildings may show large cracks in walls and failure of fill-in walls.
VIII	**Heavily damaging**	Many people find it difficult to stand. Many houses have large cracks in walls. A few well-built ordinary buildings show serious failure of walls, while weak older structures may collapse.
IX	**Destructive**	General panic. Many weak constructions collapse. Even well-built ordinary buildings show very heavy damage: serious failure of walls and partial structural failure
X	**Very destructive**	Many ordinary well-built buildings collapse
XI	**Devastating**	Most ordinary well-built buildings collapse, even some with good earthquake resistant design are destroyed
XII	**Completely devastating**	Almost all buildings are destroyed

METHODOLGY

A multitude of programs and approaches have been developed since then to mitigate seismic risk, including (ATC-13 1985, ATC-40 1996, HAZUS 1997, 1999, Arnal *et al*. 1999 and Risk-UE (Milutinovic & Trendafiloski 2003). The Vulnerability Index Method (VIM), as proposed in the Risk-UE project, is used in this study. This method was previously proposed by Benedetti & Petrini (1984) and is based on the European Macroseismic Scale (EMS-98) (Grünthal 1998). It has advantages over similar statistical methods (ATC-13 1985 and EMS-98) because it emphasizes the differences between constructions that have the same structural system. Weighting coefficients were assigned to the most important parameters influencing the seismic strength of buildings. The seismic action is defined in terms of macroseismic intensity, while the structural resistance of buildings is defined in terms of a vulnerability index with values ranging from 0 (the least vulnerable building) to 1 (the most vulnerable building) for the possible damage that can be caused by an earthquake (Cherif *et al*. 2017).

This method provides a typological classification system (Table 2) (Giovinazzi & Lagomarsino 2002), in order to group structures with the same seismic performance $\boldsymbol{V_I^{class}}$ as mentioned in table 2, and then adds behavioral modifiers specific to each building, to calculate a total vulnerability index $\boldsymbol{V_I^{building}}$ for each building, according to the following equation (Milutinovic & Trendafiloski 2003):

$$\boldsymbol{V_I^{building} = V_I^{class} + \Delta M_R + \sum_{j=1}^{n} V_{mj}}$$

Where $\boldsymbol{V_I^{class}}$ is the vulnerability index corresponding to the class of the building, ΔM_R is a regional modifier that takes into consideration the characteristics of the region or building period, and finally V_{mj} are behavioral modifiers that include other aspects that affect the seismic performance of buildings.

The vulnerability index is used to define a building vulnerability curve, this curve relates the seismic intensity, expressed in terms of macroseismic intensity to an average damage index μ_D. The mean damage grade shall be estimated for vulnerability index of buildings (VI) and the corresponding seismic intensity (I), as follows (European Commission 2004):

$$\mu_{\boldsymbol{D}} = \mathbf{2.5}\,[\mathbf{1} + \boldsymbol{tanh}(\frac{\boldsymbol{I} + \mathbf{6.25}\boldsymbol{V_I} - \mathbf{13.1}}{\mathbf{2.3}})]$$

The value defining the probability distribution corresponding to different degrees of damage. This distribution is done through a probability law, whose parameters have been adapted according to real observations on damage after different earthquakes. The vulnerability curves represent the average damage for a building type as a function of the earthquake intensity.

Table 2. Vulnerability index values for different types of buildings according to Risk-UE 2003.

