EVALUATION OF URBAN SEISMIC RISK AND DAMAGE ESTIMATION: CASE OF RIF BUILDINGS

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Summary

Rural Morocco grapples with challenges like inadequate infrastructure and insecurity, prompting a notable migration towards urban areas. This shift has resulted in improper land utilization, escalating the susceptibility to seismic disasters, notably in the central Rif region. In response to previous seismic events, national efforts have been directed towards implementing seismic regulations to mitigate risk. The primary focus of this study is to assess the seismic vulnerability and risk of Moroccan structures, with a particular emphasis on the central Rif region. Three key methodologies are examined: the empirical Vulnerability Index Method, the hybrid Japanese method integrating building models with on-site factors, and the analytical CSBM based on structure typologies. The ultimate objective is to formulate risk maps for effective prevention strategies and emergency plans, providing decision-makers with the necessary tools for assessing seismic vulnerability and risk.

1 INTRODUCTION

In Morocco, rural areas lag behind in terms of development indicators such as insufficient infrastructure, isolation, and insecurity. These structural shortcomings, coupled with occasional drought waves, have significantly contributed to rural exodus. In 1960, 71% of Moroccans lived in rural areas, but in recent years, less than 40% of the country's population remains there [1]. Nationwide, urban planning has failed to keep pace with the significant increase in population migration, leading to improper land occupation and an increase in damages from seismic disasters. The high concentration of population, buildings, infrastructure, and exposed assets transforms these regions, found in all Moroccan cities, into high-risk zones. Considering moderate seismic activity, this results in one of the most unfavorable scenarios at the national level, especially in the urban and rural areas of the central Rif region.

Recent events have demonstrated the significant seismic risk in this region [2]. Successive seismic sequences between 1992 and 1994, the 2004 earthquake [3, 4], and more recently, the 2016 earthquake [5], have caused fatalities and substantial damage [6, 7]. Moderate seismicity, high vulnerability of existing buildings, and local site effects have primarily been the cause of these significant damages. On a larger scale, the Mediterranean region is exposed to moderate-intensity earthquakes, resulting in considerable damage.

In the literature, various methods are adapted to address such large-scale problems, categorizing into three main groups: (i) Empirical methods, based on damage reports from earthquakes and building characteristics to estimate a seismic vulnerability index. These empirical methods were initially the only reasonable approaches for large-scale seismic risk analysis [8, 9]; (ii) Mechanical and analytical methods, more detailed but labor-intensive for large-scale studies. They use more complex algorithms for vulnerability assessment, allowing for more detailed studies; (iii) Hybrid methods, particularly advantageous in the absence of damage data, also allowing adjustments to the analytical model.

Nationally, preventive measures have eventually been taken to reduce damages. The introduction of the national seismic regulation R.P.S. in 2002 [10] and its revision in 2011 [11] were significant steps. However, studies focusing on seismic risk assessment are relatively rare [12, 13]. Our work falls within this theme, focusing on the assessment of seismic vulnerability and risk of Moroccan buildings. Given its seismicity, the central Rif region was considered a proof of concept. On a socio-economic level, the objective was to develop risk maps to deploy prevention strategies and emergency plans in the event of a seismic disaster. In the long term, the ambition is to provide decision-makers with a set of tools and guides to quickly assess seismic vulnerability and risk.

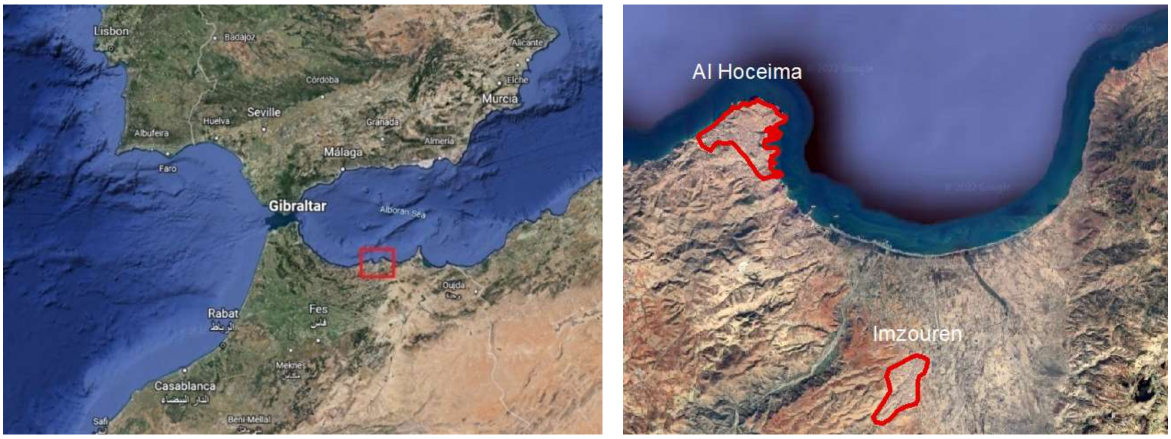
The considered approaches are distinct, each belonging to a different category, and each having its own advantages and disadvantages. The first approach is the Vulnerability Index Method, purely empirical, based on post-seismic damage reports and on-site investigations to identify parameters influencing structural vulnerability and assign an index reflecting the building's seismic performance. The second approach is a hybrid method, based on the basic performance of a building model and adding field-observed factors such as irregularities and structure maintenance. The last approach is an analytical method, abandoning individual aspects of each building (irregularities) for structure typologies. Building models are designed to derive capacity curves, and with a response spectrum of the region, estimate structural performance.

2 STUDY AREA

2.1 Seismicity in the Cities of Al Hoceima and Imzouren

The Rif region in northern Morocco is the most seismically active zone in the country. Over the past decades, the area has experienced several earthquakes, some of which were highly destructive, such as the earthquakes in 1994 (MW = 6.0) and 2004 (MW = 6.4). More recently, a magnitude 6.3 earthquake struck 50 km off the coast of Al Hoceima on Monday, January 26, 2016 [3, 5], causing material damage. The central Rif region, in particular, has been affected by several recent seismic episodes, highlighting the high level of seismicity in this area [14, 15]. This issue has been the subject of multiple studies related to seismology, seismic hazard, and seismic vulnerability [13, 16-18].

