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Earthquake vulnerability assessment of buildings in the urban area of Taza, Morocco

Evaluation de la vulnérabilité sismique des bâtiments de la zone urbanisée de la ville de Taza, Maroc

El Mehdi Nchiti[1], Abdelouahad Birouk[2], Aomar Iben Brahim[2*], Imad Kadiri[1], Mohammed El Youbi[1] & Abdellah El Hammoumi[3]

1. Laboratory of Advanced Materials Studies and Applications (LEM2A), Higher School of Technology, Moulay Ismail University in Meknes, Morocco.
*2. Departement of Globe Physics, Scientific Institute, Mohammed V University in Rabat, Morocco *(aomaribenbrahim@gmail.com).*
3. Faculty of Sciences, Mohammed V University in Rabat, Morocco.

Abstract. The prevention and management of seismic risk require a reliable anticipating approach that aims to assess the seismic hazard as well as the state of vulnerability of buildings in threatened areas. In order to obtain an assessment of the distribution of seismic damage on common buildings in the city of Taza, a combination of an approach based on the seismic hazard assessment of the study area, and two different methods for assessing the seismic vulnerability of the building stock is used. These are the so-called vulnerability index method and the deterministic capacity curve method. The seismic building code of Morocco (RPS 2000 version 2011) consigns a peak ground acceleration of 14%g for the city of Taza and therefore a possibility of significant damage in case of a significant earthquake. The analysis of historical seismicity, macroseismicity and instrumental seismicity of the study area shows that the maximum seismic intensity that can possibly be reached in Taza is of the order of VIII to X. Based on the description provided by the European Macroseismic Scale EMS-98 relative to the observed effects on the buildings, the results obtained by the two vulnerability assessment methods are in agreement and converge to similar results. These results show that the vulnerability assessed for the different seismic classes indicates that all the buildings will suffer light to very significant damages depending on the intensity and the class of the considered building.

Keywords: Seismic vulnerability, Index method, Capacity curve method, Fragility curves, Taza - Morocco, GIS, Seismic damage, Seismic hazard.

Résumé. La prévention et la gestion du risque sismique nécessitent une approche prévisionnelle fiable qui vise à évaluer l'aléa sismique ainsi que l'état de vulnérabilité du bâti dans les zones menacées. Afin d'obtenir une évaluation de la répartition des dommages sismiques sur les bâtiments courants des zones urbanisées de la ville de Taza, nous combinons une approche se basant à la fois sur l'évaluation de l'aléa sismique de la zone d'étude, et deux différentes méthodes pour l'évaluation de la vulnérabilité sismique du bâti. Il s'agit de l'approche dite méthode d'indice de vulnérabilité et la méthode déterministe de courbe de capacité. Le code parasismique du Maroc (RPS 2000 version 2011) prévoit pour la ville de Taza une accélération de 14%g et donc une possibilité de dommages importants. L'analyse de la sismicité historique, la macrosismicité et la sismicité instrumentale de la zone d'étude montre que l'intensité sismique maximale pouvant éventuellement être atteinte à Taza est de l'ordre de VIII à X. En se basant sur la description des effets observés de l'Echelle Macrosismique Européenne EMS-98, les résultats obtenus par les deux méthodes d'évaluation de vulnérabilité concordent. Ces résultats montrent que la vulnérabilité évaluée pour les différentes classes sismiques, indique que la totalité des bâtiments vont subir des dommages et des dégâts légers à très importants selon l'intensité et la classe du bâtiment considéré.

Mot-clés : Vulnérabilité sismique, Méthode indicielle, Méthode de courbe de capacité, Courbes de fragilité, Taza - Maroc, SIG, Dommages sismiques, Risque sismique.

INTRODUCTION

Morocco is a country prone to seismic risk, although it has a level of moderate seismic activity (Iben Brahim *et al.* 2003, Cherkaoui & El Hassani 2012). This threat makes it then necessary to develop studies and research on the characterization of the hazard, the assessment of vulnerability and the seismic performance of buildings. In response to these concerns, Morocco has adopted a seismic building code for the entire territory (RPS2000 2013). Its latest version was published in the official bulletin on 23 May 2013. In this code, Morocco is subdivided into five main zones of homogeneous seismicity, for a probability of occurrence of 10% in 50 years corresponding to a return period of 475 years, to simplify the assessment of seismic loads and to standardize the requirements for the design of structures in different parts of the country.

The Moroccan seismic building code defines the seismic action on ordinary buildings during earthquakes and provides a set of provisions, design requirements and calculations necessary to allow current buildings to resist to seismic action. However, the scope of the code does not extend to the necessary definitions relating to performance levels and limit states for estimating the structural capacity to resist seismic action. These concepts are rather available in international seismic codes, such as the European code (Eurocode8 2004).

The field of application of the Moroccan seismic building code (RPS2000 2013) concerns only the new constructions or the existing buildings that are subject to undergo structural-changes of use. Most of the building stock is not built according to this code, so it is necessary to assess the vulnerability of buildings to seismic risk according to a methodology that includes the assessment of seismic hazard, the definition of structural properties of buildings and the quantification of probable damage with a reasonable level of accuracy. These concepts are related, since in order to assess a building vulnerability, it is important to adopt a structural model and a seismic scenario characterizing the study area (Combescure *et al.* 2005, Mouroux & Brun 2006, Nchiti *et al.* 2020c).