Typology	**Description**	**V_I representative values**				
		$V_{I,BTM}^{min}$	$V_{I,BTM}^{-}$	$V_{I,BTM}^{*}$	$V_{I,BTM}^{+}$	$V_{I,BTM}^{max}$
M1.1	Rubble stone, fieldstone	0.62	0.81	0.873	0.98	1.02
M1.2	Simple stone	0.46	0.65	0.74	0.83	1.02
M1.3	Massive stone	0.3	0.49	0.616	0.793	0.86
M2	Adobe	0.62	0.687	0.84	0.98	1.02
M4	Reinforced or confined masonry walls	0.14	0.33	0.451	0.633	0.7
RC1	Concrete Moment Frames	-0.02	0.047	0.442	0.8	1.02
RC2	Concrete shear walls	-0.02	0.047	0.386	0.67	0.86
RC3.1	Regularly in filled walls	-0.02	0.007	0.402	0.76	0.98
RC3.2	Irregular frames	0.06	0.127	0.522	0.88	1.02
S1	Steel Moment Frames	-0.02	0.467	0.363	0.64	0.86
S2	Steel braced Frames	-0.02	0.467	0.287	0.48	0.7
S3	Steel frame + unreinf. mas. infill walls	0.14	0.33	0.484	0.64	0.86
W	Wood structures	0.14	0.207	0.447	0.64	0.86

Assessment of the seismic vulnerability of existing buildings in the city of Tetouan

Large-scale vulnerability studies apply to a group of buildings, an entire city, or a given region. The approach considered is generally statistical, as knowledge of the existing building stock is often partial. These empirical methods of vulnerability analysis are based on experience feedback and structural characteristics of buildings from visual inspections. This assessment approach is based on three steps:

Building Survey and Classification

To group buildings belonging to the same category, the notion of vulnerability class is introduced, representing, in one way or another, the probabilities of reaching a degree of damage according to the requests and their distribution (Risk-UE 2003).

From the field visits and using satellite images, we divide the city of Tetouan into homogeneous sectors according to the type of occupation (Fig. 5) and type of structure. Thus, to understand and categorize the inventory of buildings in the city of Tetouan, the team conducted a field sample and a field survey that lasted several days. During this survey, data is collected through personal means (contribution of the inhabitants of the city), photographs and includes understanding and collecting information on local building practices such as building materials and type of structure (Table 2).

Study of building typology

During the fieldwork, a precise description is required containing the different typologies of buildings (Table 2) and the construction processes followed. these typologies take into account the seismic design of buildings, three levels of seismic design are introduced:

- Pre-code: buildings with no seismic design for seismic regions are important, it consists in Morocco to this level of the design if it was built before 1961.
- Low-code: low seismic design, this level is considered for buildings built between 1961 and 2009
- Moderate-code: moderate paraseismic dimensioning and is considered for buildings built after 2009.

Calculation of the vulnerability index

The methodology adopted for the assessment of the vulnerability of buildings is that of “level 1” as proposed in the Risk-UE project (2003), which has been applied in several European cities, including the city of Nice (Mouroux *et al.* 2004). This method is based on the EMS-98 as shown in table 1, whose principle is as follows: the vulnerability of a building is evaluated according to its typology and aggravating factors (e.g., height, irregularity of the forms, position in relation to other buildings, etc.), which allows it to be assigned a vulnerability index.

Indeed, the vulnerability of a building is established using two parameters. The typology depends on the construction materials and aggravating factors that are related to the way of building construction. The values of the aggravating factors vary according to the construction materials used if the buildings are made of reinforced concrete and steel (Table 3) or masonry (Table 4) and are considered in calculation of the values of the vulnerability index.

The values obtained for V_I are very useful, as it identifies vulnerable buildings and can be used in the decision-making of any risk management plan in a study area. Finally, the vulnerability index is scaled to obtain values between 0 and 1. Noting here that for reinforced concrete and steel constructions, the aggravating factors depend mainly on the age of the building, older (over 50 years) is defined as low code and what is between 20 and 50 years is defined as medium code.