Al Hoceima (35°25' North, 3°93' West) and Imzouren (35°09' North, 3°52' West) are cities located on the northern coast of Morocco, belonging to the same province (Figure 1). Being at the heart of the Rif mountain range, they have been subjected to numerous seismic events. As a reminder, the earthquake on February 24, 2004, resulted in 629 deaths, 966 injuries, 2539 homes damaged or destroyed, and 15,600 people left homeless. The difference in observed damages from the same earthquake was significant. Even though Imzouren and Al Hoceima are equidistant from the epicenter, Imzouren suffered more damage. It was reported that the differences in damages were related to the nature of the soil and the quality of construction [6].



(a) **(b)**

Figure 1: (a) Satellite Image of the Western Mediterranean (Landsat - Google Earth) and Location of the Study Area. (b) Plan view of the Satellite Image (Google Earth) of the Cities of Al Hoceima and Imzouren

2.2 Seismic Hazard

Seismic hazard has been assessed in two different ways, depending on the vulnerability assessment method used. The first relies on a single parameter representing hazard, macroseismic intensity, and introduces two earthquake scenarios, including site effects. The second approach is more advanced and is based on the response spectrum. Multiple spectra were considered for the study.

- Seismic Hazard Assessment based on Macroseismic Intensity

Two main scenarios were considered for this study: a deterministic scenario, possibly the best approach for a city in a seismic zone, and a probabilistic scenario to compare risk differences. Given the small size of the cities, macroseismic intensity is considered constant. The deterministic scenario is based on a reference earthquake, representing the closest earthquake to the site that caused the most significant damage. In this case, we assume that this event is similar to the earthquake that struck the Al Hoceima region on February 24, 2004 [7]. The estimated intensity in the city of Imzouren was approximately IX-X on the MSK scale. The same reference event was considered in a previous study of seismic risk in Al Hoceima [13] since the two cities are relatively close to each other.

Seismic hazard for the probabilistic scenario was derived from the Risk Management Solutions Inc. report in 2012 [19]. According to the results, the city of Imzouren was assigned an intensity of VIII on the MSK scale [20] and a maximum ground acceleration equivalent to 0.303 g for a return period of 475 years. For this study, site effects were estimated from a seismic microzonation conducted in the city [21]. An iso-frequency map was created using Nakamura's H/V method. The intensity map for the city of Imzouren, including site effects, is illustrated in Figure 2 for both scenarios. As can be seen, seismic intensity in the deterministic scenario is significantly higher than that estimated by the probabilistic scenario.

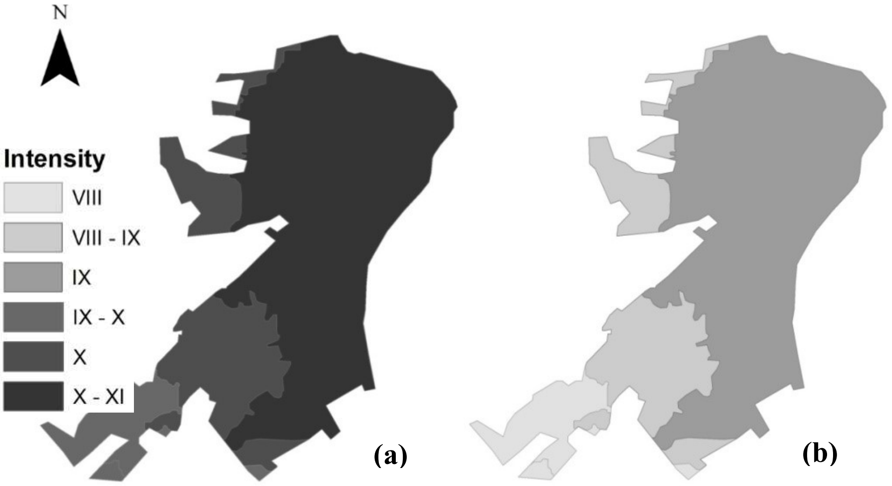


Figure 2: (a) Intensity Map of the City of Imzouren Including Site Effects According to (a) Deterministic Scenario and (b) Probabilistic Scenario

- Seismic Hazard Assessment through Response Spectra

The assessment of seismic hazard is also defined in terms of damped elastic response spectra with a 5% damping ratio, adopting a probabilistic scenario corresponding to a return period of 475 years. Two response spectra are proposed: one from the national seismic code [11] and another based on Eurocode 8 [22], considering local parameters. The second scenario is justified because building design and construction in Morocco are still deeply influenced by European construction standards. Until now, the French building code, BAEL91, and Eurocode are still considered in national construction practices.

For rocky soils, the national seismic code assigns the same acceleration value of 0.18g to both the cities of Imzouren and Al Hoceima. For the second spectrum, acceleration values are based on a risk analysis study conducted by Risk Management Solutions Inc. (RMSI) in 2012 [19], providing the following results:

- Al Hoceima: Maximum ground acceleration of 0.253 g for a return period of 475 years
- Imzouren: Maximum ground acceleration of 0.303 g for a return period of 475 years

Figure 3 displays the 5% damped elastic response spectra obtained on rocky soil. As observed, the national seismic code response spectrum is relatively flat compared to the other two spectra, reducing amplification values for shorter return periods but mitigating the decline in acceleration values as the return period increases.

Table 1 shows that both seismic codes introduce the same soil classification. The soil type will undoubtedly influence the seismic risk results for both cities. Al Hoceima structures are primarily built on firm or rocky soil, while Imzouren structures are built on relatively loose soil.

