Natural Hazards

Seismic Risk in the city of Al Hoceima (North of Morocco) using the Vulnerability Index Method, applied in Risk-UE project
--Manuscript Draft--

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Abstract:	Al Hoceima is one of the most seismic active regions in north of Morocco. It is demonstrated by the large seismic episodes reported in seismic catalogs and research studies. However, seismic risk is relatively high due to vulnerable buildings that are either old or don't respect seismic standards. Our aim is to present a study about seismic risk and seismic scenarios for the city of Al Hoceima. The seismic vulnerability of the existing residential buildings was evaluated using the Vulnerability Index Method (Risk-UE). It was chosen to be adapted and applied to the Moroccan constructions for its practicality and simple methodology. A visual inspection of 1.102 buildings was carried out to assess the vulnerability factors. As for seismic hazard, it was evaluated in terms of macroseismic intensity for two scenarios (a deterministic and probabilistic scenario). The maps of seismic risk are represented by direct damage on buildings, damage to population and economic cost. According to the results, the main vulnerability index of the city is equal to 0.49, and the seismic risk is estimated as slight (main damage grade equal to 0.9 for the deterministic scenario and 0.7 for the probabilistic scenario). However, moderate to heavy damage is expected in areas located in the newer extensions, both in the east and west of the city. Important economic losses and damage to the population are expected in these areas as well. The maps elaborated can be a potential guide to the decision making in the field of seismic risk prevention and mitigation strategies in Al Hoceima.
Response to Reviewers:	Reviewer #1: In order to increase the quality of the manuscript 1)The abstract states that: "..an adaptation of the vulnerability index method proposed by Risk-UE project is made". Therefore, could you explain what is this adaptation?. Perhaps by regional modifier?. According line 144, the regional modifier takes into account the characteristics of the region or the period of construction of the building.

What is the value of regional modifier in this study? if according to the construction period, it should be specified which has been the approach taken for setting periods of construction before 1960, between 1961 and after 1994 and 1995 (paragraph beginning at line 69). Whether they are the same periods that the Riskue project or there is a specific regulation, or other reason for setting those periods.

The regional modifier is been taken equal to zero (it's been added in line 177). The adaptation was more focused on defining the characteristic construction periods for the city and determining the building typologies. This time, it's been explained clearly (line 82).

2)In legend of Figure3b: Could you explain what "poorly, moderately and well-studied area" mean? Maybe, you could assign each class a percentage or a range of buildings or area studied…

Figure 3b's legend has been replaced by the percentage of the studied buildings for each section.

3)Nor it is clearly reflected validation of the results for the deterministic scenario . As only mentioned in passing and in a qualitative way (no casualties and slight damage in line 332) referring to Goula and Gonzalez (2004). But you have specific data of the 2004 earthquake survey reports (with 629 fatalities, 966 injuries and 15600 homeless in line 37-39).

The specific data from survey reports (with 629 fatalities, 966 injuries and 15600 homeless in line 41-43) was for the whole region of northern Morocco. Actually, most damage was observed in rural areas. However, rural housing was not considered in the study due to lack of information (number and distribution of inhabitants + lack of statistics). Moreover, these precarious dwellings (that don't respect construction standards) are regarded as illegal since 2004 by the administration and are being replaced with others meeting the construction standards.
As for the city of Al Hoceima, there was no collapse or heavy damage. Only fractures of 2nd degree (Moderate damage) were observed in some buildings of C class (VI ranging from 0.5 to 0.7) in Al Manzah district.

Minor revision:
4)Line 281. Why table 4 shows values of loss indices for AUTh, IZIIS and UNIGE, if only Aristotle University's values are taken into account in the study?

The table was corrected showing only loss indices for (AUTh) (now table 6 line 359)

5)line 62: explain the meaning of "R.C.".

"R.C." has been replaced by "reinforced concrete"

6)line 70, 79 and figure 5, terms storeys and floors should be unified

The terms now are unified using "floors" (lines 82 and figure 5)

7)Regarding the bibliographic references:

More recent references have been added.
"EMS98 1998)" has been replaced by the author (Grünthal 1998) (line 162)
"(Geological Service of Morocco, 1984)" has been replaced by the authors "Choubert and Faure-Muret 1984" (line 129) and added to the references.
The style of the references has been homogenized. However, according to the instructions for authors, in case of two authors, the expression in the citation is different than the one in the reference list.
Reference "Le Haut Commissariat Au Plan statistiques" has been replaced by the census that took place, and added to the reference list (lines 38, 81, 320)
References related to the "R.P.S.2000" have been classified according to their version (lines 24, 92, 119) and added to the reference list

Reviewer #2:
General comments:
1)The abstract should be reviewed. More results should be included in abstract. The last paragraph: "these maps also constitute valuable information for urban planning and development of the city" could be removed because seismic hazard is roughly analysed in the work.

The abstract has been reviewed and restructured according to the mentioned instructions; more results have been added and the mentioned sentence has been removed.

2)The geotechnical data of the urban area used don't appear in the manuscript. The criteria for soil classification must be specified better.

The part about soil effects has been redone. A lithological map has been added. The criteria for soil classification has been explained further (122-155)

3)In the line 217 is indicated "soil effects don't have a strong amplifying impact on the buildings in case of an earthquake" but in in figure 6 soils type B and C are shown and an increment in intensity of 0.5 degrees was proposed to construct the intensity map with soil effects (line 117).

The sentence "soil effects don't have a strong amplifying impact on the buildings in case of an earthquake" has been replaced by "since soil effect is present in small areas of the city (equivalent of 7% of the total surface)" (line 267)
The areas with soil B and C constitute only 7% of the total surface of the city.

4)The building types should be described better and must be correlated with those of Risk-UE Building Typology Matrix.

The buildings have been described better and correlated with the BTM. More results have been added to the seismic vulnerability section. (Line 226-267)

Specific Comments:
5)Line 3: is generally considered as a moderate seismic zone (include reference or specify the expected maximum ground motion).)
References have been included (line 3)

6)Line 35: Check the following: this leads to an average density of 13,770 inhabitants per square meter and an average of 4.9 inhabitants per building. There is a great inconsistency between both statements.

The sentence has been corrected. (Line 39)

7)Line 35: struck a part of the city. Damage was observed in a part of the city but only a part was struck?.

The sentence has been corrected (line 41)

8)Line42: Complete the legend of this figure.

The legend of the figure has been completed (line52)

9)Line 50: In Figure 3 (a) is not specified the limit of each district or quarter nor the meaning of the colors.

The limits of districts have been added, and the variation of colors has been removed. (line 56)

10)Line 61: Change shanty towns, I think is too pejorative. These quarter are built without urban planning and the building are irregular RC frame, as you say, then they can be described as: poor neighborhoods with carelessly built constructions or so.

The sentence has been changed to "poor neighborhoods with carelessly built

constructions" (line 68)

11)Line 64: are generally of the same kind type.

The sentence has been corrected. (Line 72)

12)Line 71: Why don't consider the Seismic Regulations of Morocco RPS2000?. Don't had new regulations?. Don't was applied?. And after 2011?.