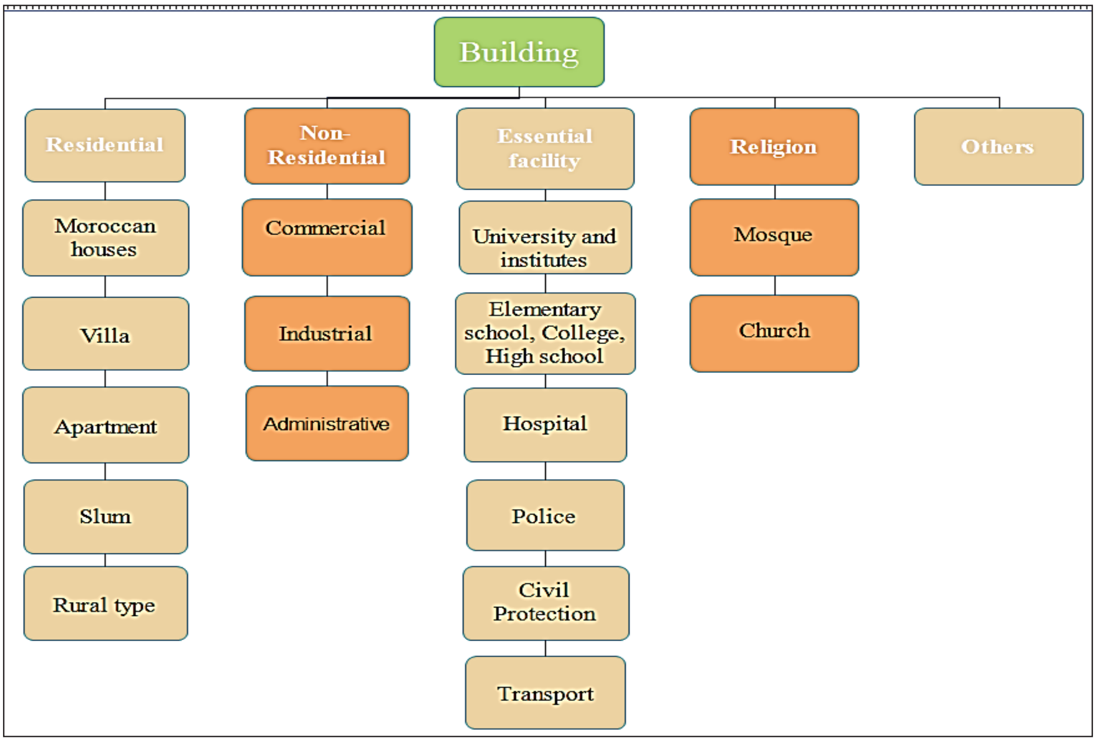

Figure 5. Classification of Buildings according to RGPH 2004.

Table 3. Aggravating factors for reinforced concrete and steel buildings by Risk-UE 2003.

Aggravating factors for buildings RC and steel	**Vulnerability factors**		**Low Code**	**Medium Code**
	Number of floors	Low (1, 2, or 3)	-0,04	-0,04
		Medium (4, 5, or 6)	0	0
		High (7 or more)	+0.08	+0.06
Plan irregularity	Shape (L, C)	Yes	+0.02	+0.01
		No	0	0
	Protuberance	Yes	+0.02	+0.01
		No	0	0
Elevation irregularity	Projection	Yes	+0.02	+0.01
		No	0	0
	Withdrawal	Yes	+0.02	+0.01
		No	0	0
	Insufficient seals (not PS)	Yes	+0.04	0
		No	0	0
	Short posts	Yes	+0.02	+0.01
		No	0	0

Table 4. Aggravating factors for masonry buildings by Risk-UE 2003.

Aggravating factors for masonry buildings	**Vulnerability factors**		
	State of maintenance	B = good	-0,04
		M = bad	+0.04
	Number of floors	Bottom (1 or 2)	-0,04
		Medium (3, 4, or 5)	0
		High (6 or more)	+0.04
Plan irregularity	Shape (L, C)	Yes	+0.02
		No	0
	Protuberances	Yes	+0.02
		No	0
Elevation irregularity	Projection	Yes	+0.01
		No	0
	Withdrawal	Yes	+0.01
		No	0
Interaction between buildings	Position in the block	A = angle	+0.04
		M = medium	-0.04
		T = head of the island	+0.06
	Height difference/ neighbour	Yes	+0.02
		No	0
	Irregularity in roofing	Yes	+0.04
		No	0
	Floor offset	Yes	+0.04
	Transparency - demolition	Yes	+0.04
	Balconies - fireplaces	Yes	+0.01
	Floors: different height	Yes	+0.04
		No	0

The methodology adopted for this study consists of two parts, bibliography and fieldwork. The bibliographical work is important to understand the area studied from a geological, tectonic, and seismic point of views. Then the fieldwork includes the visit of all the buildings and the inventory of all its typologies to establish the vulnerability curves. This methodology is represented on the flowchart in Figure 6.

