On the seismic risk assessment of the residential buildings in Northern Algeria

Smail Kechidi[1], Andrés Abarca[2], Mário Marques[3], José M. Castro[4], Ricardo Monteiro[5]

[1] Post-Doc., Department of Civil Engineering, University of Porto - Porto, Portugal.
[2] Ph.D. Student, University School of Advanced Studies IUSS Pavia - Pavia, Italy.
[3] Post-Doc., Department of Civil Engineering, University of Porto - Porto, Portugal.
[4] Assistant Professor, Department of Civil Engineering, University of Porto - Porto, Portugal.
[5] Assistant Professor, University School of Advanced Studies IUSS Pavia - Pavia, Italy.

ABSTRACT

The north of Algeria is the most active seismogenic region in the Western Mediterranean basin, with an historic occurrence of frequent and very destructive earthquakes in this area, which had led in the past few decades to approximately 50 000 fatalities and a large economic, human and social impact. Using large-scale seismic risk assessment is becoming a common trend around the world to attempt to reduce potential losses from these earthquake events. For this reason, within the scope of the ITERATE project, a collaborative effort was made to develop a web-based tool for large-scale probabilistic assessment intended to enable Algerian stakeholders to understand and calculate seismic risk through the convolution of hazard, exposure and vulnerability. A great amount of information was collected, organized and processed to determine the characteristics of the building stock inventory in Northern Algerian in terms of quantity, location, typology and structural behaviour, adopting the province of Blida as a first case study. Furthermore, the vulnerability of the inventory was evaluated through the development of fragility curves, based on the observed behaviour of a great number of nonlinear structural models under the effect of multiple ground motion records, accounting for epistemic and aleatory uncertainties. The developed exposure and vulnerability models, along with an updated seismic hazard model were loaded to a specifically developed web application which allows the probabilistic evaluation of seismic event scenarios, as well as automated predictions in terms of human and economic losses.

Keywords: Northern Algeria, Residential buildings, Vulnerability, Seismic risk, Web-based platform.

INTRODUCTION

Large scale seismic risk assessment has become increasingly popular to support risk management and decision-making process by combining hazard, exposure and vulnerability [1]. However, in less developed countries such as Algeria, the required resources, datasets and tools might not currently exist. Within the scope of the ITERATE "Improved Tools for Disaster Risk Mitigation in Algeria" project (http://www.iterate-eu.org/), which aims at disaster risk prevention and reduction in Algeria through the proposal of an improved framework for seismic risk assessment, the development of a web-based and open-source platform capable of rapidly performing earthquake loss estimations while interacting with other sources of information and applications such as the Seismographic Network of Algeria and smartphone/tablet application for data collection, is described in this paper. The study for Northern Algeria starts by covering a well identified seismic prone region, the province of Blida, as a first case study.

The main objective of the web-based platform (WBP) is to estimate in an automatic and reliable way the seismic risk in Northern Algeria in terms of spatial distribution of economic, human and social losses. The tool (i.e., WBP) responds to the needs of different types of end-users. For example, structural engineers are able to visualize the potential need for seismic retrofitting of a building given its typology and location within the Algerian territory. For public authorities responsible for the definition of risk mitigation policies, the platform provides loss maps highlighting the priority areas.

In the following section, the components required to assess seismic risk i.e., hazard, exposure and physical vulnerability of the exposed elements, are described. Subsequently, a brief description of the main parts of the WBP is presented. Lastly, in order to highlight the capabilities of the WBP to reliably reproduce the casualties endured during pervious seismic events, scenario event-based damage simulation of the Bourmerdès earthquake of 2003, is carried out.

SEISMIC RISK ASSESSMENT COMPONENTS

Within the aim of empowering Algeria's capacity to enforce seismic risk reduction measures through the development of state-of-the-art tools for the seismic risk assessment, updated models of hazard (characteristics and frequency of earthquakes at the site), vulnerability (impact of ground motion to the exposed assets) and exposure (inventory of assets at the site) have been developed.

Exposure model

The development of a dataset featuring the prevailing building typologies and their metrics (i.e., number of dwellings and buildings) as well as their spatial distribution and replacement cost, is a fundamental task to reliably evaluate physical vulnerability and economic losses due to seismic hazard. For this purpose, such dataset was created for the province of Blida chosen as a first case study. Blida is an economic and cultural center with a large population and is thereby considered presentative of the Northern Algerian context.

Four main building categories have been determined to characterize most of the as-built building stock in Blida:

- RC moment resisting frame buildings
- Dual RC system: moment resisting frame and shear wall buildings
- Reinforced concrete shear wall buildings
- Unreinforced masonry buildings

Using the previously described categories, a set of classes has been defined to distinguish each building typology according to its seismic vulnerability, as described in Table 1.