The design and construction requirements part from the RPS2000 has been applied in the city before the 2000s. After the 1994 earthquake in Al Hoceima, building design and construction required an immediate solution. Based on expert judgment and other standards (PS92 and BAEL), decision have been made to better the seismic protection, and have been applied immediately in the city, but were added subsequently to the RPS2000 (2002) for a national coverage.
The decision made for defining code levels is now better explained (Line 82)

13)Line 105: Geological Service of Morocco, 1984 is not included in reference list.

"Geological Service of Morocco, 1984" citation has been replaced by its authors "Choubert and Faure-Muret 1984" (line 129) and added to the reference list.

14)Line 206: No details about vulnerability are presented. Why?. What is the main vulnerability factors that were assessed and their values?, what type of buildings change their final vulnerability index?, what were the causes?.

The seismic vulnerability of the city has been given its own part. More details about the results have been added and more comments on the importance of behavior modifiers have been added (Line 226-267)

15)Line 217: It should be emphasized that Figure 9 shows mean damage index for two seismic hazard scenarios and for this reason no large differences are appreciated between both. Additionally, it would be discussed that heavy and destruction damage there could be in areas with DSm>1.5.

The comment has been added in line 269. Additionally, figures showing the probability of damage for each district had been added to highlight the possibility of heavy damage or collapse in some of the districts (figure 12 and 13).

16)Line 254: No details appear in the manuscript about the number of persons who are assumed to live in each household of the building in Al hoceima city.

A reference has been added for the number of persons per household (which is equal to 5) in line 321.

Seismic Risk in the city of Al Hoceima (north of Morocco) using the Vulnerability Index Method, applied in Risk-UE project

Seif-eddine Cherif • Mimoun Chourak • Mohamed Abed • Luis Pujades

Abstract
Al Hoceima is one of the most seismic active regions in north of Morocco. It is demonstrated by the large seismic episodes reported in seismic catalogs and research studies. However, seismic risk is relatively high due to vulnerable buildings that are either old or don't respect seismic standards. Our aim is to present a study about seismic risk and seismic scenarios for the city of Al Hoceima. The seismic vulnerability of the existing residential buildings was evaluated using the Vulnerability Index Method (Risk-UE). It was chosen to be adapted and applied to the Moroccan constructions for its practicality and simple methodology. A visual inspection of 1.102 buildings was carried out to assess the vulnerability factors. As for seismic hazard, it was evaluated in terms of macroseismic intensity for two scenarios (a deterministic and probabilistic scenario). The maps of seismic risk are represented by direct damage on buildings, damage to population and economic cost. According to the results, the main vulnerability index of the city is equal to 0.49, and the seismic risk is estimated as slight (main damage grade equal to 0.9 for the deterministic scenario and 0.7 for the probabilistic scenario). However, moderate to heavy damage is expected in areas located in the newer extensions, both in the east and west of the city. Important economic losses and damage to the population are expected in these areas as well. The maps elaborated can be a potential guide to the decision making in the field of seismic risk prevention and mitigation strategies in Al Hoceima.

Keywords: Seismic vulnerability • Seismic risk • Al Hoceima • Risk-UE

1   **1.   Introduction**
2
3   The Rif region, in north of Morocco, is generally considered as a moderate seismic zone (Poujol et al. 2014). It is also
4   recognized as the most seismically active part of Morocco (Cherkaoui et al. 1990; El Alami et al. 1998; Bezzeghoud and
5   Buforn 1999), its high level of seismicity makes it one of the most studied active zones in the western Mediterranean
6   (d'Acremont et al. 2014; Tahayt 2009). It has experienced several earthquakes, some of them very destructive, as in the case
7   of 1994 (M_W=6.0) and 2004 (M_W=6.4) earthquakes (Woerd et al. 2014). Also, very recently, a 6.3 magnitude earthquake

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struck 50 Km from Al Hoceima early on Monday January 26th 2016 (USGS), causing some material damage. This seismicity is due to the convergence between the Eurasian and African plates (Casado et al. 2014). Despite the relatively moderate activity in the north, some of its existing buildings have a high degree of vulnerability. Therefore, a significant probability of damage can be expected even in the case of not excessively severe earthquakes. Since the 2004 earthquake, seismologists became more interested in seismic hazard in the region (Ait Brahim et al. 2004; Mourabit et al. 2013). However, the same cannot be said about seismic vulnerability, which is a relatively new field, to what it hasn't been given the proper attention it deserves, hence the importance of this study.

The Vulnerability Index Method (VIM) was used to assess the seismic vulnerability. The method was a part of the Risk-UE project; it has been applied to assess the seismic risk for seven European cities (Barcelona, Bitola, Bucharest, Catania, Nice, Sofia and Thessaloniki) (Mouroux et al. 2004; Pitilakis et al. 2006; Lantada et al. 2010) around the Mediterranean Sea. The choice for this assessing technique is motivated by its simplified methodology which allows considering numerous uncertainties. In fact, it defines the seismic action in terms of macroseismic intensity, the seismic resistance of buildings in terms of a vulnerability index, and it considers five non-null damage states. Moreover, both the deterministic and probabilistic scenarios have been considered, including soil effects. The deterministic scenario refers to the 2004 earthquake that struck the northern region of Morocco as a reference earthquake while the probabilistic scenario has a probability of exceedance of 10% in 50 years (R.P.S. 2000, Version 2011).

The goal of our study is to elaborate seismic risk maps, based on the seismic hazard assessment in terms of intensity and defined by both scenarios and the seismic vulnerability of the studied buildings. The seismic risk is represented by the distribution of the expected damage grade in the city, as well as the estimated number of homeless people and the economic losses in each area of Al Hoceima (Fig. 1).
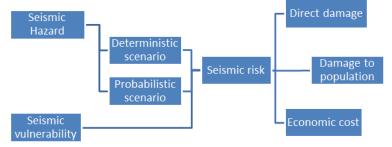
Fig. 1 Methodology adopted for the seismic risk assessment in the city of Al Hoceima

2. The city of Al Hoceima

The city of Al Hoceima is located in the Rif Mountains, northeast of Morocco (Mediterranean Sea) (Fig. 2) with a terrain characterized by a slope going from 10% to 40%. According to the official statistics of 2014 (RGPH 2014), the city counts 56.666 citizens (13.770 inhabitants per square kilometer) and 11.554 residential buildings. It is also worth mentioning that the population of the city triples in the summer. It's on the night of February 24th, 2004, an earthquake, 6.4 of moment magnitude struck the city and the surrounding communities (Woerd et al. 2014), causing 629 fatalities, 966 injuries, 2 539 destroyed and damaged houses and 15.600 homeless (Tahayt et al. 2009). Most damage was observed in rural areas (Faradi 2004; Corella 2004; Poujol et al. 2004; Goula and Gonzalez 2004).