In this context, this paper presents successively: In section I, a characterization of the reference seismic hazard from the regional to the local scale of the study area. In addition, the assignment of all buildings in our study area to their respective seismic class. In section II, the vulnerability index of the different types of buildings is evaluated in order to help quantify and map the vulnerability and seismic damage of all buildings. The deterministic Pushover method is then used for two seismic building classes to evaluate more precisely the response of these classes in terms of displacement, ductility, damage distribution and mode of failure, and to validate the results of the seismic hazard characterization by the vulnerability index method (VIM). Finally, in the conclusion, we highlight the importance of this methodology and the results obtained in this research paper.

SEISMIC HAZARD OF THE STUDY AREA AND SEISMIC VULNERABILITY CLASSES

Morocco and its surroundings are part of the continent-continent collision zone between Africa and Eurasia. The study area (Taza) is located in northeastern Morocco. It is approximately 120 km east of Fez and 160 km south of Al Hoceima, overlapping on two active mountain Plio-Quaternary ranges: the Rif in the north, and the Middle Atlas in the south. According to the Moroccan seismic building code, the city of Taza occurs within the second most important seismic zone of Morocco. The assessment of the seismic vulnerability of the buildings requires a solid knowledge of the seismic hazard associated to this city.

Seismic hazard at the city of Taza

In order to better assess the seismic hazard associated with the city of Taza, the historical seismicity, macro-seismicity data and instrumental seismicity are studied. The instrumental seismicity helps to define seismic characteristics deduced from the recordings realized with different geophysical instruments. Macroseismicity allows to attribute a seismic intensity to the earthquakes on an international intensity scale by exploiting all sources of information on the different seismic events, in particular those, which occurred before the advent of instrumental seismicity. Historical seismicity allows to attribute a degree of severity to historical seismic events by analyzing the descriptions of the effects on populations and effects observed on ordinary objects, buildings and the natural environment. The conversion of the intensities determined from these last two methods into magnitudes allows expansion in (earlier) time of the seismic catalog making it cover a longer span of time.

Thus, studies of seismicity in Morocco indicate that seismic activity is significant in the Rif and the Atlas Mountains and relatively low in other regions (Iben Brahim *et al.* 2004, Seber *et al.* 1996). El Mrabet (1991) lists at least one earthquake affecting the city of Taza in the 16th, 17th and 20th centuries. During the period from 1045 to 2023, all earthquakes recorded in the northern region and surrounding areas of our study area have moment magnitudes less than 7.0 and depths between 0 and 150 km. The maximum intensity and magnitude were generated by the Meknes earthquake of November 27, 1755, which has been assigned a maximum magnitude of 6.5 to 7.0 (Poujol *et al.* 2017).

The map of Figure 1 shows that the city of Taza was affected in the north by the historic earthquake of April 11, 1624, with a maximum epicentral-intensity IX-X (MSK) and an estimated magnitude of 6.7. Another earthquake was felt in the city of Taza in July 1719 which had an epicentral-intensity of VIII (MSK) and a magnitude of 5.8 in the east. The so-called Lisbon earthquake of November 1, 1755, and the Atlantic February 28, 1969 event, located at a distance of ~500 km from the Moroccan coast were strongly felt in Morocco. In particular, the Lisbon earthquake of 1755 produced significant damages that affected the western coasts of Morocco, destroying parts of the cities of Tangier, Asilah, Larache, Mehdia, Salé, Rabat, Casablanca, and Safi as well as causing loss of life (Blanc 2009, Kaabouben *et al.* 2009).

Although the map of maximum felt intensities in Morocco by Cherkaoui & El Hassani (2012) shows that the maximum felt intensities in our study area are in the range of VI to VII, Figure 1 shows that the maximum intensity for the study area is about IX corresponding to the earthquake of 1624 not far from Taza. Since, the seismicity data available is limited in time to about 1000 years, if we consider a longer time-span, we can easily expect to have a maximal intensity of X in the study area.

Classification of buildings in seismic vulnerability classes

The RPS2000 subdivides the Moroccan territory into five zones which have peak ground accelerations (PGA) that vary between 4%g and 18%g and which roughly increase from south to north. Following this zoning, the study area belongs to the second-highest seismic zone with a PGA of 14%g. Thus, the city of Taza is located in an area that can suffer significant damage in case of a major earthquake.

The buildings in the study area of Taza are categorized according to the synthetic schema for the taxonomy of buildings in Morocco developed in the present article and illustrated in Figure 2. This schematic combines four levels: Seismic classification according to the European Macroseismic Scale EMS-98 (Grünthal 1998), classification according to the general census of population and housing in Morocco 2014 (RGPH2014 2014), classification by process of construction and classification based on the structural aspects adopted in Morocco. This classification allows to assign to each class an index reflecting a distinct vulnerability to seismic hazards.

After an analysis of the different urban documents relative to our study area and field surveys, we implemented a classification based on the synthetic schema of Figure 2. The totality of the collected data is integrated into a worksheet and then into a geographic information system (GIS). This GIS helped produce thematic maps and facilitate their interpretation as shown in Figure 3.