Table 1. Building classes.

Construction type	Number of storey	Design level*	Vulnerability class
RC moment-resisting frames	Low-rise (1-3)	Medium-code	RC MRF LR MC
		Post-code	RC MRF LR C
	Mid-rise (4-7)	Pre-code	RC MRF MR PC
RC shear wall	Mid-rise (4-7)	Post-code	RC SW MR C
	High-rise (>7)	Post-code	RC SW HR C
Dual RC system: moment-resisting frames and shear walls	Low-rise (1-3)	Post-code	RC MRF-SW LR C
	Mid-rise (4-7)	Pre-code	RC MRF-SW MR PC
		Medium-code	RC MRF-SW MR MC
		Post-code	RC MRF-SW MR C
	High-rise (>7)	Pre-code	RC MRF-SW HR PC
		Medium-code	RC MRF-SW HR MC
		Post-code	RC MRF-SW HR C
Unreinforced Masonry	Low-rise (1-3)	Pre-code	UM LR PC

**Design level defined according to the construction period: <1981, 1981-1999 and >1999.*

In 2008, 127 205 residential buildings were reported, housing 149 775 dwellings which has been increased significantly to 205 477 dwellings in June 2017 where its distribution among all the municipalities within the province of Blida is shown in Figure 1. The map in Figure 1 shows within each municipality the building fractions in each building classes defined in Table 1. This was derived based on official census data (the total number of dwellings recorded in 2017) together with a disaggregation based on local experts' opinion and previous research studies.

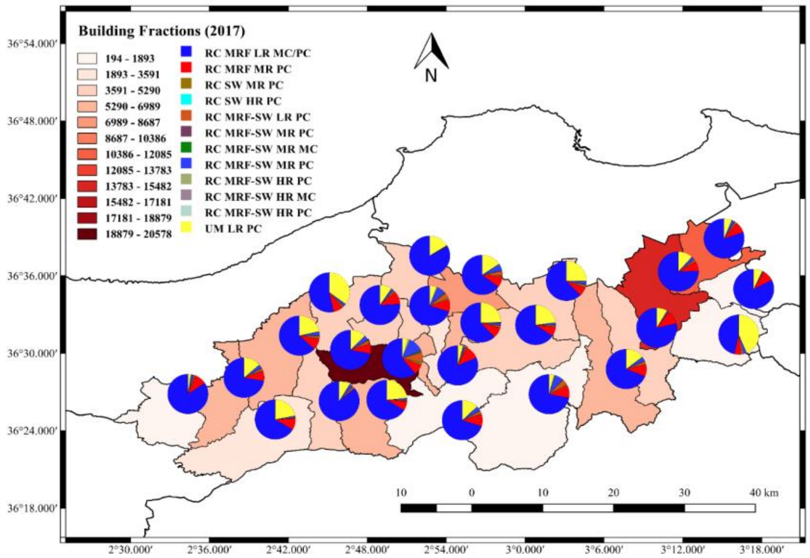
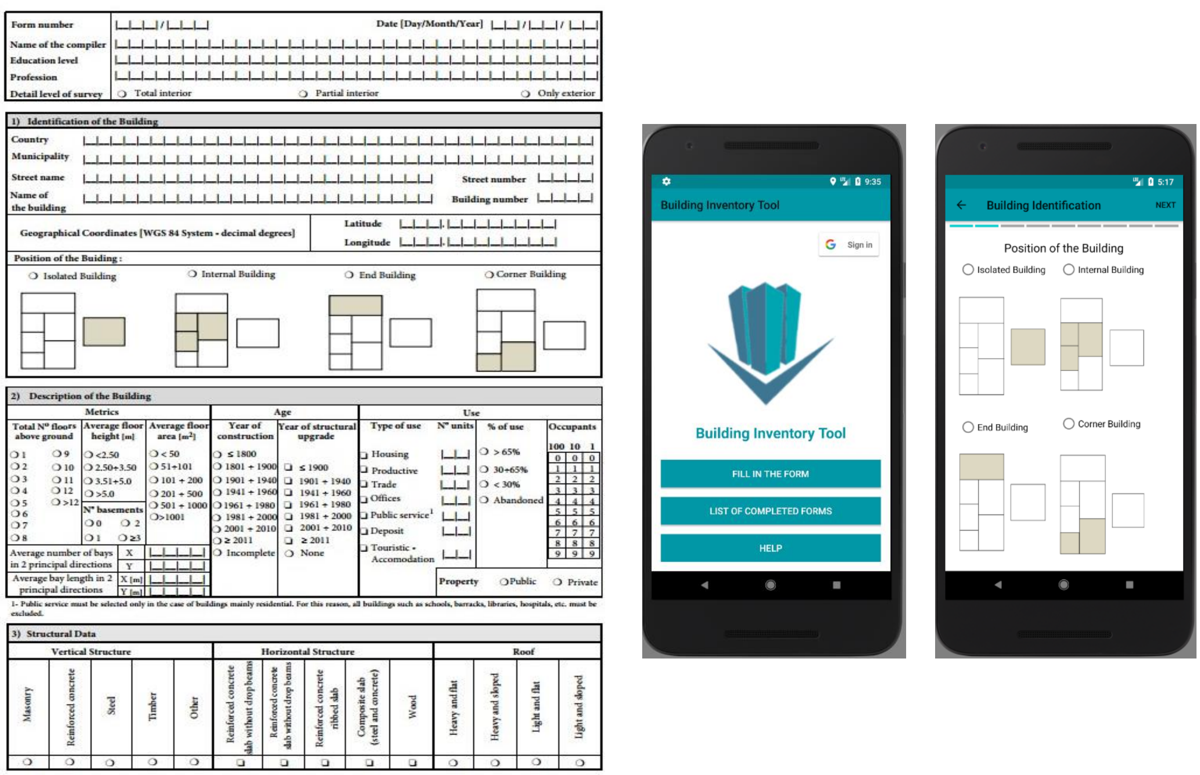