For the purposes of this study, the city was subdivided into sections according to several factors; for instance, district limits, building classes (residential, commercial, etc.) and other factors of building construction (Fig. 3a). Each section is represented by a pattern of buildings which typifies the main similar characteristics of the construction area. Due to limited

48 resources, some areas have been focused on more than others. The priority has been given to the downtown area, since it is
49 the most populated. Figure 3b shows the study level of each section represented by the percentage of the studied buildings.
50

51
52 **Fig. 2   a** Landsat satellite image of western Mediterranean (Google Earth) and location of the city of Al Hoceima. **b** Plan
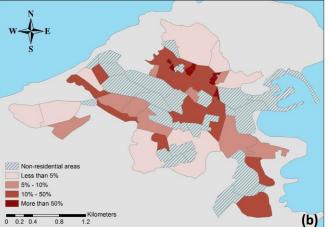53 view of satellite image (Google Earth) of the Al Hoceima cape
54

55
56 **Fig. 3   a** Administrative districts and subdivision of Al Hoceima. **b** Study level of the areas represented by the percentage
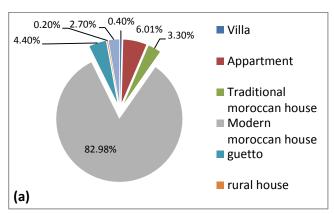57 of the studied buildings in Al Hoceima
58
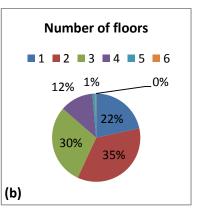59

60 **3.   Residential buildings**

61

62 Al Hoceima is a newly established city (20th century); this is justified by the absence of a Medina (an old downtown) and the
63 fact that most of the buildings are reinforced concrete structures. As most cities, Al Hoceima has a city center surrounded by
64 residential districts. The city center is relatively the oldest quarter in the city and its buildings aren't similar, since there are
65 many reconstruction sites in these areas. In fact, many new buildings designed with the latest seismic code standards are
66 situated close to old constructions lacking the basic standards of construction. Extensions were built after 2004 in the south-
67 eastern and western part of the city, for instance *Bades*, which is the newest neighborhood destined for tourism, and the
68 southern part of the *Mirador Bas* and *Mirador Haut* districts, which can be described as poor neighborhoods with carelessly
69 built constructions (Fig. 4). For these two neighbourhoods, it can be noted that reinforced concrete irregular frames constitute
70 mainly the framework of encountered constructions; a steep slope characterizes the ground and, finally, the absence of

respect to the current construction rules. Unlike the city center, the buildings in the new neighborhoods are generally of the same type.

Fig. 4   **a** Buildings in *Mirador Bas* neighborhood. **b** Buildings in the *Mirador Haut* quarter

Fig. 5   **a** Building distribution according to their types, as stated in the official statistics of the city in 2004 (RGPH 2004). **b** Distribution of the number of floors by building according to the studied 1102 buildings

One type of housing prevails in the city, and it is the modern Moroccan house (RGPH 2004). The latter is often a reinforced concrete structure with two to three floors (Fig. 5). Construction standards in the Rif region have experienced changes depending on 2 major events:

1. The 1960 earthquake in Agadir: The night of February 29th, 1960, Agadir had experienced one of the world's most destructive earthquakes in the 20th Century (Coburn and Spence 2002). The studies and investigations in site led to elaborate the first seismic standard, namely "Agadir Standard". However, without a proper seismic code, Moroccan construction has been greatly affected by this standard.
2. The 1994 earthquake in Al Hoceima: A violent earthquake ($M_w=6.0$) struck the region of Al Hoceima killing three people and causing extensive damage (Akoglu et al. 2006; RMSI 2012). After the earthquake, constructive measures have been taken to protect buildings in the Rif region; they were inspired by the PS92 and BAEL 91. These decisions were applied after 1994 in the area and, subsequently, contributed in elaborating the first national seismic code R.P.S.2000.

Thus, three code levels have been defined following the construction periods (Table 1).

Table 1 Adopted code level for existing buildings in Al Hoceima

Construction period	Pre 1960	1960 – 1994	Post 1994
Code level	Low code	Medium code	High code

4

96

97 The direct relation between the period of construction and the code level is valid for most districts except for *Mirador Bas*
98 and *Mirador Haut*, since the two neighborhoods have been recently built (after 2004) but don't respect the latest codes of
99 construction. The data collected represents 1.102 buildings, which is around 10% of the total households in the city. The
100 information gathered is centered on the geometry and the structural nature of the buildings as well as the location of the unit
101 compared to the adjacent buildings.

102

103

104 **4.   Seismic action assessment in terms of intensity for Al Hoceima**
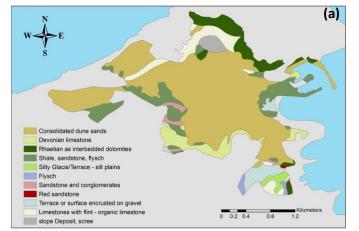
105

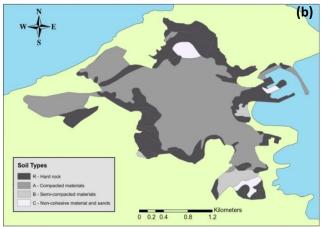106 **4.1. Deterministic and probabilistic scenarios**

107

108 In this study, the seismic action has been estimated in terms of macroseismic intensity using a deterministic and a
109 probabilistic scenario. Given the small size of the city, the macroseismic intensity at the basement is considered to be
110 constant all over the city for both scenarios. The deterministic scenario refers to a reference earthquake chosen as the closest
111 one to the site with the highest epicentral intensity. In this case, the reference earthquake is the one that struck the city in
112 February 24th, 2004 with an epicentral intensity of IX and the expected intensity for the city of Al Hoceima is VIII
113 (Cherkaoui and El Hassani 2012). The event occurred at an epicentral distance less than 10km from the city and has been
114 assigned a depth between 6 and 10km (Woerd et al. 2014).

115

116 The probabilistic seismic hazard in terms of intensity has been addressed before by the RMSI (Risk Management Solutions
117 Inc.) in 2012. According to the results, the city of Al Hoceima is expected to be affected by an intensity of VII-VIII and an
118 equivalent peak ground acceleration of 0.253g for a return period of 475 years (a probability of exceedance of 10% in 50
119 years). According to the Seismic Regulations of Morocco (R.P.S. 2000, Version 2011) the expected acceleration for a return
120 period of 475 is 0.18g which is inferior to the one estimated by the RMSI report.

121

122 **4.2. Seismic scenarios with soil effects**

123

124 Several approaches are used for the assessment of soil effects. A good method would be to construct a site dependent
125 scenario ground motion map and to identify zones prone to seismically induced slope failure and liquefaction. To this end, a
126 suitable geotechnical zonation of the urban area is needed (Faccioli 2006).

127

128

129 **Fig. 6   a** Lithological map of Al Hoceima (Choubert and Faure-Muret 1984 *modified*). **b** Distribution of soil types in the
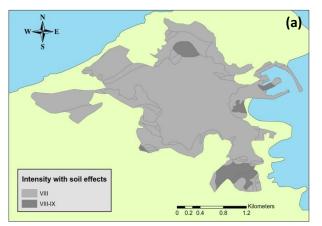130 city of Al Hoceima

131

132   Due to the lack of geotechnical data on the region, a lithological map was used (Fig. 6a). The study area is situated within the
133   eastern part of the Rif intermountain belt and is dominated by geological formations of the inner domain characterized by
134   carbonated rocks (calcareous and dolomites), these are overlain in part by Paleozoic terrains (Ghomarides) (Talhaoui et al.
135   2004). Based on the analysis of surface geological formations, a map of different types of soils was compiled (Fig. 6b). The
136   sites were classified in four main categories, zone A, B and C corresponding respectively to: compacted materials, semi-
137   compacted materials and non-cohesive materials in addition to Hard rock (R) (Table 1).
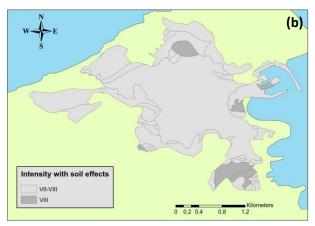
139   The intensity is implemented depending on the type of soil. The increments are calculated by empirical methods (Secanell
140   1999; Bard 1997). This way for introducing soil effects in terms of intensity was also recommended within the Risk-UE
141   project (Faccioli 2006) in case geotechnical data in not available. For soil types R and A, no increment in intensity is applied,
142   while for soil types B and C an increment in intensity of 0.5 degrees was applied to construct the intensity map with soil
143   effects.