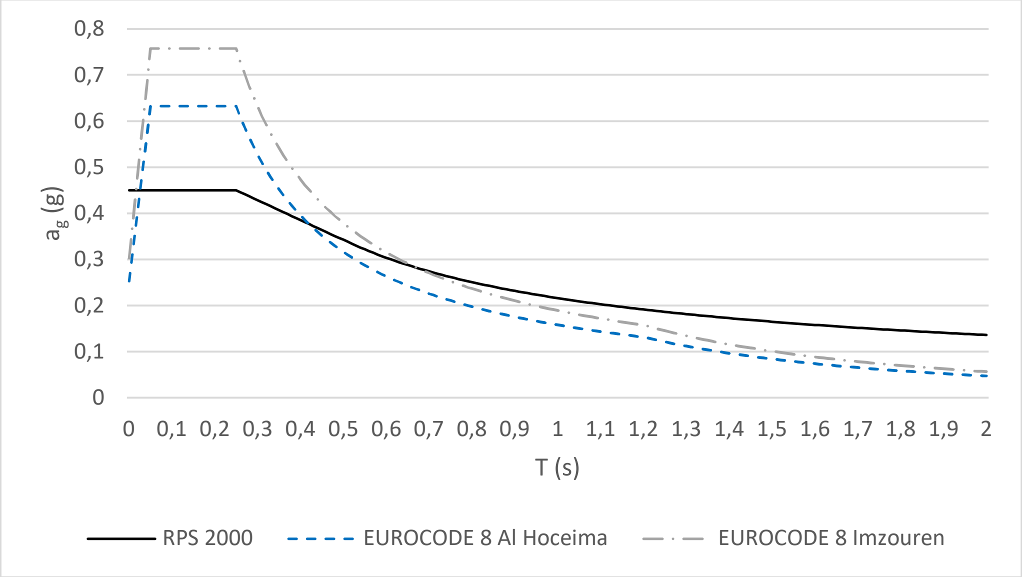


Figure 1: 5% elastic response spectra for the probabilistic scenario, expected on outcrop rock

Description of stratigraphic profile	EUROCODE 8		National Seismic Code (RPS2000)		
	Ground Type	$V_s(m/s)$	Soil Class	$V_s(m/s)$	Soil Factor
Rock or other rock-like geological formation	A	> 800	S1	$V_s \geq 760$	1
Deposits of very dense sand, gravel, or very stiff clay	B	360 – 800	S2	360 – 760	1.2
Deep deposits of dense or medium dense sand, gravel or stiff clay	C	180 – 360	S3	180 – 360	1.4
Deposits of a loose-to-medium cohesionless soil, or predominantly soft-to-frim cohesive soil	D	< 180	S4	< 180	1.8
A soil profile consisting of a surface alluvium layer	E	-	S5	-	-

Table 1: Soil Types according to Eurocode 8 and National Seismic Code (RPS2000)

2.3 Building Typology

The urban municipalities of central Rif are modern 20th-century developments. According to the most recent census [1], the modern Moroccan house is the dominant construction typology. It is typically a low to medium-rise structure with a reinforced concrete frame. Existing constructions in Al Hoceima and Imzouren are no exception and share similar characteristics. Most buildings have regular geometry and do not exceed six stories (Figure 4). They also have relatively small construction areas, ranging from 100 m² to 150 m² [17].

The structural models used to generate capacity and fragility curves were obtained by considering the construction peculiarities of existing reinforced concrete buildings. Detailed information on their design was obtained through years of data collection, georeferencing, organizing, and classifying the existing building database in both cities [13, 16]. The database collection began with a preliminary survey in the cities to determine the best method for assessing the seismic performance of existing buildings. Additionally, the design and construction details obtained from consulting firms working in the study area allowed us to generate 3D building models based on existing structural typologies [17].

Figure 4: Examples of Residential Buildings in the Study Region

The inspection primarily focused on residential buildings across both cities, representing different neighborhoods and typologies. A total of 2,746 existing buildings between the two cities were considered. Recorded information, such as structural system, position, number of floors, observed irregularities, etc., was stored in a GIS database. The following observations highlighted several similarities, enabling the classification of buildings into a limited number of typologies:

- Most buildings are reinforced concrete frame structures.
- Structures are low-rise and built on relatively small areas (100-150 m²).
- Most buildings are regular structures with simple geometric shapes.

3 METHODOLOGY AND RESULTS

The data collection principle aimed to gather a maximum number of information, allowing the consideration of a variety of vulnerability assessment methods. The approach began with a simple empirical method for quick and credible results. Subsequently, attention was given to hybrid and analytical methods, focusing more on structural behavior, albeit more time-consuming but closer to the real model.

3.1 Vulnerability Index Method

The seismic risk assessment was conducted in terms of macroseismic intensity, considering both probabilistic and deterministic scenarios. Site effects were also taken into account as Imzouren is built on sedimentary soil. The seismic vulnerability of the buildings was assessed using a Vulnerability Index Method (VIM) adapted and applied to the local characteristics of Moroccan buildings. Seismic risk is represented by direct damages to buildings, damages to the population, and economic losses. Population damages are defined in terms of casualties, injuries, and individuals needing relocation (homeless). Economic losses are calculated based on reconstruction costs, derived from direct damages to buildings. The extensive building database necessitated the use of a geographic information system (GIS) for this study.

The city has been subdivided into several sections representing 11 neighborhoods. Each section is characterized by a certain number of inspected buildings that define the structural nature and geometry of the residential structures in the region. The survey targeted buildings throughout the city, where geometric features were inspected (Figure 6). It is noteworthy to observe the number of reinforcements and reconstructions, especially in the southern part of the city, where the damages from the 2004 earthquake were more significant. However, the reinforcements are not consistently applied, often involving the jacketing of ground-floor columns with steel reinforcement.

Three construction periods have been defined for residential buildings in Imzouren (Table 2): before 1960, between 1960 and 1994, and after 1994. The two events (1960, 1994) are highly significant in the seismic history of Morocco, representing a substantial shift in construction practices, particularly in the Al Hoceima region.