RESULTS

The study lists all the buildings in the city of Tetouan of which 82% of the total number of buildings studied are used for residential purposes (Moroccan houses, villa and apartments), and 13% of the total number of buildings studied are used as non-residential buildings (shops, industries, etc.), about 5% are used as essential facilities (hospitals, schools, administrations, etc.), and the rest occupy religious facilities (mosques, churches and religious schools) or are in an unclassified class (others), their distribution is represented in Figure 7.

The distribution of the different typologies studied in the area (Fig. 8), provides an overview of the distribution of the buildings in the inventory by structural type. Moreover, the buildings of Tetouan city consist largely of reinforced concrete constructions, masonry constructions, and load-bearing walls that are located mostly in the old Medina (Fig. 8) which are not, in general, in compliance with the seismic rules where the low resistance of these constructions facing the seismic action. The steel frames buildings are located in the industrial area and in shopping centers.

According to the vulnerability index map (Fig. 9), it can be seen that it depends mainly on the construction materials of buildings and their geometry. A vulnerability index between 0.6 and 1 indicates a high vulnerability of buildings to seismic risk, which coincides with the old Medina (Fig. 9).

In this area, the type of constructions in the majority of masonry structures and load-bearing walls having built before the application of the seismic regulation code in Morocco RPS 2000, which geometries and typologies are different from other buildings. The second interval between 0.4 and 0.6 is considered as a less vulnerable interval that predominates in the Tetouan city with all reinforced concrete constructions, and the last interval located between 0 and 0.4, indicates areas of low vulnerability and reflects the steel frames (Fig. 9).

Vulnerability curves are the graphical representation of the average damage probability. These functions generally express the average damage or loss for a building or a class of buildings as a function of earthquake intensity. The vulnerability curves of the buildings corresponding to the typologies studied at the level of the province of Tetouan are presented in Figure 10.

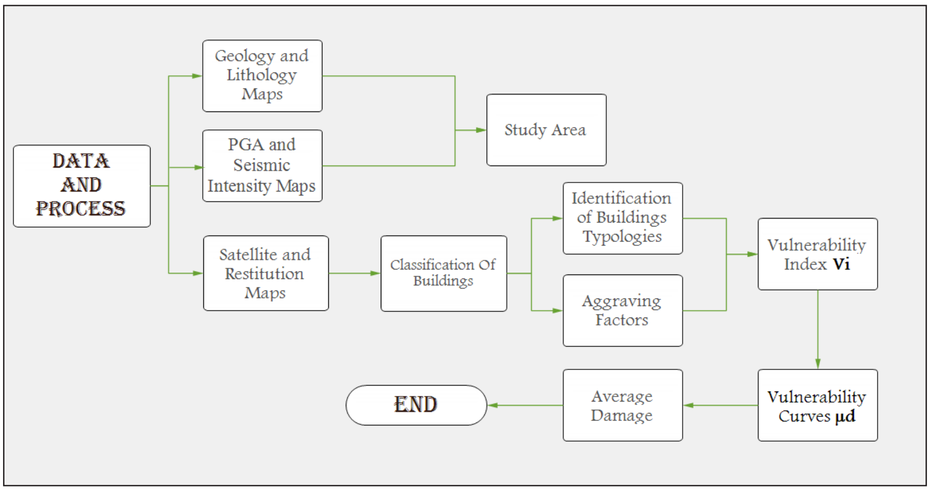

Figure 6. Methodological flowchart of the vulnerability assessment in the Tetouan city.