145   **Table 1** Site classification for the city of Al Hoceima

Zones	Sites	Increments (Intensity)
A - Compacted materials	Consolidated dune sands	+0.0
B - Semi-compacted materials	Terrace or surface encrusted on gravel,	+0.5
C - Non-cohesive materials	Slope Deposit, scree, Silty Glacis/Terrace - silt plains	+0.5
R – Hard Rock	Limestone, flysch, sandstone, dolomites, shale	+0.0

147   Figure 7a shows the map for deterministic seismic hazard with soil effects in terms of intensity for the city of Al Hoceima,
148   while Figure 7b presents the map for the probabilistic seismic hazard for a return period of 475 years including soil effects for
149   the city of Al Hoceima. As can be seen from the figures the deterministic scenario's intensity is slightly higher than the one
150   expected from the probabilistic scenario. As for the terrain affected by soil effect, it represents only 7% of the total surface of
151   the city.

154   **Fig. 7   a** Deterministic intensity map with soil effects for the city of Al Hoceima. **b** Probabilistic intensity map for a return
155   period of 475 years including soil effects for the city of Al Hoceima

158   **5.   Seismic risk assessment using the Vulnerability Index Method**

160   The Vulnerability Index Method (VIM), as proposed in the Risk-UE project (Giovinazzi and Lagomarsino 2002) is used in
161   this work. This method was formerly proposed by Benedetti and Petrini (1984) and is based on the European Macroseismic
162   Scale (Grünthal 1998). It has advantages over similar statistical methods (ATC-13 1985, Grünthal 1998), because it focuses
163   on the differences among constructions that have the same structural build. The most important parameters affecting the
164   seismic strength of the buildings are given weighted coefficients quantifying their relative importance. The method requires

165 the seismic action to be interpreted in terms of macroseismic intensity and the structural resistance of the buildings as a
166 vulnerability index taking values going from 0 (least vulnerable building) to 1 (most vulnerable building).
167
168 This method provides a typological classification system (Giovinazzi and Lagomarsino 2002) in order to group structures
169 with a similar seismic performance V_I^{class} (Table 2), then adds behaviour modifiers to evaluate a final vulnerability index of
170 each building $V_I^{building}$, according to the equation below (Milutinoviç and Trendafiloski 2003):
171

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

172
173 where V_I^{class} is the vulnerability index corresponding to the class of the building, ΔM_R is a regional modifier which takes into
174 account the characteristics of the region or building period, and lastly, Vm_j are behaviour modifiers that include other aspects
175 that affect the seismic performance of the building.
176
177 In the case of Al Hoceima, the regional modifier was taken equal to zero. The adaptation of the VIM was sequenced around
178 defining the code level according to the main construction periods.
179
180 **Table 2** Vulnerability index values for several cases of the building typology matrix, BTM, proposed by Risk-UE
181 (Milutinoviç and Trendafiloski 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
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 infilled 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
W	Wood structures	0.14	0.207	0.447	0.64	0.86

182
183 Two kinds of behavior modifiers are defined; building modifiers and location modifiers (Table 3). The building modifiers
184 take into account the characteristics of the building isolated from its vicinity, like the state of preservation, number of floors,
185 horizontal and vertical irregularities. Whereas the location modifiers study the building in its environment; for instance,
186 aggregate buildings and soil morphology (Milutinoviç and Trendafiloski 2003).
187
188 Concerning damage, the Risk-UE VIM version uses five non-null damage states; *Slight*, *Moderate*, *Substantial to Heavy*,
189 *Very Heavy* and *Destruction* (Grünthal 1998). A mean damage grade μ_D is introduced to characterize the expected damage
190 for a building, for a given vulnerability (V_I) and intensity *(I)* by the following equation:
191

$$\mu_D = 2.5 \left[1 + tanh \left(\frac{I + 6.25V_I - 13,1}{\phi} \right) \right] \tag{2}$$

192
193 where ϕ is the ductility index, which is evaluated taking into account the building typology and its constructive features
194 (Lagomarsino and Giovinazzi 2006). For residential buildings, it takes a value of 2.3 (Lantada et al. 2010).
195

196 **Table 3** Scores for the vulnerability factors V_m for reinforced concrete buildings (Milutinoviç and Trendafiloski 2003)

Vulnerability Factors		Code Level		
		Pre or Low	Medium	High
Code Level		+0.16	0	-0.16
Bad Maintenance		+0.04	+0.02	0
Number of floors	Low (1,2)	-0.04	-0.04	-0.04
	Medium (3,4,5)	0	0	0
	High (6 or more)	+0.08	+0.06	+0.04
Plan Irregularity	Shape	+0.04	+0.02	0
	Torsion	+0.02	+0.01	0
Vertical Irregularity		+0.04	+0.02	0
Short-column		+0.02	+0.01	0
Bow windows		+0.04	+0.02	0
Aggregate buildings (insufficient aseismic joint)		+0.04	0	0
Foundation	Beams	-0.04	0	0
	Connected beams	0	0	0
	Isolated footing	+0.04	0	0
Soil Morphology	Slope	+0.02	+0.02	+0.02
	Cliff	+0.04	+0.04	+0.04

197
198 A weighted mean damage index, DS_m, can be calculated by using the following equation (Milutinoviç and Trendafiloski
199 2003):

$$DS_m = \sum_{k=0}^{5} kP[DS_k] \tag{3}$$

200
201 where the integer k takes values from 0 to 5 for the damage states k considered in the analysis and $P[DS_k]$ represents the
202 corresponding probabilities of occurrence for the damage state k.

203
204 The damage distribution is calculated using the beta distribution.

205
206 Probability density function:
207

$$p_\beta = \frac{\Gamma(t)}{\Gamma(r)\Gamma(t-r)} \frac{(x-a)^{r-1}(b-x)^{t-r-1}}{(b-a)^{t-1}} \qquad a \le x \le b \tag{4}$$

208
209 Cumulative Density Function:
210

$$P_\beta(x) = \int_a^x p_\beta(\varepsilon)d\varepsilon \tag{5}$$

211
212 Where $a = 0$; $b = 6$; $t = 8$; $r = t(0.007\mu_D^3 - 0.052\mu_D^2 + 0.2875\mu_D)$
213
214 The discrete beta density probability function is calculated from the probabilities associated with damage grades k and k+1 (k
215 = 0, 1, 2, 3, 4, 5), as follows
216

$$p_k = P_\beta(k+1) - P_\beta(k) \tag{6}$$

217
218 The fragility curve defining the probability of reaching or exceeding certain damage grade are obtained directly from the
219 cumulative probability beta distribution as follows:

220

$$P(D \geq D_k) = 1 - P_\beta(k) \tag{7}$$

221

222 It can be considered that DS_m is close to the most likely damage state of the structure. This damage index is equivalent to the
223 mean damage grade, μ_D, and it is useful for mapping and analyzing damage distributions by using a single parameter.