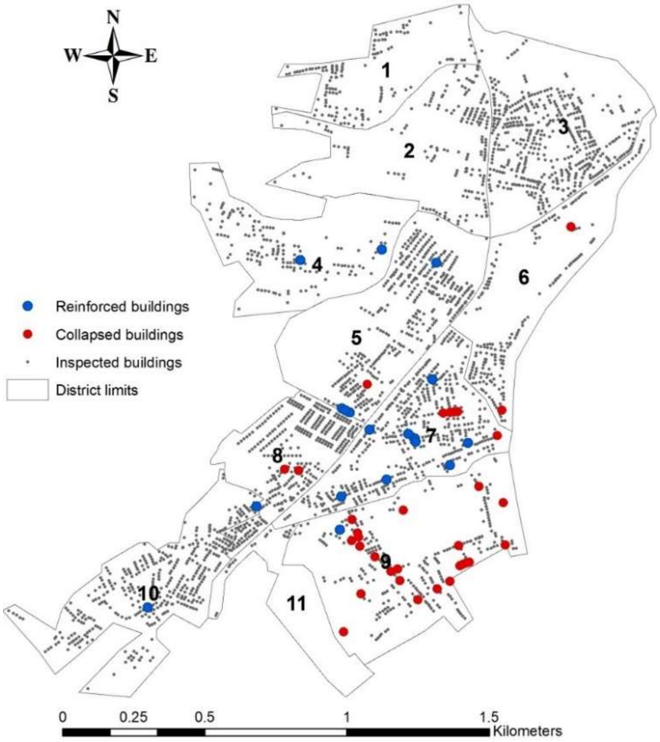


Figure 5: Administrative Boundaries and Inspected Buildings in the City of Imzouren

Construction period	Before 1960	1960-1994	After 1994
Code level	Low code	Medium code	High code

Table 2: Adopted Code Levels for Existing Buildings in Imzouren

The Vulnerability Index Method (VIM) was chosen as one of the assessment procedures that were successfully developed and applied to many European cities. The key advantage of VIMs is their ability to determine the vulnerability characteristics of each building, rather than defining vulnerability based solely on typology. The method provides a typological classification system [23] to group structures with similar seismic performance V_I^{class}. It then adds behavior modifiers Vm_j specific to each building to calculate a total vulnerability index $V_I^{building}$ for each building using the following equation [24]:

$$V_I^{building} = V_I^{class} + \Delta M_R + \sum_{j=1}^{n} Vm_j \quad (1)$$

The Vulnerability Index Methodology (VIM) was tailored to the specific characteristics of

Moroccan buildings [13] and applied to the studied buildings in Imzouren. The results indicate that the vulnerability index ranges from 0.2 to 0.86, with an average value of 0.38. The city exhibits low vulnerability, as demonstrated in Table 3. The findings align well with the 2004 census, where 4.7% of households were below the relative poverty threshold, and 7.6% were below the vulnerability threshold [25]. This adaptation of the VIM to Imzouren provides valuable insights into the seismic vulnerability of buildings in the city, aiding in the identification of areas that may require targeted interventions for seismic risk reduction and resilience enhancement.

Label	**District name**	**MVI**	**Label**	**District name**	**MVI**
1	Laazib	0.44	7	Quartier Masjid	0.38
2	Iboujiren	0.44	8	Souk	0.31
3	Zaouia	0.42	9	Tanaouia 1	0.33
4	Ait Moussa et Amar	0.41	10	Hay Rabia	0.32
5	Quartier Commercial	0.41	11	Tanaouia 2	0.32
6	Ait M'hand Ou Yahya	0.40			

Table 3: Average Vulnerability Indices of the Neighborhoods in Imzouren

The collected data on building seismic vulnerability were combined with the macroseismic intensity of the region, including site effects. The results are presented below.

- Direct Damages

The distribution of damages follows the same pattern as the site effects (Figure 2); damages are more significant in the eastern part of the city where site effects are more pronounced. The values of damage degrees range from 0.58 to 4.59 for the deterministic scenario and from 0.17 to 3.77 for the probabilistic scenario, with average values of 2.08 and 0.89, respectively. This corresponds to moderate damage for the deterministic scenario and light damage for the probabilistic scenario. Figures 7 and 8 depict the distribution of damages in different city neighborhoods for both deterministic and probabilistic hazard scenarios.