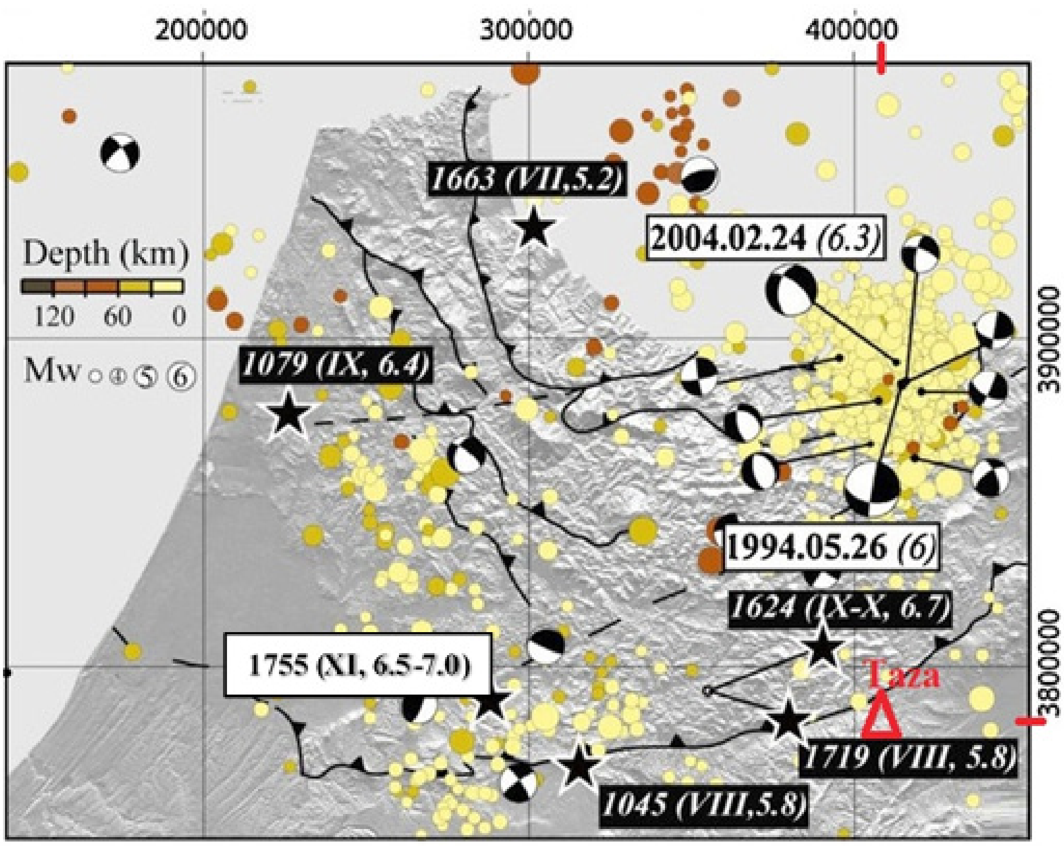

Figure 1. Summary map of instrumental and historical seismic activity affecting the city of Taza. The map shows the focal mechanisms of the main instrumental earthquakes. The red triangle on the map indicates the position of the city of Taza (modified after Poujol *et al.* 2014).

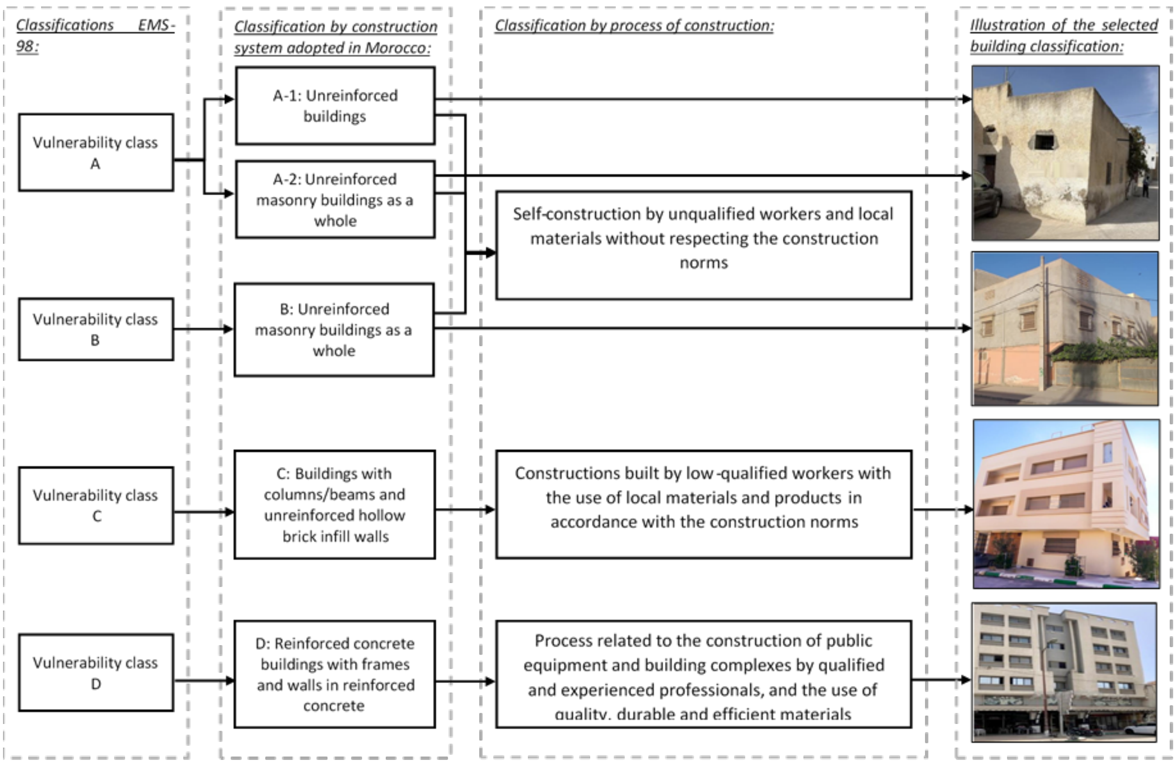

Figure 2. Synthetic schema of the classification of buildings in Morocco.