224
225

226 **6.   Seismic vulnerability of the city of Al Hoceima**

227

228 All the available data have been collected and integrated into a spreadsheet program, then introduced in a geographic
229 information system, which allowed performing a building analysis. Display of results has been compiled using the previously
230 mentioned subdivision of the urban area (Fig. 3), in order to allow clearer and more coherent results.

231

232 The majority of the buildings in the city of Al Hoceima are constructed with reinforced concrete, since the city is newly
233 established. The residential buildings are, in most cases, moment frame constructions with two to three floors and have a
234 ground surface ranging from 100m^2 to 150m^2. Three main building typologies are distinguished, all in reinforced concrete:
235 structures with reinforced concrete moment frame, regular reinforced concrete structure with masonry infill walls and
236 irregular moment frame structures. These typologies correlate respectively with RC1, RC3.1 and RC3.2 in the building
237 typology matrix proposed by Lungu et al. 2001 (Table 2).
238 The results following the buildings inspection (Table 4) show that each building class has a predominant code level. This is
239 related to the changes in construction habits and laws in each main period (before 1960, between 1961 and 1994, after 1995).

240

241 **Table 4** distribution of building typologies depending on Code Level for the studied buildings

Code Level	Number of Buildings (%)	Low Code	Medium Code	High Code
RC1	544 (50%)	9%	73%	18%
RC3.1	224 (20%)	0%	15%	85%
RC3.2	334 (30%)	68%	29%	3%

242

243 The VIM was favored over vulnerability curve methods like HAZUS (1999) and LM2 (Milutinoviç and Trendafiloski 2003),
244 because it focuses on the differences among constructions that belong to the same building type. While a vulnerability curve
245 represents one class of building with a code level, it doesn't take into account the different behavior modifiers related to the
246 building and its location (Table 3). Particularly, in the case of Al Hoceima, vulnerability factors have a significant presence
247 (Fig. 8). In order to showcase the importance of modifiers, we compared the vulnerability index taking into account only the
248 class and code level (V_{LC}, V_{MC}, and V_{HC}), with the vulnerability indices of the studied buildings (Fig. 9). As can be seen, the
249 difference of values is significant, especially in Low Code, where increments of behavior modifiers become more punishing.
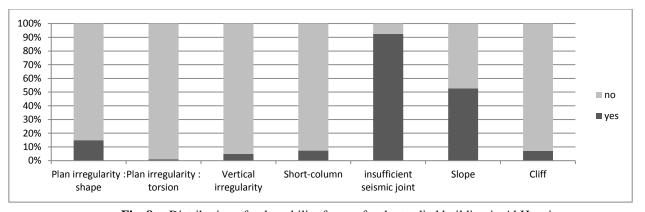
250

251
252 **Fig. 8**   Distribution of vulnerability factors for the studied building in Al Hoceima

253

9

254

255

256
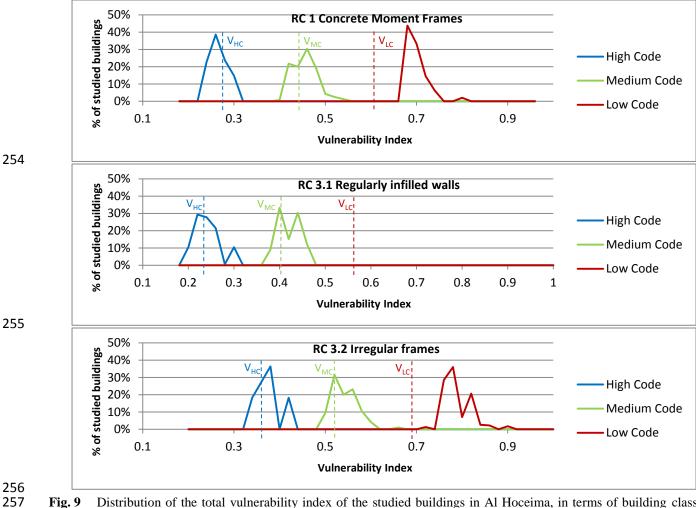257 **Fig. 9**   Distribution of the total vulnerability index of the studied buildings in Al Hoceima, in terms of building class and
258 code level
259

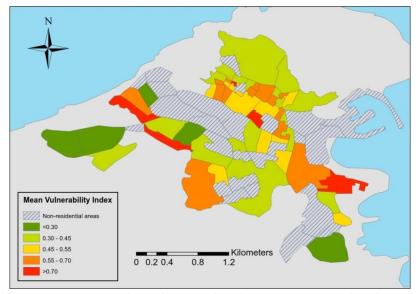260
261   **Fig. 10** Mean vulnerability index for the residential buildings in the city of Al Hoceima

262

263 The vulnerability index takes values ranging from 0.2 to 0.9 for the studied buildings, with a mean value of 0.49. Values of
264 V_I for the different sections in the city are shown in Figure 10. As it could have been predicted, the southern neibourhoods in
265 *Mirador Bas* and *Mirador Haut* are by far the most vulnerable areas in Al Hoceima, with mean vulnerability indices of 0.81
266 and 0.83 respectively. This is primarily due to the poor choice of terrain and the low quality of construction in these regions
267 in particular.

268

269

270 **7. Seismic risk scenarios for the city of Al Hoceima**

271

272 **7.1. Physic direct damage**

273

274 Concerning the mean damage grade, it almost follows the distribution of the vulnerability index in Figure 10, since soil effect
275 is present in small areas of the city (equivalent of 7% of the total surface). Figure 11 shows values of damage according to
276 both deterministic and probabilistic scenarios, no large differences are noticed between both. The values of physical damage
277 are ranging from 0.17 to 3.07 for the deterministic scenario and 0.11 to 2.54 for the probabilistic one, with mean values of
278 0.96 and 0.7 respectively. This corresponds in both cases to a *slight* damage state according to Table 5.
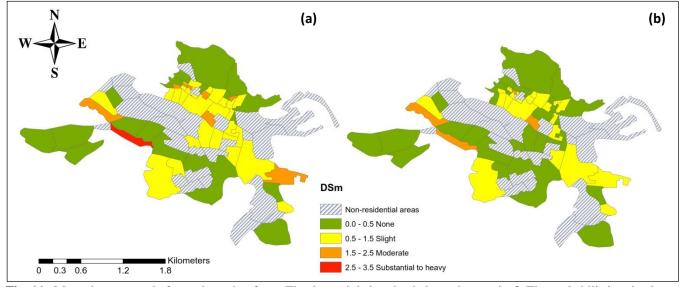
279

283 **Fig. 11** Mean damage grade for each section for, **a** The deterministic seismic hazard scenario. **b** The probabilistic seismic
284 hazard scenario

285

286 **Table 5** Mean damage index values and damage states

Mean damage index intervals (DS$_m$)	Most probable damage state
0.0 – 0.5	None
0.5 – 1.5	Slight
1.5 – 2.5	Moderate
2.5 – 3.5	Substantial to heavy
3.5 – 4.5	Very heavy
4.5 – 5.0	Destruction

287

288 Also in this case, the highest damage is expected in the southern neibourhoods of *Mirador Bas* and *Mirador Haut* districts,
289 with mean values of 2.6 and 2.44 for the deterministic scenario and 2.06 and 1.91 for the probabilistic one. These values
290 correspond to a *Moderate damage* expected in these regions, except the physical damage in the case of *Mirador Bas*

according to the deterministic scenario, which is *Substantial to heavy*. The damage distribution shows that there is possibility of very heavy damage on buildings in some districts (Fig. 12, Fig 13), especially in *Mirador Bas*, *Mirador Haut* and *Morobikho*, which are the most affected regions in the city.