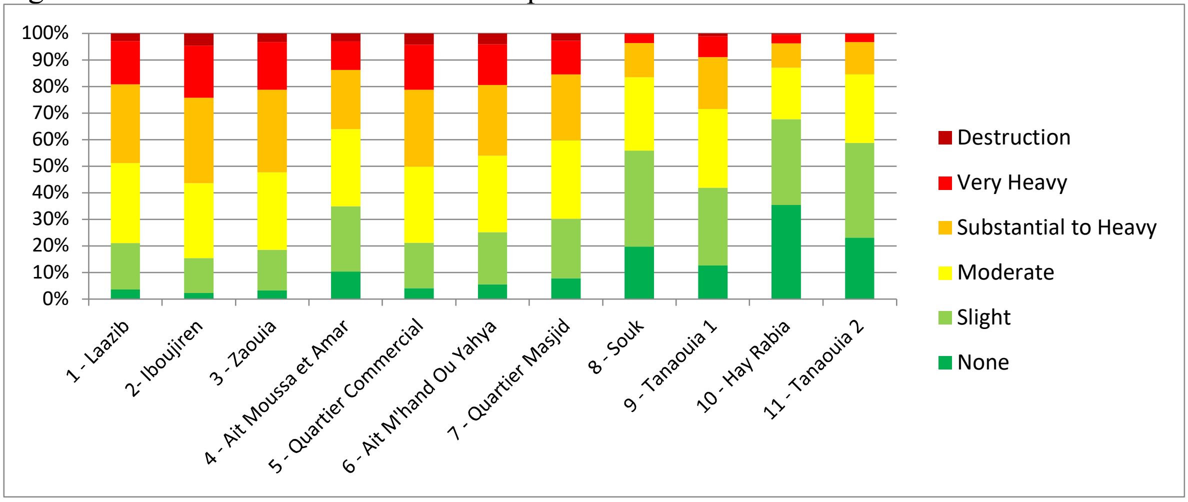


Figure 6: Damage distribution based on the deterministic scenario

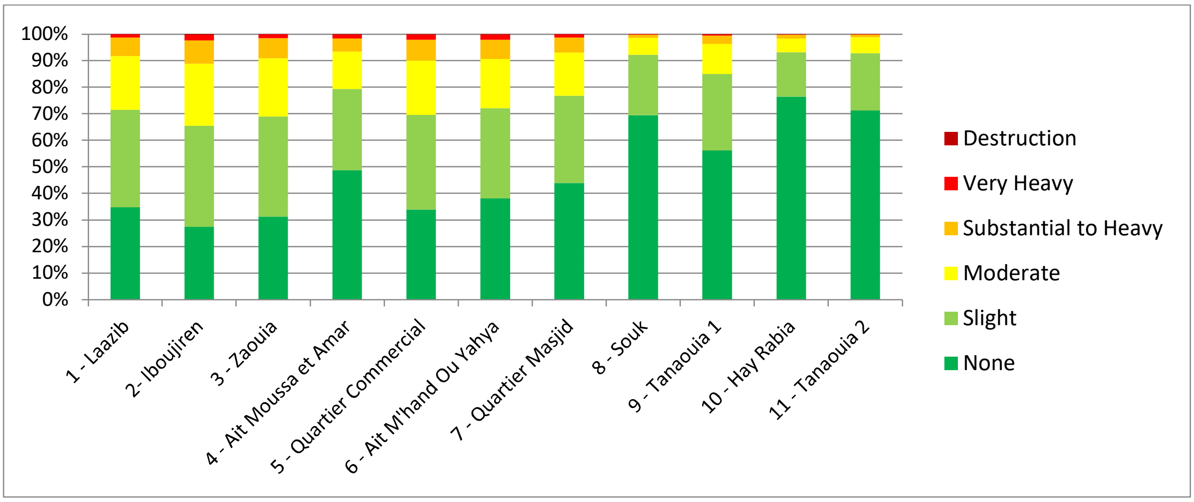


Figure 7: Damage distribution based on the probabilistic scenario

- Damage to the population

Damage to the population is estimated taking into account the number of victims and homeless individuals. Initially, to assess the number of victims and injured individuals, the model proposed by Coburn and Spence (2002) is used [26]. The results are provided only for the deterministic scenario, where collapsed buildings are considered. Table 5 shows the total number of victims and injuries for each district in the city of Imzouren. The estimated number of victims is 580, and the estimated number of deaths is 147, strongly correlated with the estimated number of collapses, which is 84 for the deterministic scenario.

Label	**District name**	**Light injuries**	**Injuries requiring hospitalization**	**Life-threatening cases**	**Fatalities**
1	Laazib	12	13	12	13
2	Iboujiren	36	37	36	37
3	Zaouia	31	32	31	32
4	Ait Moussa et Amar	7	7	7	7
5	Quartier Commercial	26	27	26	27
6	Ait M'hand Ou Yahya	15	16	15	16
7	Quartier Masjid	10	10	10	10
8	Souk	1	1	1	1
9	Tanaouia 1	5	5	5	5
10	Hay Rabia	0	0	0	0
11	Tanaouia 2	0	0	0	0
Total		**143**	**147**	**143**	**147**

Table 4: Number of victims for the deterministic scenario for each district of Imzouren

- Economic Losses

Economic losses are considered in terms of the costs of reconstructing damaged buildings. This value is estimated by the cost of reconstructing reinforced concrete buildings, excluding the cost of land [27]. The total economic losses are 197 million euros in the case of the deterministic scenario and 48.4 million euros in the case of the probabilistic scenario. Losses according to the deterministic scenario represent 43% of the estimated losses from the 2004 earthquake, taking into account the value in dollars and exchange rates, which is accurate considering the statements in the technical reports of the damage in the Al Hoceima region.

3.2 Seismic Index Method (Japanese Method)

In this project, the main objective was to develop a technique as straightforward as a building survey but more targeted and suitable for the context of reinforced concrete (RC) construction in Morocco. The study area is limited to RC residential buildings in the cities of Al Hoceima and Imzouren. Both Imzouren and Al Hoceima are modern 20th-century settlements where residential buildings are often low to medium-rise RC frames. For this reason, the Japanese Seismic Index method [28] appears to be an interesting tool in the study area. Instead of an internal visual inspection of structural elements, which was not possible in this case, building models were developed based on construction practices and requirements. The advantage is that it is a rapid screening method based on a solid understanding of structural element design practices in the region.

36 models were generated based on the following parameters, directly determined from the evaluation sheets resulting from the field survey:

- Number of floors: 1 to 6 floors.
- Construction period: before 1991, between 1991 and 2002, after 2002.
- Seismic code: there is only one national seismic regulation [10] applied since 2002 and revised in 2011 [11].

The models have a rectangular shape with an area of 12 m × 10 m. Residential zoning plans for both cities show that buildings mostly have an area ranging from 100 m^2 to 150 m^2, so considering all models with an area of 120 m^2 was both appropriate and practical for representing these structures. The structural nature of the models is an RC frame as it is the main type found in residential dwellings. Emphasis was placed on vertical structural elements given their importance in resisting horizontal loads.

The main idea of the approach is to approximate the basic seismic performance of the building using the yield and ultimate limits of the capacity curves of building models. The basic performance is assumed to be free from any shape or irregularity complexity. The negative effect of architectural features on the seismic performance of buildings is well recognized by the earthquake engineering community [29]. Thus, an irregularity index and a deterioration index would be included in the equation to calculate the final seismic performance index. Therefore, the seismic index of the structure I for each building is calculated as follows:

$$I = B \times R \times T \tag{2}$$

where B is the basic seismic index of the structure, R is the irregularity index, and T is the deterioration index. The key aspect of this equation is not to limit the building definition to a capacity curve but also to consider the various shape complexities and structural defects that the building may have.

The seismic index I will be assigned two values, I_y and I_u, which are calculated as follows:

$$I_v = B_v \times R \times T \ \ and \ \ I_u = B_u \times R \times T \tag{3}$$

B_y and B_u will be explained in more detail in the following section. In general, high values of the seismic index I indicate good seismic behavior of the structure.

The seismic evaluation of existing reinforced concrete buildings was applied to all inspected buildings in the cities of Al Hoceima and Imzouren. Structures with a value index $I_y \geq 1$ imply that they are safe and, in the event of an earthquake, are likely to suffer no damage. In cases where $I_y < 1$ and $I_u \geq 1$, the seismic performance of the buildings is in an uncertain plastic state, and they are likely to experience structural damage but not partial or total collapse. If $I_u < 1$, it means that the structure yields and is likely to collapse at any moment.