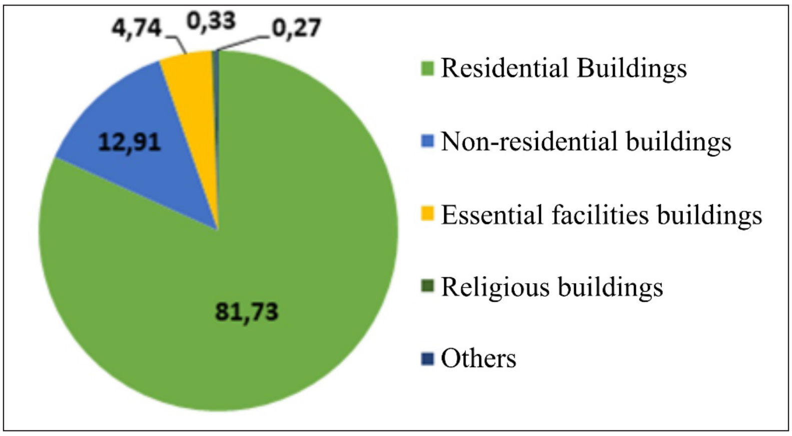

Figure 7. Distribution of the buildings in the Tetouan city according to their occupation.

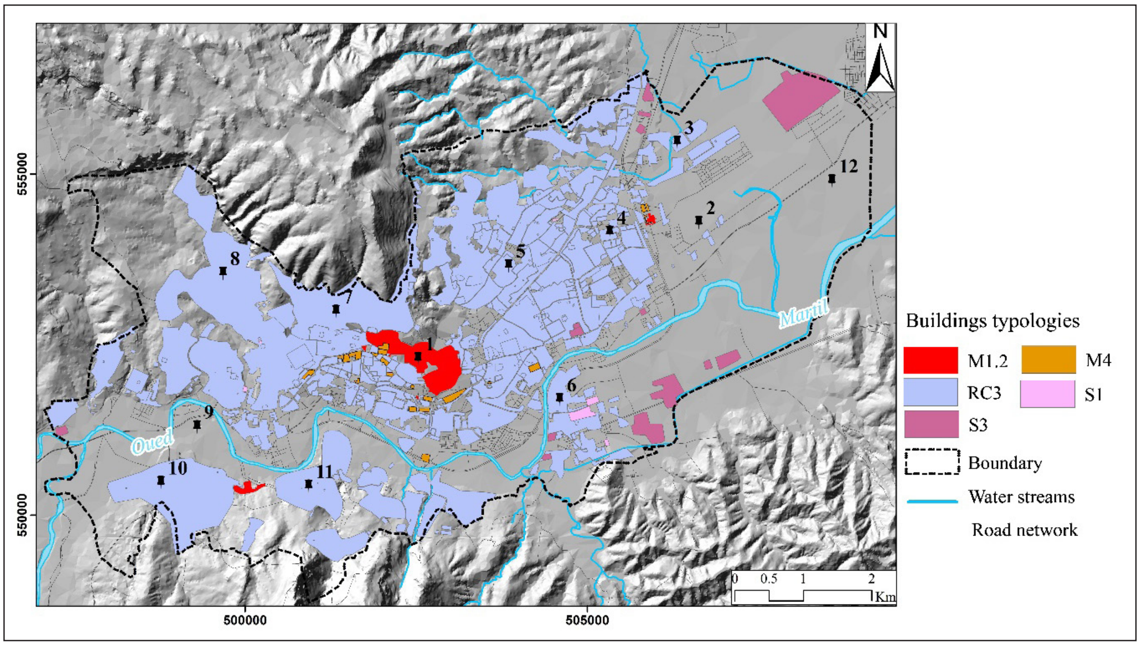

Figure 8. Distribution of the different typologies studied in the Tetouan city (HAZUS methodology). 1: Old Medina, 2: Airport, 3: Souani, 4: Aviation, 5: Touelah, 6: Coelma, 7: Dersa, 8: Samsa, 9: Urban Park, 10: Tamouda, 11: Korat Sbaa, 12: The water treatment station.