Table 1. Vulnerability index for different classes of buildings in the urban area of Taza.

Representative typology of buildings	Representative values of V_I					ΔV_m	ΔV_f	Vulnerability Index V_I
	V_I^{min}	V_I^-	V_I^*	V_I^+	V_I^{max}			
Buildings of vulnerability class A	0.460	0.650	0.740	0.830	1.02	0.020	0.040	0.800
Buildings of vulnerability class B	0.30	0.490	0.639	0.953	1.02	0.020	0.040	0.699
Buildings of vulnerability class C	0.06	0.127	0.522	0.88	1.02	0.020	0.040	0.582
Buildings of vulnerability class D	-0.020	0.027	0.394	0.714	0.919	0.040	0.040	0.474

VULNERABILITY ASSESSMENT OF BUILDINGS IN THE CITY OF TAZA

We first use the Vulnerability Index approach for the assessment of the vulnerability of current buildings in the city of Taza and then we use the Pushover method, which is a deterministic approach, based on the seismic performance of buildings (Nchiti *et al.* 2020b).

Seismic damage assessment of buildings

Buildings Characterization by the Vulnerability Index

For each seismic class described above, values of the vulnerability index are evaluated according to the structural parameters identified as contributing to the overall vulnerability of the structure (Nchiti *et al.* 2020a). These parameters are: type and organization of the resisting system, quality of the resisting system, conventional resistance under horizontal loading, location of the structure and foundations, characteristics of the floors, irregularity in plane and elevation, and non-structural elements. Taking into account these parameters and the classification described above, the different buildings are grouped by similar vulnerability indices, which values vary between 0 and 1. Table 1 shows that the vulnerability index for the study area has values that vary from 0.4 to 0.8.

Seismic damage distribution of current buildings

From the distribution of buildings achieved by using the vulnerability index approach discussed above, the method of statistical analysis of damages observed following a seismic scenario is used to help produce vulnerability curves. The mean damage rate M_D is introduced to characterize the predictable damage of buildings, for a given vulnerability index (V_I) and intensity (I) by equation (1) (Milutinovic & Trendafiloski 2003, Nchiti *et al.* 2020c):

$$M_D = 2.5\left[1+\tanh\frac{I+6.25V_I-13.1}{2.3}\right] \quad (1)$$

Figure 4 shows the functions of the resulting damage levels for the selected building typologies.

For the passage from the mean damage to the degrees of damage, EMS-98 recommends the binomial distribution, which has a good correspondence with the distribution of the damage actually observed. Equations (2) and (3) express the probability density function (PDF) and the cumulative distribution function (CDF):

$$\text{PDF: } p_\beta(x) = \frac{\Gamma(t)(x-a)^{q-t}(b-x)^{t-q-1}}{\Gamma(q)\Gamma(t-q)(b-a)^{t-1}} \quad (2)$$

$$\text{CDF: } P_\beta = \int_a^b p_\beta(\varepsilon)\,d\varepsilon \quad (3)$$

Where a=0 and b=6 while t and q are the distribution parameters and is a continuous variable that varies between a and b. The fragility curve that defines the probability of reaching or exceeding a certain degree of damage is obtained from the beta distribution of the cumulative probability in equation 4:

$$P(D \geq D_n) = 1 - P_\beta(n) \quad (4)$$

For the distribution of damages per vulnerability class, Figure 5 shows the vulnerability or fragility curves for the selected building typologies. Through a geographic information system, a set of thematic maps similar to the one in Figure 6 can be produced to help map the different types of constructions in classes of vulnerability, the different homogeneous sectors by vulnerability index and the distribution of the degrees of physical damage in terms of seismic intensity on the study area.

Physical damage probabilities of building typologies by Pushover analysis

To verify the results derived from the VIM-method, two buildings of classes B and C typology are analyzed, using the deterministic approach, called the Pushover analysis (Chopra & Goel 2002, Bendada *et al.* 2016). These two buildings shown in Figure 7, are modelled using finite element software under a seismic lateral loading evaluated according to the Morocco seismic building code (RPS2000 2013). In this method, a seismic load is applied in an increasing manner and the total shear force is plotted against the lateral displacement at each increase, until the collapse state is reached.

For this method, a statistical distribution model of the cumulative lognormal type is used. In this model, two parameters of the cumulative probability function ($S_{d,dn}$, β_{dn}) are used to define the probability of exceeding a damage state (Bendada *et al.* 2017, Nchiti *et al.* 2020d):

$$P\left[d_n / S_d\right] = \Phi\left[\frac{\ln\left(S_d / S_{d,dn}\right)}{\beta_{dn}}\right] \quad (5)$$

Many models have been developed for the identification of damage levels. The model proposed by Milutinovic & Trendafiloski (2003) consists in identifying the performance levels according to the displacements measured at the top. Four levels of damage, ranging from no damage for DG1 to collapse for DG4, are defined by equations (6) and (7):

$$\begin{cases} \overline{S}_{d1} = 0.7Dy \\ \overline{S}_{d2} = Dy \\ \overline{S}_{d3} = Dy + 0.25(Du - Dy) \\ \overline{S}_{d4} = Du \end{cases} \quad (6)$$