Figure 9 shows that buildings designed with seismic regulations perform better than their counterparts built without a code, in both elastic and plastic modes. The figure also indicates that I_y and I_u values tend to decrease with the height of the buildings. This could explain the common practice of adding shear walls if the building has more than 4 stories. It is important to note that the I_u values for 6-story buildings with seismic design, built after 2002, are higher than the values obtained for 3, 4, and 5-story buildings. The main reason is that the 6-story buildings are located in the most important avenues of the two cities; their owners invest more money in their design and construction.

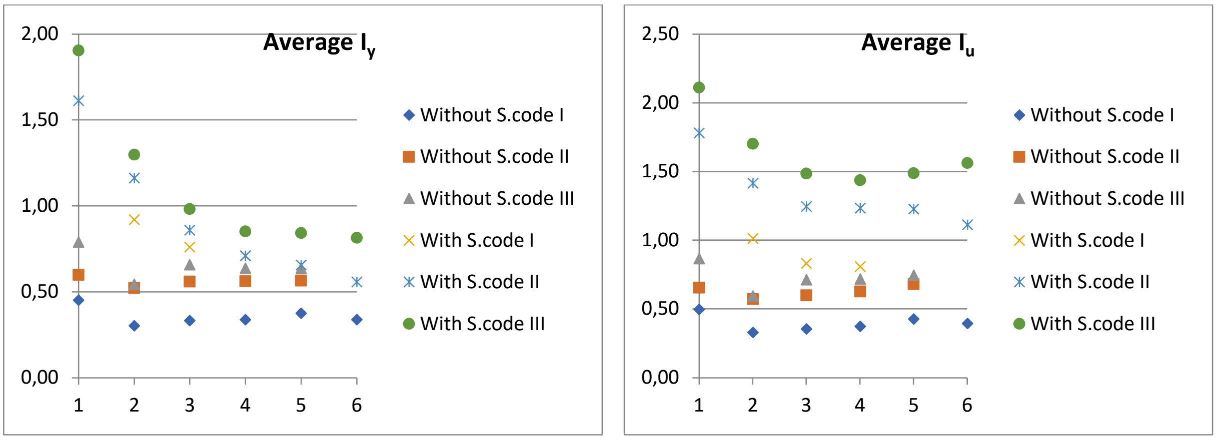


Figure 8: Average values of $\boldsymbol{I_y}$ and $\boldsymbol{I_u}$ for all combinations

According to the national seismic regulation [10], to ensure an acceptable level of safety during an earthquake and its aftermath, it is required that the entire structure has a relatively low probability of collapse during life of the building. In other words, it is crucial that the structure remains standing during a seismic event, even if it sustains damage. This is precisely what was observed in the results depicted in Figure 10. When comparing the I_y and I_u indices of buildings designed with the seismic code, it is noteworthy that the I_u values are significantly higher than the I_y values, providing a substantial margin for the building to withstand damage. Conversely, buildings without the code show that I_y and I_u are very close to each other, implying that the building may experience instant collapse and could be very dangerous for residents who may not have enough time to evacuate.

A total of 36 buildings damaged as a result of the earthquake were studied and assessed using the proposed method to compare the I_y and I_u values with the observed damage state for each construction. Figure 11 shows the results of this comparison. As expected, the average values for each damage state are generally decreasing (Table 8). The I_y values are all less than 1, explaining the presence of damage in the first place.

Mean index	Slight	Moderate	Heavy	Very Heavy	Collapse
I_y	0.575	0.503	0.533	0.439	0.443
I_u	0.813	0.710	0.657	0.492	0.454

Table 5: Average values of $\boldsymbol{I_y}$ and $\boldsymbol{I_u}$ for each damage state of the 2004 damaged buildings

Figure 9: Distribution of I_y and I_u values in terms of the number of floors and compliance with the code.

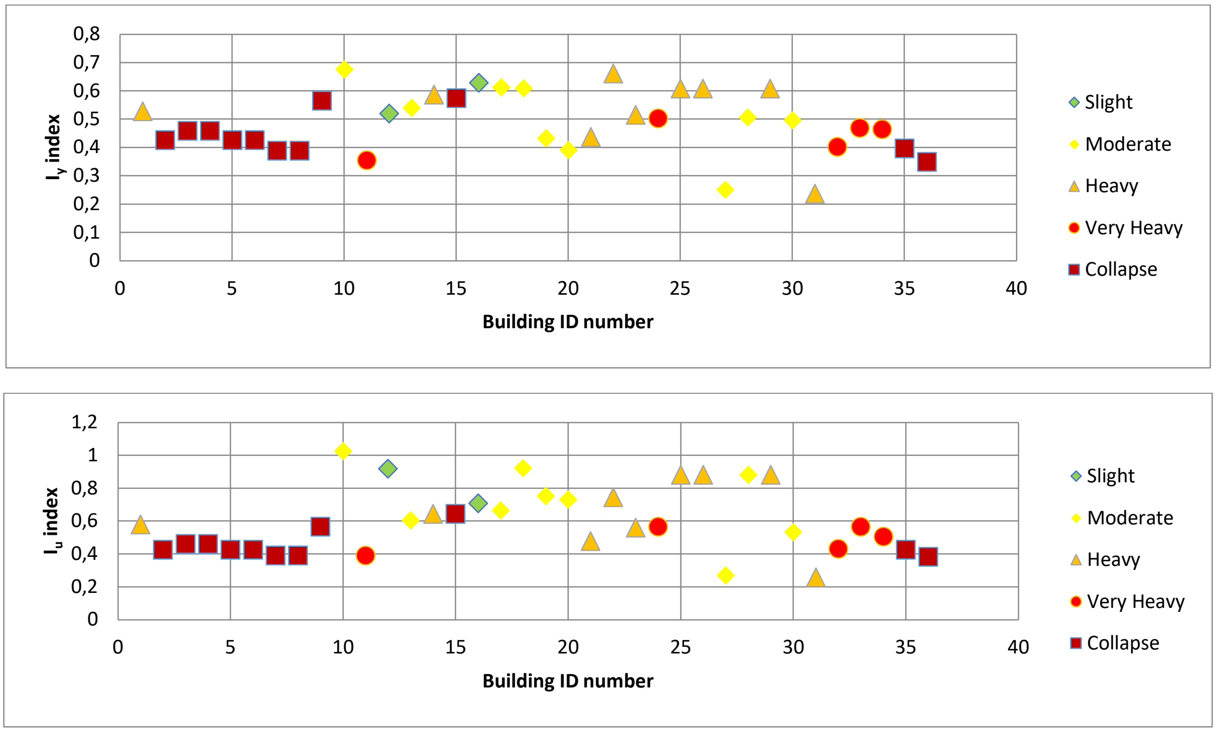


Figure 10: I_y and I_u values and damage states for the buildings affected by the 2004 earthquake