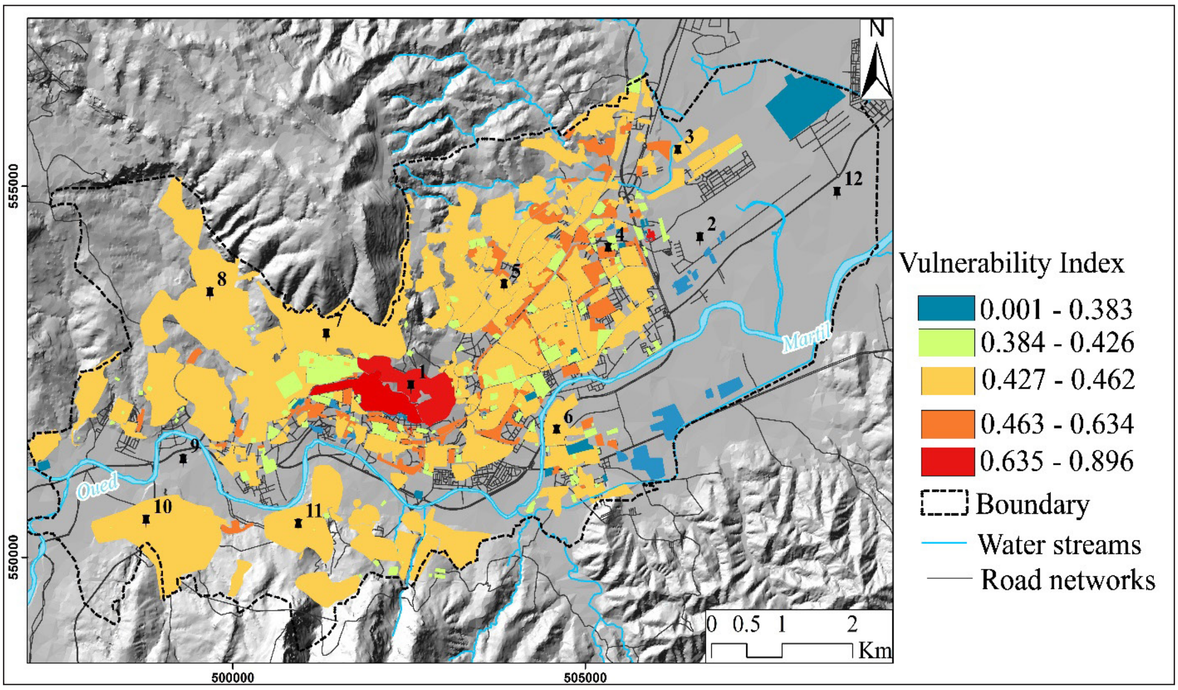

Figure 9. Vulnerability index VI* map of the Tetouan city. 1: Old Medina, 2: Airport, 3: Souani, 4: Aviation, 5: Touelah, 6: Coelma, 7: Dersa, 8: Samsa, 9: Urban Park, 10: Tamouda, 11: Korat Sbaa, 12: The water treatment station.

The seismic intensities deduced from the maximum accelerations at the level of Tetouan and its region indicate a value of VII to VIII (Fig. 4). The vulnerability curves show that the average damage at the level of the RC3.1 and M4 typologies are lower than M1.2, which allows us to deduce that the M1.2 typology is more vulnerable in case of an earthquake intensity higher than VII. The different approaches of the vulnerability assessment are generally based on vulnerability curves that express the percentage of damage suffered by a type of structure for different seismic intensities. These curves are developed from the observation of damage during past earthquakes, from expert opinion, or from analytical methods. However, the direct application of these curves cannot be done if the typology of the buildings under study is different from that of the buildings used to develop the vulnerability functions.