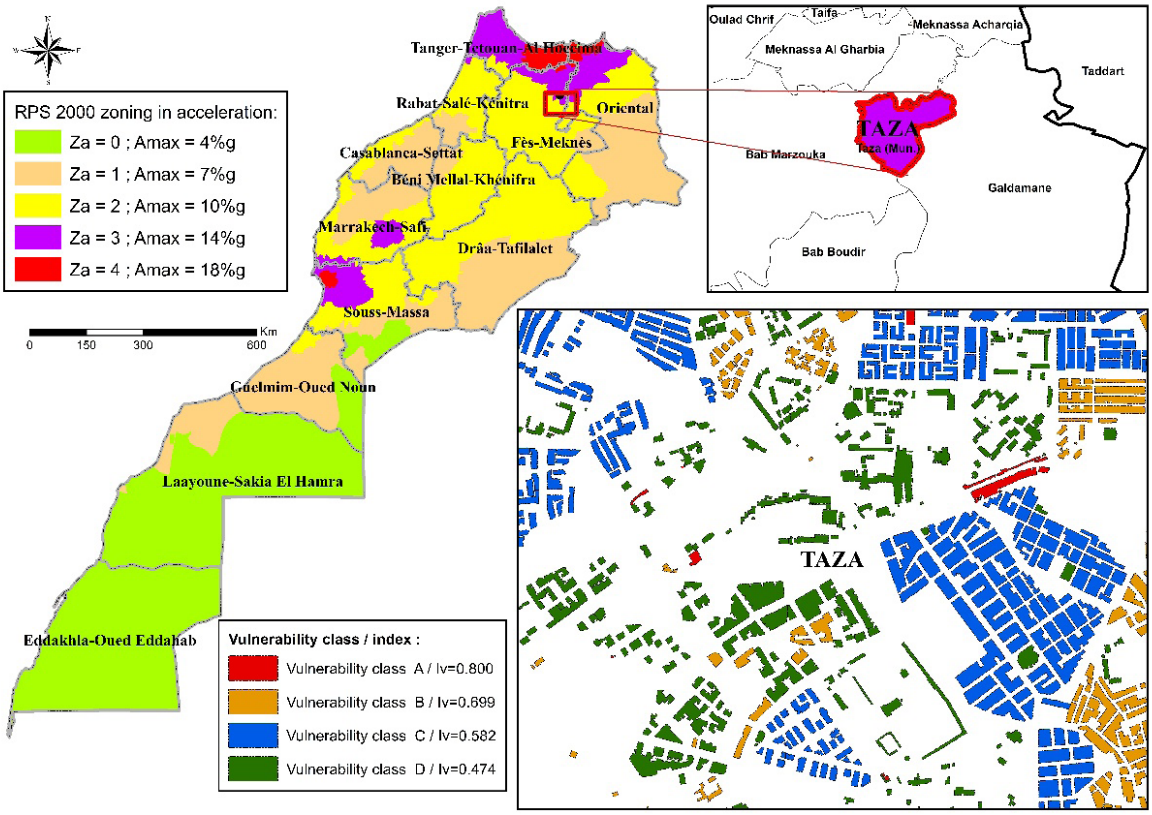

Figure 3. Spatial representation of seismic vulnerability classes of buildings in the Taza urban area.

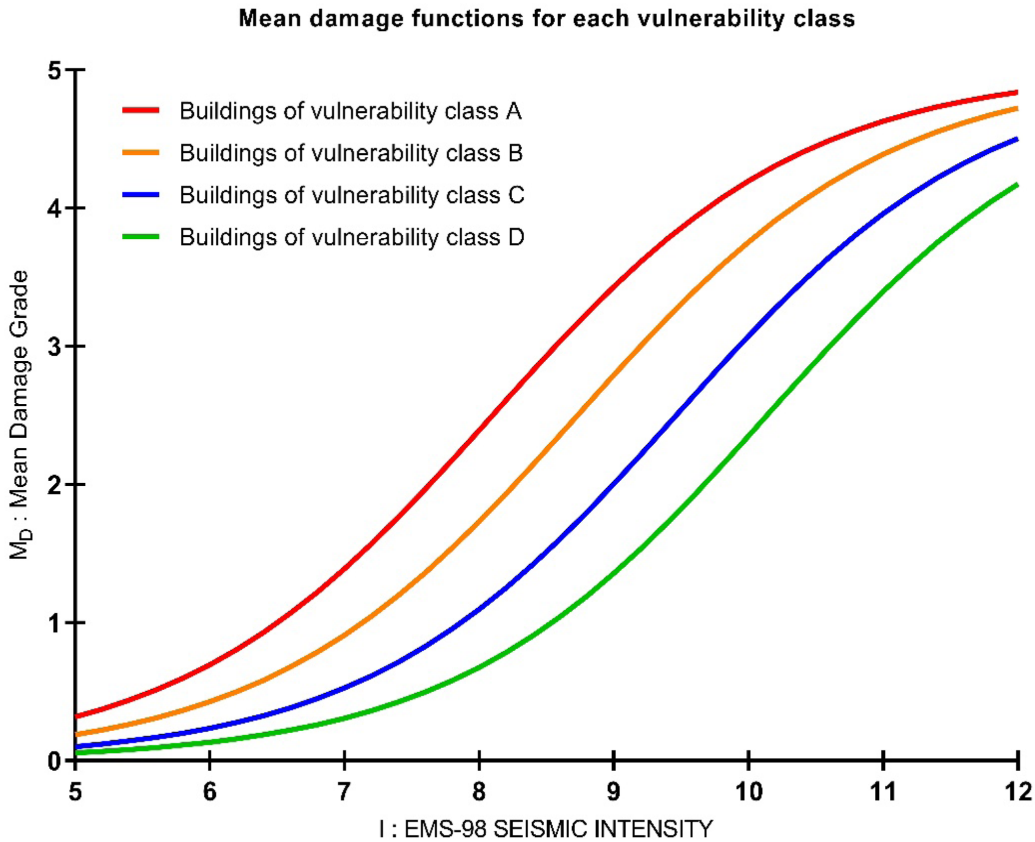

Figure 4. Mean damage functions for each vulnerability class in the urban area of Taza.