3.3 Capacity Spectrum Based Method

The Capacity Spectrum Based Method (CSBM) [30] is a performance-based seismic analysis method that can be applied at different scales. The approach can potentially provide a rapid assessment of a large inventory of buildings on a large scale, or on a smaller scale, assess the seismic performance of a new or existing structure to estimate its damage state. The procedure compares the capacity of a structure with seismic demand. The structure's capacity is represented in terms of a force-displacement curve obtained from a nonlinear static analysis (pushover). Shear force and roof displacement are converted into a spectral acceleration and spectral displacement of an equivalent single-degree-of-freedom (SDOF) system. The seismic demand is represented by response spectra. An Acceleration/Displacement Response Spectrum (ADRS) is used. The graphical overlay of the two curves allows for a visual assessment of how the structure will behave under seismic loading. In contrast to the two previous methods that focus on individual buildings, this approach addresses structural typology.

Fragility curves define the probability that the expected damage of a structure d exceeds a given damage state ds_i, as a function of a parameter quantifying the severity of seismic action. In this study, this parameter is the spectral displacement Sd. It is generally assumed that fragility curves are described by the following log-normal probability density function:

$$P\left[\frac{ds_i}{Sd}\right] = \phi\left[\frac{1}{\beta_{ds_i}}\ln\left(\frac{Sd}{\overline{Sd}_{ds_i}}\right)\right] \tag{4}$$

where $\overline{Sd}_{ds_i}$ is the threshold spectral displacement representing a 50% probability of damage state ds_i. β_{ds_i} is the standard deviation of the log of this spectral displacement. ϕ is the standard cumulative distribution function, and Sd is the spectral displacement.

The same 36 building models introduced in the adaptation of the Japanese method are used in this study. The existing buildings, along with their corresponding models, are regular, so it can be assumed that the structures' response is represented by their fundamental mode of vibration. This makes pushover analysis, despite its limitations, suitable for assessing seismic risk scenarios in the cities of Al Hoceima and Imzouren. Each building model underwent a non-linear static pushover analysis in the weakest direction to obtain capacity curves.

Capacity curves were generated, allowing us to obtain capacity spectra, as illustrated in an example in Figure 12. The curves represent only six models, but the remainder exhibit a similar trend. Subsequently, the capacity spectra were approximated to bilinear curves using FEMA 273 guidelines [31].

The fragility curves of the building models were obtained after calculating the parameters $\overline{Sd}_{\mathrm{i}}$ and β_i. It is crucial to determine a spectral displacement indicative of the most probable performance of the structure in the event of an earthquake. The spectral displacement resulting from the performance point is the sought-after parameter, derived from the intersection between the capacity spectrum and the response spectrum.

Subsequently, the weighted average damage index DS_m is calculated. The values represent previously predicted outcomes. Indeed, buildings complying with the seismic code exhibit better performance, and newly constructed structures also perform better. The highest damage index values mainly concern structures built on soft soils. There is also a significant difference when comparing the results of probabilistic scenarios (RPS and Eurocode 8). According to the first scenario, the higher the building height, the more the damage increases. For the second scenario, the values are more balanced concerning the elevation of the structure. Additionally, on average, the DS_m values for the RPS scenario are slightly higher than those for the Eurocode

8 scenario.

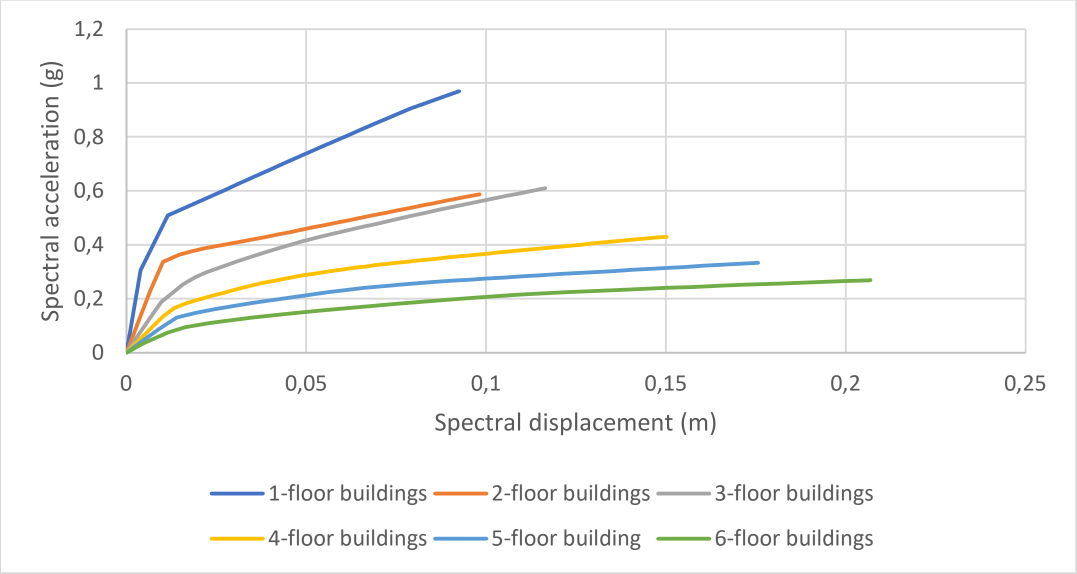
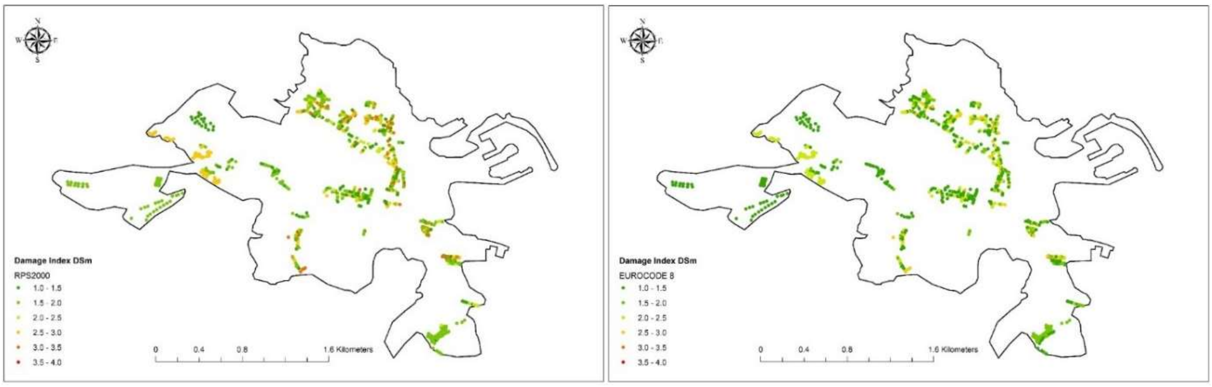