DISCUSSION

The objective of the application carried out within the framework of the European research program (Risk-UE) was to initiate a process of taking into account the seismic risk in urban development and regional planning (Mouroux *et al.* 2004). This initiative was taken in close liaison and with the support of local services. The optimal goal of this study is to obtain the active appropriation of risk prevention by local authorities, based on their appreciation of the problem.

In a context where the elaboration of emergency measures to prepare for possible natural disasters, earthquakes as an example, is becoming more and more popular, the evaluation of the seismic vulnerability of existing buildings is a matter of necessity. Initially developed and applied in regions regularly affected by violent earthquakes, such as Al Hoceima city (Jabour *et al.* 2004, Stich *et al.* 2005, Akoglu *et al.* 2006, Kariche *et al.* 2018, Talhaoui *et al.* 2022) and the third event occurred on an offshore fault. These earthquake sequences occurred within a period of 22 yr at ~25 km distance and 11-16-km depth. The three events have similar strike-slip focal mechanism solutions with NNE-SSW trending left-lateral faulting for the 1994 and 2016 events and NW-SE trending right-lateral faulting for the 2004 event. The seismic vulnerability assessment methods are now being extended to regions of low to medium seismicity such as the Tangier peninsula (Guerra-Merchán *et al.* 2014). This study helping for a better understanding of the vulnerability of the built heritage and consequently put in place a development and planning policy that will integrate the seismic risk in the various urban plans.

The analysis of the seismic vulnerability of existing buildings in the Tetouan city gives an estimate in quantitative and qualitative terms, in particular the estimation of their degree of damage to seismic events. The estimation of this seismic vulnerability has been conducted in this study by a method of classification of buildings according to the VIM method. This method consists of assigning a vulnerability index to each building. In this study, the old medina buildings, built before 1961 with typology M4 and M1.2 (Fig. 8) and no seismic design (Pre-Code), are the more vulnerable buildings in the Tetouan city (Fig. 9). On the other hand, most of the buildings in the Tetouan city built before 2009 with typology RC3.1 (Fig. 9), according to the moderate code (RPS 2000, v 2011) corresponding to the low vulnerable buildings.

Therefore, as Morocco suffered several destructive and violent earthquakes with high seismic intensities (Jabour *et al.* 2004, Cherkaoui *et al.* 2012), we present the average damage rate based on the macroseismic intensity scale (EMS-98) as shown Figure 10. However, the seismic intensities deduced from the maximum accelerations in the region level indicate a value of VII to VIII. Thus, the vulnerability curves show that the average damage of the reinforced concrete typology is lower than masonry typology, which allows us to deduce that masonry buildings are more vulnerable in case of a seismic intensity higher than VII, which is in agreement with the above discussion.