Figure 1. Map for Blida at municipality level showing with pie charts the building fractions.

In order to refine and update the information collected form the census with more parameters which aid in the definition of the fragility of the inventory, additional data has been collected via different stakeholders by adopting a proper building data collection form shown in Figure 2a that was reproduced electronically (see Figures 2b and 2c) so as to rapidly and efficiently reach a significant number of assets within the province. The different fields of building information to collect were put together in a user-friendly Android smartphone/tablet application entitled Building Inventory Tool (BIT). The use of the BIT speeds up the process, with respect to paper forms, minimizes errors and transfers exact information such as geographic location and photos. Furthermore, the application connects directly to the WBP so that the information can be uploaded and checked in real time.



(a) *(b)* *(c)*

Figure 2. (a) Building data collection form, (b) homepage of the Building Inventory Tool application and (c) Building Description section.

Around 3 000 buildings have been surveyed where Figure 3 illustrates their spatial distribution along with their fragility curves for different damage states (i.e., slight, moderate, extensive and collapse) derived using the methodology described in the following section.

(a) *(b)*

Figure 3. Representation of the building inventory portfolio in the WBP, (a) spatial distribution and structural parameters, (b) fragility curves.

Vulnerability model

The evaluation of seismic physical risk of structures is typically performed using fragility curves, which are functions that indicate the probability of a building, or a set of buildings with similar characteristics, to exceed a specific damage state, given a level of ground shaking. Ideally, the derivation of these fragility curves is done empirically, by collecting enough information from damage of a large set of buildings from past earthquakes in the area of study. However, this is very unlikely since enough post-earthquake quality data is typically non-existing and, therefore, analytical methodologies need to be implemented.

The methodology defined for creating fragility curves for each typology follows the procedure used by [2] in which multiple references were consulted to obtain a wide set of capacity curves for each of the building typologies identified as part of the Algerian residential building inventory described above. The structural behaviour of each typology will be accounted for as the average capacity curve obtained from this previous step, which will then be used to create a large number of synthetic equivalent single degree of freedom (SDOF) oscillators that will represent the building-to-building variability of the entire inventory.

Afterwards, a set of 40 ground motion records that are compatible with the Algerian hazard context were selected then scaled to 10 different intensities to represent the record-to-record variability. Both sources of variability (i.e., building-to-building and record-to-record variabilities) were combined through a series of nonlinear time history (NLTH) analyses, leading to a distribution of damage per ground motion intensity level. A schematic representation of the above-described process is shown in Figure 4.