$$\begin{cases} \beta_{Sd1} = 0.25 + 0.07\ln(Du/Dy) \\ \beta_{Sd2} = 0.2 + 0.18\ln(Du/Dy) \\ \beta_{Sd3} = 0.1 + 0.4\ln(Du/Dy) \\ \beta_{Sd4} = 0.15 + 0.5\ln(Du/Dy) \end{cases} \quad (7)$$

Where: Du: is the ultimate displacement and Dy: the displacement at the elastic limit. In order to determine the damage of a structure and consequently its vulnerability, the performance point of a structure during a seismic excitation is a key parameter. This point is determined by the point that coincides with the intersection of the capacity spectrum and the demand curve represented by an inelastic response spectrum (Lopes *et al.* 2020).

According to the Morocco seismic building code, the response spectrum is expressed as an amplification factor vs period curve. In order to convert it to an acceleration-displacement format ($S_{ae}(T)$, $S_d(T)$); the equation (8) is used:

$$\begin{cases} S_{ae}(T) = (A_{max}/g)D(T) \\ S_d(T) = (T^2/4\pi^2)S_a(T) \end{cases} \quad (8)$$

With: D(T) is the dynamic amplification factor and A_{max} is the peak ground acceleration derived from seismic zoning of the Morocco seismic code and g is the acceleration of gravity. According to Fajfar (2000), we use inelastic spectra obtained from the elastic spectrum by division with a reduction coefficient $R\mu$, defined as a function of the ductility factor μ by applying equation (9):

$$\begin{cases} \text{If } T < T_C \text{ So } R_\mu = (\mu - 1)\frac{T}{T_C} + 1 \\ \text{If } T_C < T < T_D \text{ So } R_\mu = \mu \end{cases} \quad (9)$$

T_C and T_D are the limit periods between the short medium and long period domains. μ is defined as the ratio of the ultimate displacement and the elastic limit displacement.

Figures 8a and 8b show the results of the deterministic analysis of the selected buildings. The fragility curves, which define the probability of reaching or exceeding a certain degree of damage, are obtained from the beta distribution of the cumulative probability in Equation 5. Figure 9 shows that the damage probabilities obtained by the deterministic method, based on the Pushover analysis of the seismic classes B and C buildings, are limited by those obtained by the vulnerability index method for a seismic scenario of seismic intensity between VIII and IX. This shows that the results of the two-vulnerability methods used in this study are in agreement.

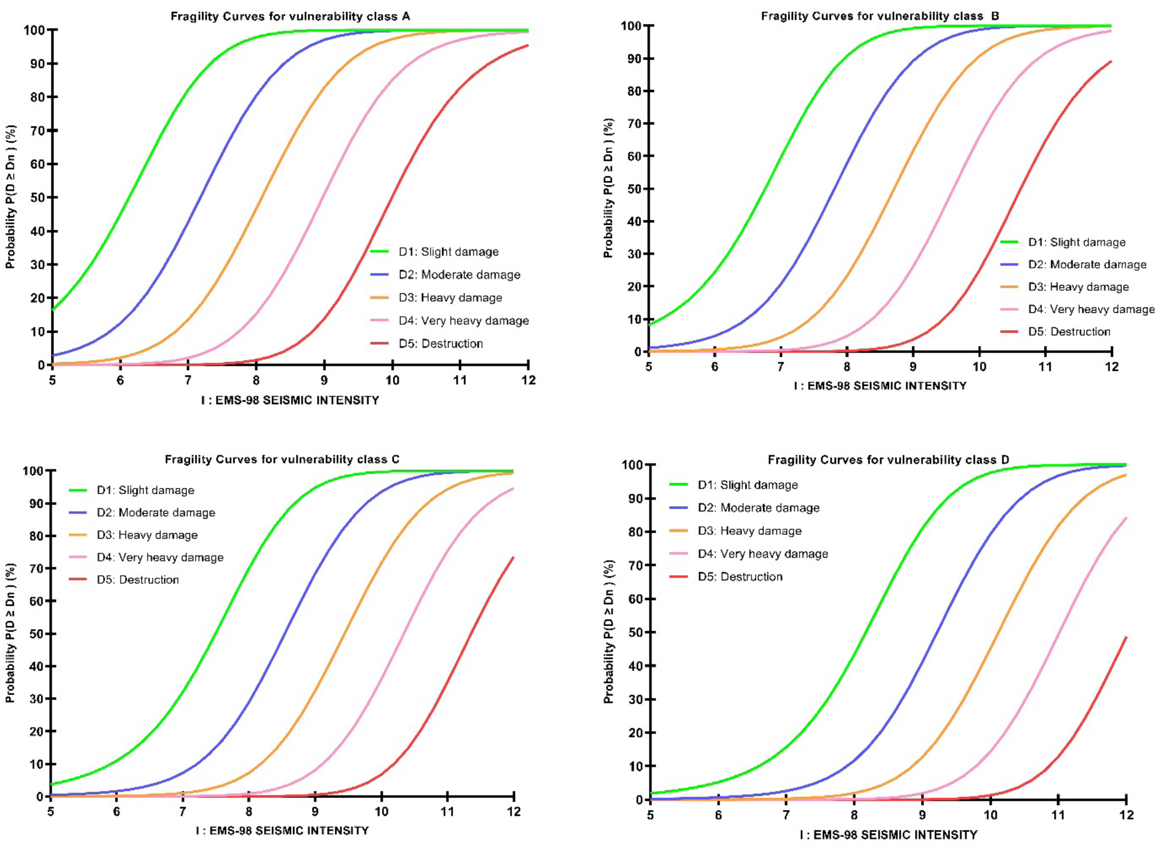

Figure 5. Fragility curves for each vulnerability class in the urban area of Taza.