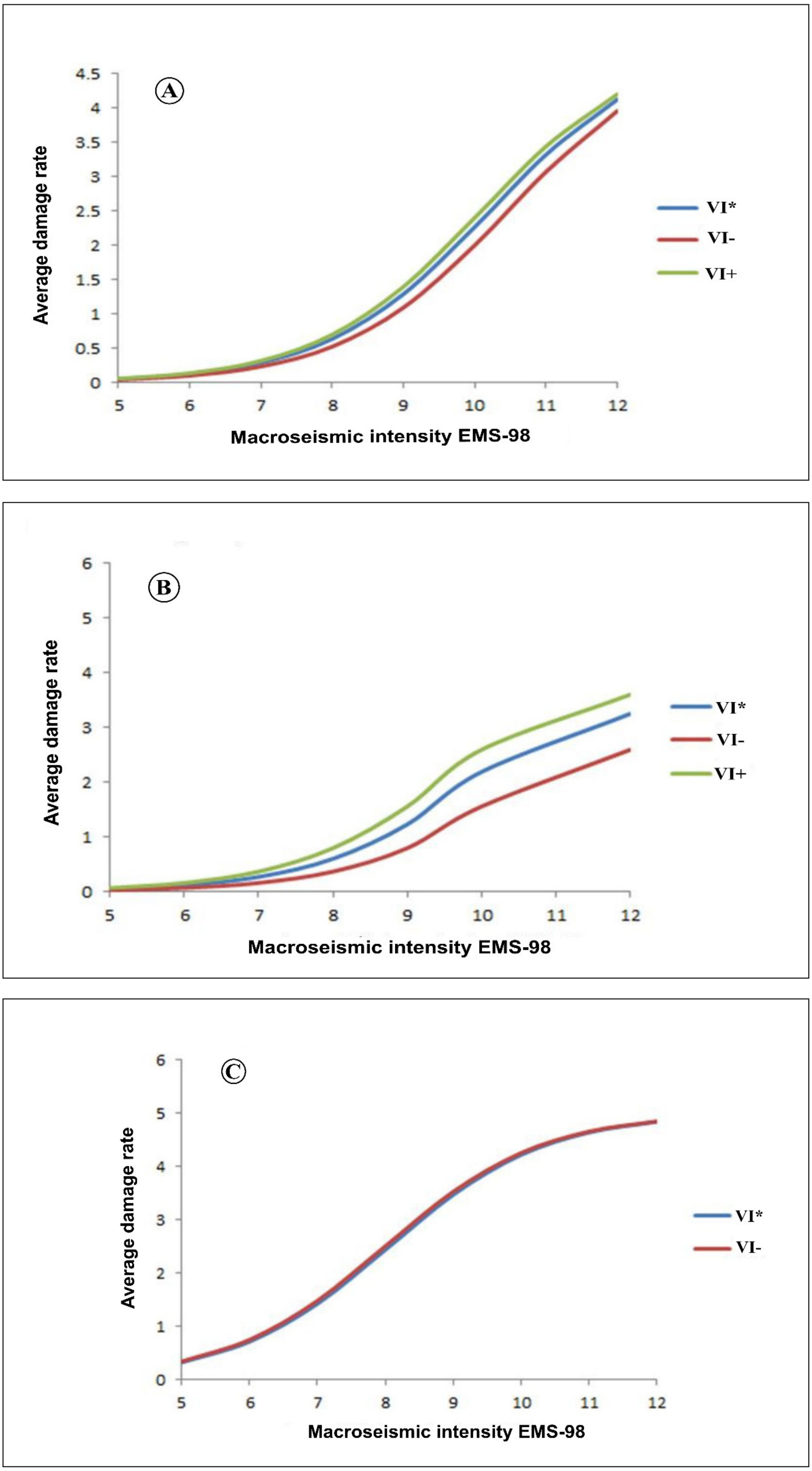

Figure 10. Vulnerability curves for buildings corresponding to the a) RC3.1 typology, b) M4 typology and c) M1.2 typology. Where VI* (most probable value of the vulnerability index), Vi- and VI+ (limits of the plausible range of the vulnerability index).

Nevertheless, in northern Morocco, Cherif *et al*. (2017, 2018) used the vulnerability index method in the context of urban developing planning as well as in risk mitigation. According to these studies, the VIM approach is a tool to provide useful information relating to seismic vulnerability assessment. The same can be said about our study where the effectiveness of this method was considered sufficient to achieve our research goals.

CONCLUSION

In this paper, we use the vulnerability index method (VIM) approach, which was developed within the Risk-UE (2003) project for the vulnerability seismic of existing buildings evaluation in the Tetouan city. Our preliminary findings suggest that the old Medina and its neighbourhood's buildings with simple stone and reinforced, confined masonry walls typologies (M1.2 and M4) are more vulnerable compared to other areas of the city. In the other hand, the buildings with typology RC3.1 (Regularly in filled walls) built with reinforced concrete are a good example of the construction in the zone characterized by a moderate seismicity. Although, we conclude that the validity of the VIM method quality depending of the input data used in their following procedures and preparation. To perfume this model, we need to better characterize the buildings and soil structures which are built on. From a socio-economic point of view, the results of this study suggest that the most vulnerable buildings need to retrofitting and the reinforcement of these building is recommended to mitigate severe damage in case a severe earthquake.

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