Figure 11: Capacity spectra of buildings with seismic code built after 2002

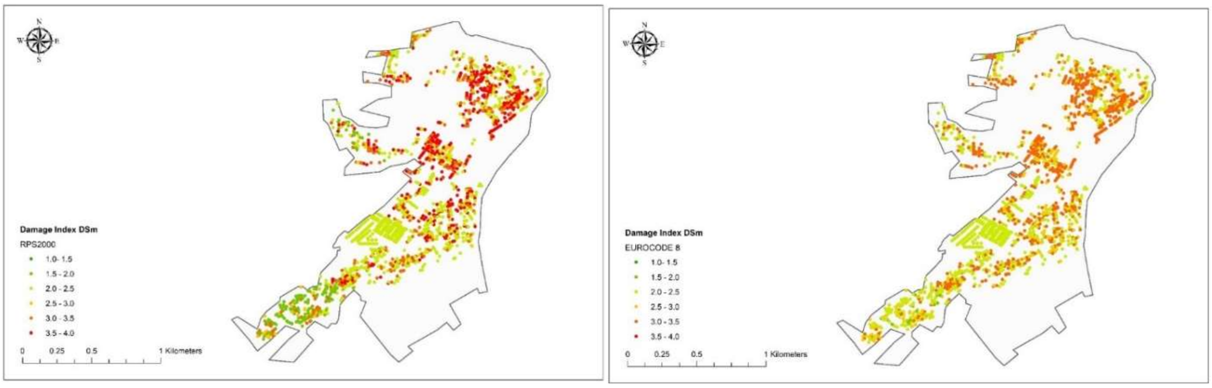
The average damage indices DS_m calculated will be represented for each of the 2,746 buildings targeted in this study [18]. The results are presented in Figure 13 for the city of Al Hoceima and in Figure 14 for Imzouren. The average value of the damage index in Al Hoceima is 2.05 and 1.78 for the RPS and Eurocode 8 scenarios, respectively, corresponding to a "moderate" damage state. The damage index in the Imzouren municipality is 2.77 and 2.75 according to the RPS and Eurocode 8 risk scenarios, respectively, indicating a "heavy" damage state.



(a) **(b)**

Figure 12: Damage distribution in the city of Al Hoceima, following (a) the RPS2000 risk scenario and (b) the Eurocode 8 risk scenario

The distribution of damages in the cities of Al Hoceima and Imzouren is quite similar to the findings in previous studies [13] [16, 17]. The disparity in results in Al Hoceima primarily stems from the vulnerability of structures. The seismic hazard uniformly affects the entire city, and site effects are minimal since the soil is mostly of type A, B or C. High-vulnerability buildings are structures that were constructed without consideration for seismic regulations, often three or four stories tall. These structures are built on the outskirts of the city, indicating their association with rural exodus. There are also older vulnerable structures scattered randomly in the city center that have not been reinforced since the 2004 earthquake. As for the municipality of Imzouren, the distribution of damage is more related to the soil type. We can clearly see that the damage distribution follows the soil typology model illustrated in Figure 2. Buildings with the highest damage indices are structures that do not comply with the seismic code and are built on loose soils.



(a) **(b)**

Figure 13: Damage distribution in the city of Imzouren, following (a) the RPS2000 risk scenario and (b) the Eurocode 8 risk scenario

4 CONCLUSIONS

The collective findings suggest important characteristics that should be considered when selecting an appropriate seismic vulnerability assessment method for buildings. Here is a summary of the results from the studies:

- The Empirical Vulnerability Index (VIM) method is the fastest and simplest approach to implement. It allows for the individual treatment of buildings on the scale of a small town, and even a large city with sampling. Data collection could be carried out by non-specialists rather than highly qualified experts, making the method most attractive to decision-makers for developing urban suitability maps. Its major drawback is the degree of uncertainty introduced by errors in assessing characteristic parameters of the evaluation method, especially if the workforce is not properly trained.
- It was found that the Japanese hybrid assessment technique (Seismic Index Method) better captures the characteristics that an appropriate vulnerability assessment method should possess. However, its applicability is limited by the fact that each building typology must have its own model. The set of 36 models developed in this study would be limited if considering the method for a larger, more diverse city in terms of buildings. The laborious work of developing models is the most time-consuming step, but once completed, the method becomes as easy to apply as a visual inspection method.
- The last method, Capacity Spectrum Based Method (CSBM), is the most internationally recognized approach. The technique proves highly effective for seismic vulnerability and risk assessment in large cities. The principle is to classify the entire set of buildings into a limited number of typologies and conduct a detailed study on each building typology. The method fits well in a context where the urban fabric is more extensive (major cities in Morocco) and where it would be impossible to assess buildings individually. However, it will be necessary to overlook certain parameters that have a significant impact on seismic performance, such as plan and elevation irregularities, soft stories, and short columns, etc.

Additionally, considering Moroccan construction practices and the level of control in construction sites, it would be wise to account for these uncertainties.

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