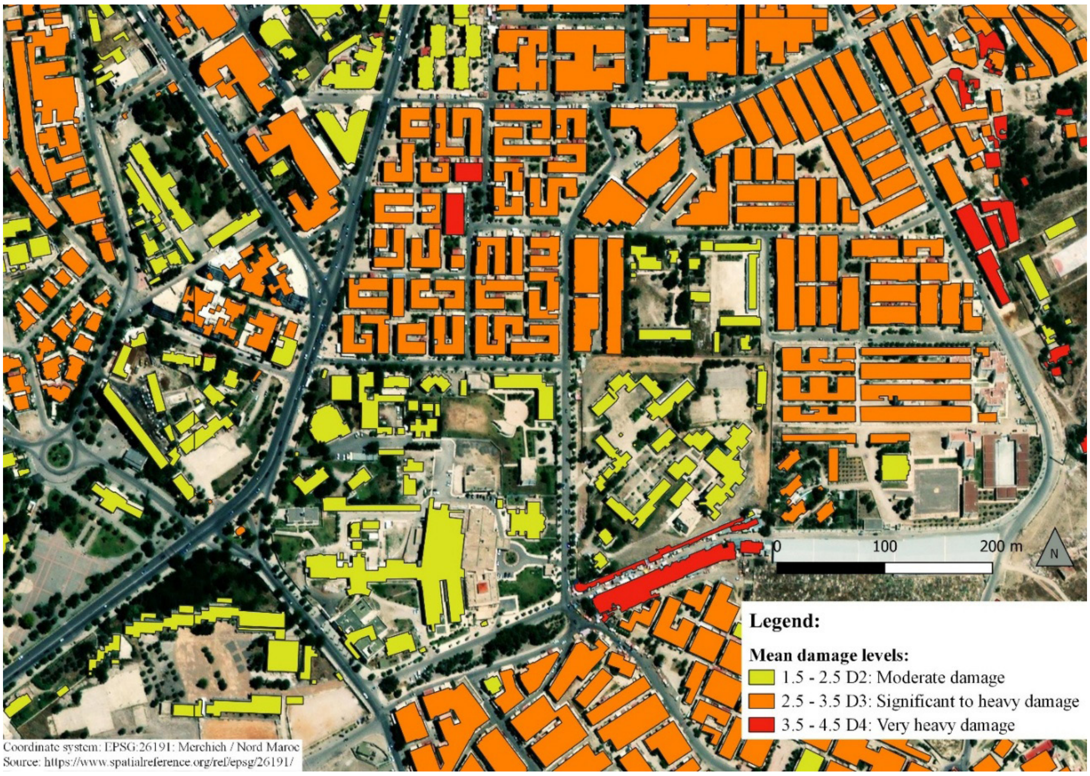

Figure 6. Distribution of mean damage levels for a seismic intensity scenario of IX in the Taza study area.

Reference buildings of vulnerability class B

Description: Constructions of seismic class B, reinforced as a whole in masonry, built with hollow brick masonry walls, columns, beams and slabs in RC of 2 to 3 stories.
Reference buildings of vulnerability class C

Description: Constructions of seismic class C, buildings with columns/beams and infill walls of brick hollow not braced, mainly constructed with brick masonry walls, columns, and slabs in reinforced concrete of 1 to 4 stories

Figure 7. Illustration of the classification of buildings selected for the analysis by the deterministic method.

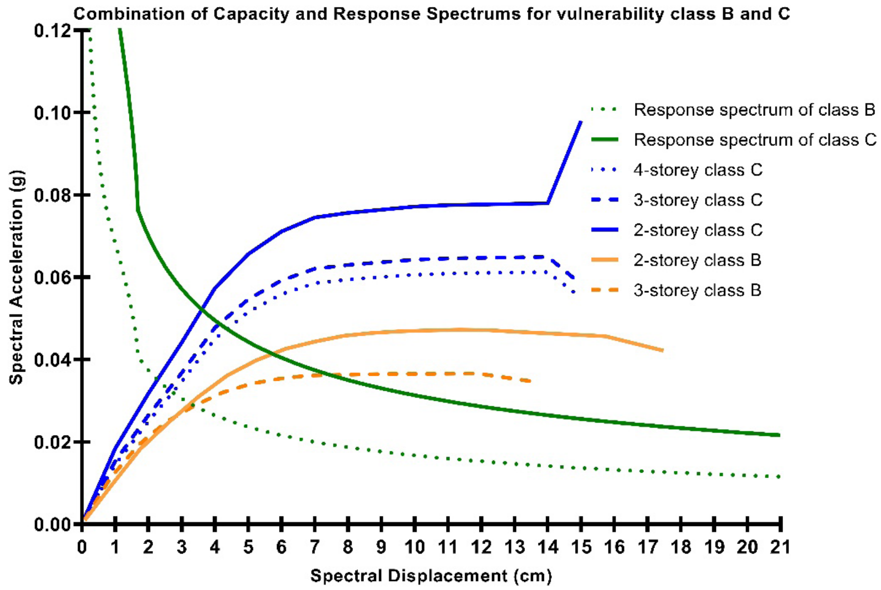

Figure 8a. Combination of capacity and response spectrums, identification of the performance point for the selected seismic classes B and C.