Fig. 12 Probability of damage states in the residential districts of Al Hoceima for the deterministic scenario
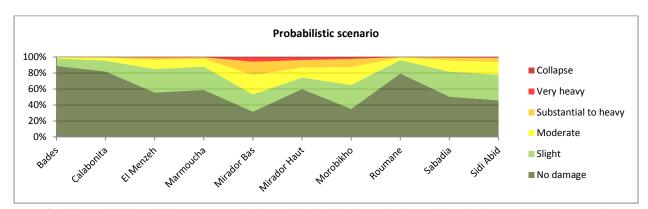

Fig. 13 Probability of damage states in the residential districts of Al Hoceima for the probabilistic scenario

7.2. Damage to population

According to Coburn and Spence (2002), deaths and injuries may occur if a building has collapsed, which isn't the case in the city of Al Hoceima based on this study. Therefore, there are no casualties expected for both scenarios. However, the number of people that must be relocated due to uninhabitable buildings is an important part in disaster management, and should be focused on. The methodology that has been applied is based on HAZUS (1999), it considers the 100% of residential units located in buildings that are in the *very heavy* and *destruction* damage state and the 90% that are in *substantial to heavy* damaged structures to be uninhabitable.

The total number of uninhabitable residential units due to structural damage is computed by the following relationship:

$$\%MF = 0.9 \times \%H_{MF} + 1.0 \times \%VH_{MF} + 1.0 \times \%D_{MF} \qquad (8)$$
$$UNU_{SD} = U_{MF} \times \%MF$$

with U_{MF} being the total number of multi-family residential units, $\%H_{MF}$, $\%VH_{MF}$ and $\%D_{MF}$ the damage state probability for *substantial to heavy*, *very heavy* and *destruction* structural damage state, respectively, in the multi-family residential occupancy class.

The total number of persons relocated from each building with a typology (P_{UNU}), is obtained with the following relation:

12

$$P_{UNU} = P_h \times UNU_{SD} \tag{9}$$

where P_h is the number of persons who are assumed to live in each household of the building. According to the RGPH 2004, an average of 5 persons per household is estimated for the city.

The numbers of homeless people that are expected in both the deterministic and probabilistic scenarios are displayed in Figure 14. The total number of homeless people expected in both scenarios is 1991 and 117 respectively. The big difference between the two results is due to the fact that the damage exceeded the "*Substantial to heavy*" limit in the deterministic scenario. It is also worth mentioning that 76% of the homeless are located in *Mirador Bas* and *Mirador Haut* areas for the deterministic scenario and 95% of the homeless for the probabilistic one, while the two latter districts represent only 8% of the total area of Al Hoceima.
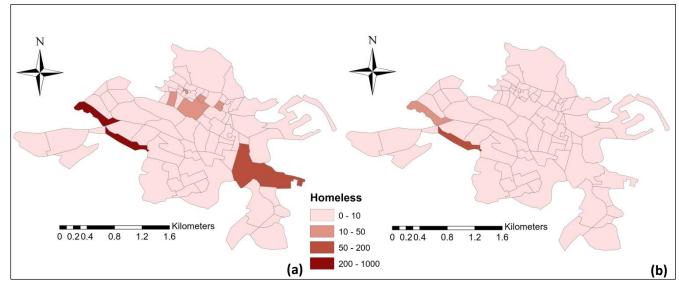

Fig. 14 Number of homeless people for each section for, **a** The deterministic seismic hazard scenario. **b** The probabilistic seismic hazard scenario

7.3. Economic Cost

The economic cost is estimated as the present restoration cost of the damaged buildings. This value is estimated by reconstructing the building with reinforced concrete without including the land cost. The absolute economic cost (S_{Cost}) in thousands of Euros is given by the following equation (HAZUS 1999):

$$S_{Cost} = \sum_{k=2}^{5} CS(k) = V_C \sum_{K=2}^{5} \sum_{J=1}^{Ne} [Area(j).P_s(k,j).RC(k,j)] \tag{10}$$

where S_{Cost} is the sum of the $CS(k)$ repair costs due to the damage state k (damage state 1 *none* is not considered since there is no induced cost); V_C is the cost per unit area (m^2); *Area* is the building area; $PS(k, j)$ is the probability for the building j to be in the damage state k and $RC(k, j)$ is the repair value due to the damage state k for the building j ; $RC(k, j)$ is given as a percentage of the reposition cost per square meter according to Table 6. AUTh loss indices have been used in this study since damages in case of *Slight* and *Moderate* are easily repaired and don't require great expenses.

Vc includes the construction cost of the building and the cost of furniture, and it's been calculated using the following equation:

13

$$V_C = GL_C + (n-1).F_C + n.M_C \qquad (11)$$
$$F_C = 0.5 \times GL_C$$

351

352 Where GL_C is the construction cost of the ground level of a reinforced concrete building, F_C is the construction cost of a floor
353 other than the ground level, M_C is the cost of residential building contents and n is the number of floors. A reasonable value
354 of GL_C for a residential building is 150 €/m² according to the Moroccan construction market, while M_C is given a value of 28
355 €/m². Figure 15 shows the economic cost in thousands of Euros for each section in the city, caused by the deterministic and
356 probabilistic earthquake hazard scenarios. The total economic cost for the city is 5.6 Millions of Euros in case of the
357 deterministic scenario, and 5.1 Millions of Euros in case of the probabilistic scenario.