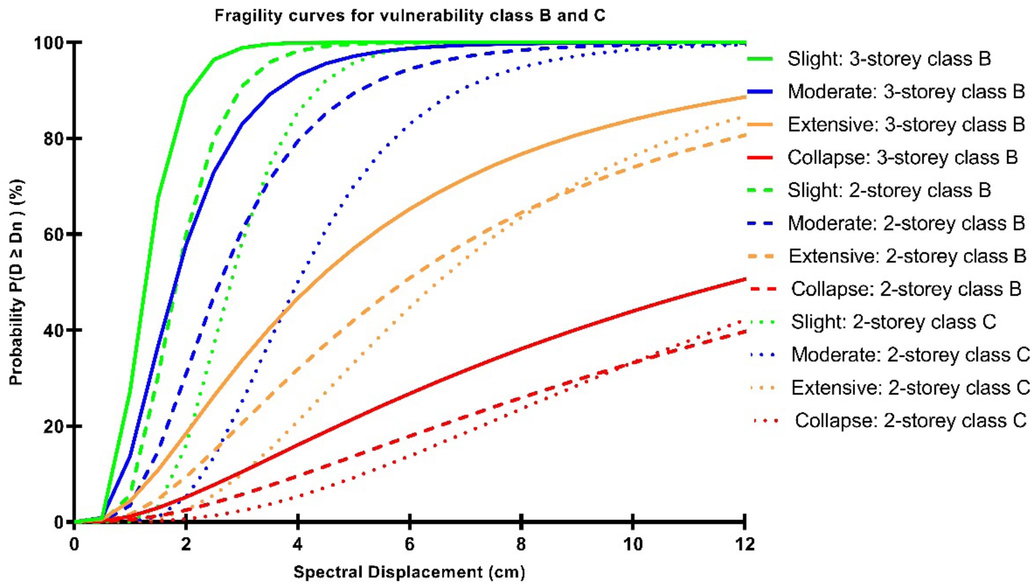

Figure 8b. Fragility curves for the selected seismic classes B and C.

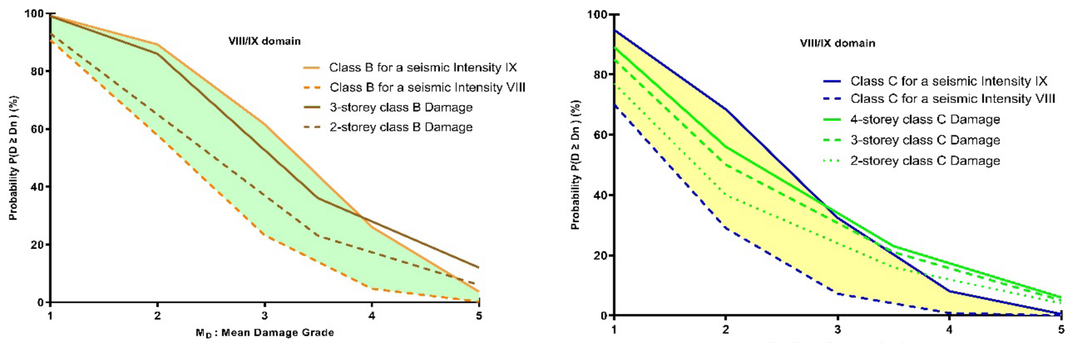

Figure 9. Comparison of damage percentages for vulnerability classes B and C.

CONCLUSION

The assessment of seismic vulnerability and the construction of fragility curves of current buildings in the city of Taza-Morocco is studied according to a methodology based on the combination of the characterization of seismic hazard, the approach called the Vulnerability Index Method (VIM) and the seismic classification of buildings, as well as the deterministic capacity curve (M_D) method.

The approach adopted consists in making a distribution of buildings in classes of vulnerability according to a synthetic scheme developed in this article. Thus, based on a seismic scenario, we define representative typologies of the selected classes and their associated vulnerability classes in order to estimate the distribution of damage to common buildings. Seismicity data concerning the principal seismic events in and surrounding the study area are detailed. The seismic hazard is defined by the seismic intensity parameter ranging from VIII to X for the urban area studied.

The results of the seismic vulnerability of this study show that the majority of buildings in the city of Taza have vulnerability indices between 0.4 and 0.8 (vulnerability classes B and C). Particularly, these are load-bearing masonry constructions or reinforced concrete of the column-beam frame type with infill walls in hollow bricks. Following seismic scenarios corresponding to seismic intensities VIII, IX and X, some conclusions can be drawn:

- For a seismic scenario of intensity VIII, all buildings will suffer negligible to moderate damage. In particular, buildings of vulnerability class A will suffer moderate damage. Most of the buildings in vulnerability class B, C and D will suffer negligible to slight damage.

- For a seismic scenario of intensity IX, all buildings will suffer slight to heavy damage. In particular, most of the buildings of the vulnerability class A, B and C will suffer critical to heavy structural damage, some of them moderate damage. While the buildings of the D vulnerability-class will suffer negligible to slight damage.

- In case of an intensity X seismic scenario, all buildings will undergo moderate to heavy damage. In particular, buildings of vulnerability class A and B will suffer very heavy structural damage; some will suffer critical to heavy damage. Buildings in vulnerability class C will suffer serious to heavy damage. While the buildings of the vulnerability D class will undergo only moderate damage.

In addition, these results show a correspondence with the description of the observed effects of the EMS98 Intensity Scale on the buildings indicator with increasing seismic intensity.

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