358

359 **Table 6** Loss Indices for reinforced concrete buildings

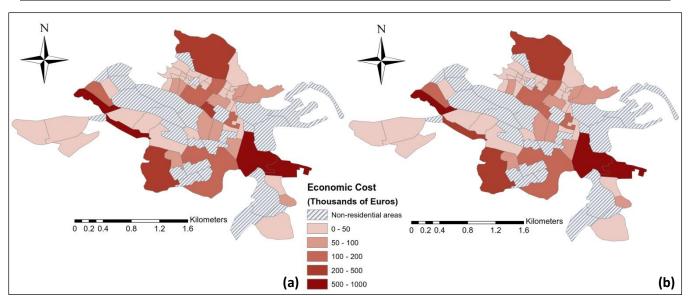| Damage Grade	Damage Grade Label (VIM)	Description	Loss Indices Aristotle University of Thessaloniki (AUTh)
0	None	No damage	0.0
1	Slight	Negligible to slight damage	0.0 – 0.05
2	Moderate	Slight structural, moderate nonstructural	0.05 – 0.2
3	Substantial to heavy	Moderate structural, heavy nonstructural	0.2 – 0.5
4	Very heavy	Heavy structural, very heavy nonstructural	0.5 – 1.0
5	Destruction	Very heavy structural, total or near total collapse	1

360

361
362
363
364 **Fig. 15** Distribution of economic cost for each section for, **a** The deterministic seismic hazard scenario. **b** The probabilistic
365 seismic hazard scenario

366
367
368 **8.   Discussion and conclusions**

369

370 The seismic risk assessment has been performed for the city of Al Hoceima using the VIM version, as proposed in the
371 framework of the Risk-UE project. The seismic hazard assessment and the seismic vulnerability assessment allowed
372 estimating the distribution of the expected damage caused by the considered seismic scenarios. The data gathered for this
373 study allowed an acceptable assessment of the vulnerability indices of the buildings. However, the study might benefit from
374 more data collection, particularly around areas that haven't been well studied as is previously shown in Figure 3 (b). Seismic
375 hazard has been assessed by means of macroseismic intensity, considering both the deterministic and probabilistic scenarios,

14

376 including soil effects. The intensity ranges from VIII to VIII-IX for the deterministic scenario, while it varies from VII-VIII
377 to VIII for the probabilistic scenario.
378
379 The risk assessment in the city has been performed, using the seismic hazard scenarios. The results show that for a city that is
380 often threatened by earthquakes, the damage expected is slight, since Al Hoceima is not exposed to soils effects and most of
381 the buildings (especially the ones built before 2004) have low vulnerability indices. However, the highest damage (substantial
382 to heavy) is expected in newly established neighborhoods, which is uncommon. As a matter of fact, if the 2004 earthquake
383 were to strike the city in 2016, the damage would probably be more important. The city doesn't have any adequate lands for
384 construction left; therefore local people are building their homes in inappropriate spots threatened mostly by slopes, with
385 minimal consideration for the seismic standards of construction.
386
387 This method has proven to be a simple statistical tool for evaluating the vulnerability of residential buildings and assessing
388 seismic risk when limited information is available. However, validation of results is crucial, and it is a major issue for
389 earthquake scenarios because of the great uncertainties involved. The best validation test is the occurrence of the simulated
390 earthquake scenario; this would prove the similarities between the simulation and the observed damage, and validate both the
391 method used and the quality of the data.
392
393 According to damage reports of the 2004 earthquake (Faradi 2004; Corella 2004; Poujol et al. 2004; Goula and Gonzalez
394 2004) Al Hoceima was not affected by the earthquake and the majority of these buildings have withstood the shocks. The
395 number of buildings affected by the earthquake remains insignificant at the urban area of Al Hoceima. However, In Al
396 Manzah district, there were some cracks in partitions and openings in corner buildings particularly those built on sloping
397 ground (Faradi 2004). In this case, the simulated earthquake scenarios occur twelve years after the 2004 earthquake. If the
398 new expansions and neighborhoods (western and south-eastern part of the city) that have been constructed after 2004 are
399 excluded from the scenarios; the results would concur with the real damage that occurred in the aftermath of the 2004
400 earthquake. Moreover, seismic vulnerability results based on this study concur with past studies in the city, using the EMS98
401 (Louhibi et al. 2013). For these reasons, the risk scenarios developed in this paper are considered to be reliable.
402
403 The results of this study represent a potential guide for earthquake protection and risk management in the city, as well as a
404 powerful tool in urban development. It is worth noting that the original results described in this paper, together with the
405 complete and detailed technical information concerning the expected damage, loss to property and damage to population, will
406 be delivered to the civil protection services of the municipality of Al Hoceima who will be using them for updating the
407 emergency plans of the city.
408

409 **References**
410

411 Akoglu AM, Cakir Z, Meghraoui M, Belabbes S, El Alami SO, Ergintav S, Akyüz HS (2006) The 1994–2004 Al Hoceima
412   (Morocco) earthquake sequence: Conjugate fault ruptures deduced from InSAR. Earth and Planetary Science Letters
413   Volume 252, Issues 3–4, 15 December 2006, Pages 467–480 doi:10.1016/j.epsl.2006.10.010
414 d'Acremont E, Gutscher M-A, Rabaute A, Mercier de Lépinay B, Lafosse M, Poort J, Ammar A, Tahayt A, Le Roy P, Smit J,
415   Do Couto D, Cancouët R, Prunier C, Ercilla G, Gorini C (2014) High-resolution imagery of active faulting offshore Al
416   Hoceima, Northern Morocco. Tectonophysics Volume 632, 29 September 2014, Pages 160–166,
417   http://dx.doi.org/10.1016/j.tecto.2014.06.008
418 Ait Brahim L, Tadili B, Nakhcha C, Mouayn I, Ramdani M, Limouri M, El Qadi A, Sossey Alaoui F, Benhalima M, (2004)
419   Using active faults and seismicity for the strong motion modeling in the eastern Rif (northern Morocco). Pure Appl
420   Geophys 161 (2004) 1081–1091 0033 – 4553/04/061081 – 11 DOI 10.1007/s00024-003-2487-9
421 ATC-13 (1985) Earthquake damage evaluation data for California, ATC-13. Applied Technology Council, Redwook City
422 BAEL 91 (1992) Règles techniques de conception et de calcul des ouvrages et constructions en béton armé suivant la
423   méthode des états-limites. Décret n092-72 du 16 janvier 1992.

424   Benedetti D, Petrini V (1984) Sulla vulnerabilitá sismica di edifici in muratura: proposte di un metodo di valutazione.
425   L'industria delle Construzioni 149:66–78

426   Bezzeghoud M, Buforn E (1999) Source parameters of the 1992 Melilla (Spain,Mw = 4.8), 1994 Al Hoceima (Morocco Mw
427   = 5. 8) and Mascara (Algeria, Mw = 5.7) earthquakes and seismotectonic implications. Bull. Seismol. Soc. Am. 89,359–
428   372

429   Casado CL, Henares J, Badal J, Peláez JA (2014) Multifractal images of the seismicity in the Ibero-Maghrebian region
430   (westernmost boundary between the Eurasian and African plates). Tectonophysics 627 (2014) 82–97

431   Cherkaoui T, Hatzfeld D, Jebli H, Medina F, Caillot V (1990) Etude microsismique dela région d'Al Hoceima. Bull. Inst. Sci.
432   Rabat 4, 25–34

433   Cherkaoui T, El Hassani A (2012) Seismicity and Seismic Hazard in Morocco 1901-2010. Bulletin de l'Institut Scientifique,
434   Rabat, section Sciences de la Terre, 2012, n° 34, p. 45-55

435   Choubert G, Faure-Muret A (1984) Carte géologique du Rif : Al Hoceima - Echelle 1/50 000. N° 302

436   Coburn A, Spence R (2002) Earthquake protection, 2nd edn. Wiley, Chichester

437   Corella PM (2004) Al-Hoceima Earthquake. Field Report,51p.

438   El Alami SO, Tadili BA, Cherkaoui TE, Medina F, Ramdani M, Ait Brahim L, Har-nafi M (1998) The Al Hoceima
439   earthquake of May 26, 1994 and its aftershocks:a seismotectonic study. Ann. Geofisic. 41, 519–537

440   Faccioli E (2006) Seismic hazard assessment for derivation of earthquake scenarios in Risk-UE. Bull Earthq Eng 4:341–364

441   Faradi (2004) Seisme d'Al Hoceima du 24-2-2004 Constat Technique, p 3

442   Giovinazzi S, Lagomarsino S (2002) Wp04: guidelines for the implementation of the level I methodology for the
443   vulnerability assessment of current buildings. RISK-UE project: an advanced approach to earthquake risk scenarios with
444   applications to different European towns. Contract No.EVK4-CT-2000-00014, Genoa

445   Goula X, Gonzalez M (2004) Visite technique à la zone endommagé par le séisme d'Al-hoceima du 24 février 2004.
446   Generalitat de Catalunya. Institut Cartogràfic de Catalunya, ICC-GS-192/2004 (fr)

447   Grünthal G (1998) European macroseismic scale 1998. Centre Européen de Géodynamique et de Séismologie, Luxemburg

448   HAZUS (1999) Earthquake loss estimation methodology technical manual, prepared by the National Institute of Building
449   Sciences for Federal Emergency Management Agency (FEMA), Washington, D

450   Jabour N, Kasmi M, Menzhi M, Birouk A, Hni L, Hahou Y, Timoulali Y, Bedrane S, (2004). The February 24th, 2004 Al
451   Hoceima earthquake, Newsletter of European-Mediterranean Seismological Centre, N° 21, ISSN: 1607-1980.

452   Lagomarsino S, Giovinazzi S (2006) Macroseismic and mechanical models for the vulnerability and damage assessment of
453   current buildings. Bull Earthq Eng 4:415–443

454   Lantada N, Irizarry J, Barbat AH, Goula X, Roca A, Susagna T, Pujades LG (2010) Seismic hazard and risk scenarios for
455   Barcelona, Spain, using the Risk-UE vulnerability index method. Bull Earthquake Eng, DOI 10.1007/s10518-009-9148-
456   z

457   Louhibi S, Chourak M, El Kihel E, El Hammoumi A, Douiri A (2013) Evaluation of the Seismic Vulnerability of Buildings
458   in Al Hoceima (Morocco). International Journal of Earth Sciences and Engineering. December2013, P.P.1505-1511.
459   ISSN 0974-5904, Volume 06, No. 06(01)

460   Lungu D, Aldea A, Arion A, Vacareanu R, Petrescu F, Cornea T (2001) WP1 report: European distinctive features, inventory
461   database and typology. RISK-UE project: an advanced approach to earthquake risk scenarios with applications to
462   different European towns. Contract No. EVK4-CT-2000-00014

463   Milutinoviç ZV, Trendafiloski GS (2003) WP04: vulnerability of current buildings handbook. RISK-UE project: an advanced
464   approach to earthquake risk scenarios with applications to different European towns. Contract No. EVK4-CT-2000-
465   00014, Institute of Earthquake Engineering and Engineering Seismology (IZIIS), Skopje

466   Mourabit T, Abou Elenean KM, Ayadi A, Benouar D, Ben Suleman A, Bezzeghoud M, Cheddadi A, Chourak M, ElGabry
467   MN, Harbi A, Hfaiedh M, Hussein HM, Kacem J, Ksentini A, Jabour N, Magrin A, Maouche S, Meghraoui M, Ousadou
468   F, Panza GF, Peresan A, Romdhane N, Vaccari F, Zuccolo E (2013) Neo-deterministic seismic hazard assessment in
469   North Africa. J Seismol DOI 10.1007/s10950-013-9375-2

470   Mouroux P, Bertrand M, Bour M, Brun BL, Depinois S, Masure P, Risk-UE Team (2004) The European Risk-UE project: an
471   advanced approach to earthquake risk scenarios. In: Proceedings of the 13th world conference earthquake engineering,
472   Vancouver (CD-ROM, Paper No. 3329)

473 Pitilakis K, Alexoudi M, Argyroudis S, Anastasiadis A (2006) Seismic risk scenarios for an efficient seismic risk
474   management: the case of Thessaloniki (Greece). Advances in Earthquake Engineering for Urban Risk Reduction. pp
475   229-244. DOI 10.1007/1-4020-4571-9_15
476 Poujol A, Ritz J-F, Tahayt A, Vernant P, Condomines M, Blard P-H, Billant J, Vacher L, Tibari B, Hni L, Koulali Idrissi A
477   (2014) Active tectonics of the Northern Rif (Morocco) from geomorphic and geochronological data. Journal of
478   Geodynamics Volume 77, July 2014, Pages 70–88, doi:10.1016/j.jog.2014.01.004
479 PS92 (1995) Règles PS applicables aux bâtiments. NF P 06-013 -DTU Règles PS 92, Décembre 1995.
480 RGPH 2004 (2004) Recensement général de la population et de l'habitat 2004. http://www.hcp.ma/Recensement-general-de-
481   la-population-et-de-l-habitat-2004_a633.html
482 RGPH 2014 (2014) Population légale des régions, provinces, préfectures du royaume d'après les résultats du RGPH 2014 (12
483   Régions).http://www.rgph2014.hcp.ma/Note-sur-les-premiers-resultats-du-Recensement-General-de-la-Population-et-
484   de-l-Habitat-2014_a369.html
485 RMSI (2012) Morocco natural hazards probabilistic analysis and national strategy development. Earthquake hazard report.
486   Department of Economic and General Affairs, Kingdom of Morocco
487 R.P.S. 2000 (2002) Règlement de construction parasismique. Ministère de l'Aménagement du Territoire, de l'Urbanisme, de
488   l'Habitat et de l'Environnement. Secrétariat d'Etat à l'Habitat
489 R.P.S. 2000, Version 2011 (2011) Règlement de construction parasismique. Ministère de l'Habitat, de l'Urbanisme et de
490   l'Aménagement de l'Espace
491 Secanell R (1999) Avaluació de la perillositat sísmica a Catalunya: anàlisi de sensibilitat per a diferents models d'ocurrència i
492   paràmetres sísmics, Ph.D. Thesis, University of Barcelona
493 Tahayt A, Feigl KL, Mourabit TL, Rigo A, Reilinger R, McClusky S, Fadil A, Dorbath L, Serroukh M, Gomez F, Ben Sari
494   D, Berthier E (2009) The Al Hoceima (Morocco) earthquake of 24 February 2004, analysis and interpretation of data
495   from ENVISAT ASAR and SPOT5 validated by ground-based observations. Remote Sensing of Environment 113
496   (2009) 306–316. doi:10.1016/j.rse.2008.09.015
497 USGS (2016) M6.3 - 50km NNE of Al Hoceima. Morocco.http://earthquake.usgs.gov/earthquakes/eventpage/us10004gy9#
498   general_region
499 Woerd JVD, Dorbath C, Ousadou F, Dorbath L, Delouis B, Jacques E, Tapponnier P, Hahou Y, Menzhi M, Frogneux M,
500   Haessler H (2014) The Al Hoceima Mw 6.4 earthquake of 24 February 2004 and its aftershocks sequence. Journal of
501   Geodynamics. Volume 77, July 2014, Pages 89‑109. doi:10.1016/j.jog.2013.12.004