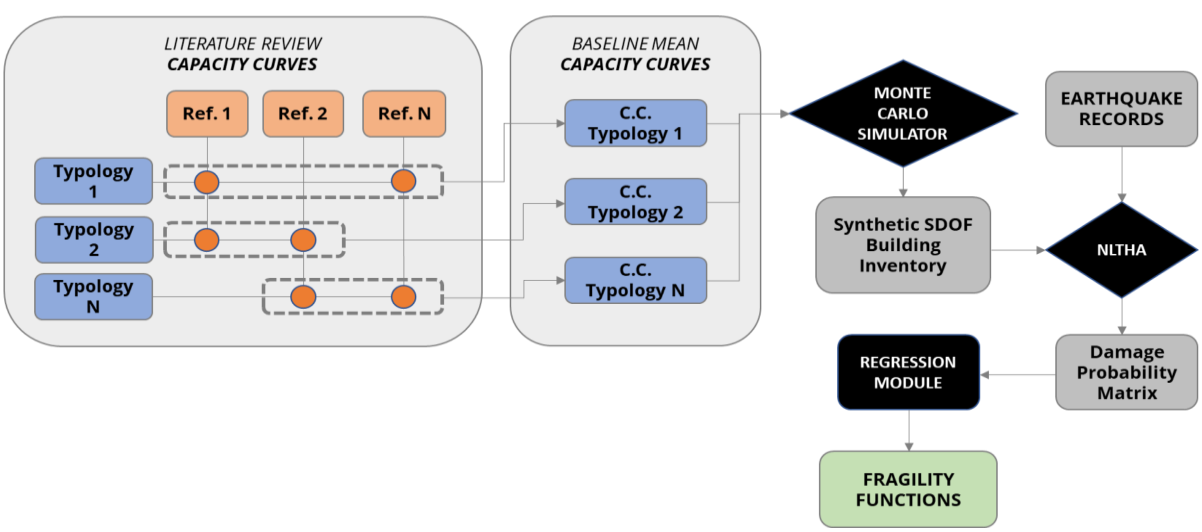
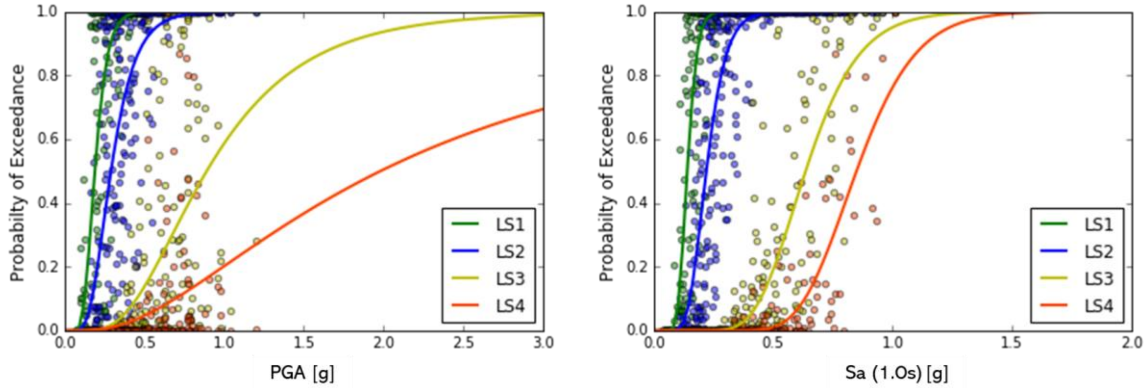


Figure 4. Methodology for physical vulnerability assessment.

The resulting fragility functions for the RC MRF LR C building class, using both peak ground acceleration (PGA) and spectral acceleration (Sa) at the structural period of best fit intensity measures of ground motion along with the data scatter, are presented graphically in Figure 5.



(a) *(b)*

Figure 5. Fragility curves for RC MRF LR C typology with different IM: (a) PGA and (b) Sa at 1.0 sec (best fit) [Slight (LS1), Moderate (LS2), Extensive (LS3) and Collapse (LS4)].

As for the hazard model adopted in this study, it was is developed by the Algerian partner (Centre for Research in Astronomy Astrophysics and Geophysics "CRAAG" [3]) of the ITERATE project. The reader is referred to [4-5] for further details.

WEB-BASED PLATFORM

The present WBP aims to provide stakeholders with accurate and reliable information regarding the true seismic risk that the Algerian society is exposed to. Two major analyses are needed to assess the seismic risk: a scenario-based analysis, that includes both real-time analysis of the potential consequences of any seismic event recorded by the Algerian seismic network, and a scenario simulator of a fictitious seismic event created by the user. An additional feature of the WBP is the ability to perform probabilistic-based analysis which goes beyond the scope of the study presented herein.

In terms of outputs, the platform represents visually and through a set of maps, plots and tables, the estimates of the seismic consequences, namely, hazard maps (ground motions at each pair of latitude and longitude), damages in structures and economic losses. Likewise, the exposed assets, collected from the BIT application are also represented (see Figure 3). Figure 6 shows the homepage of the WBP.

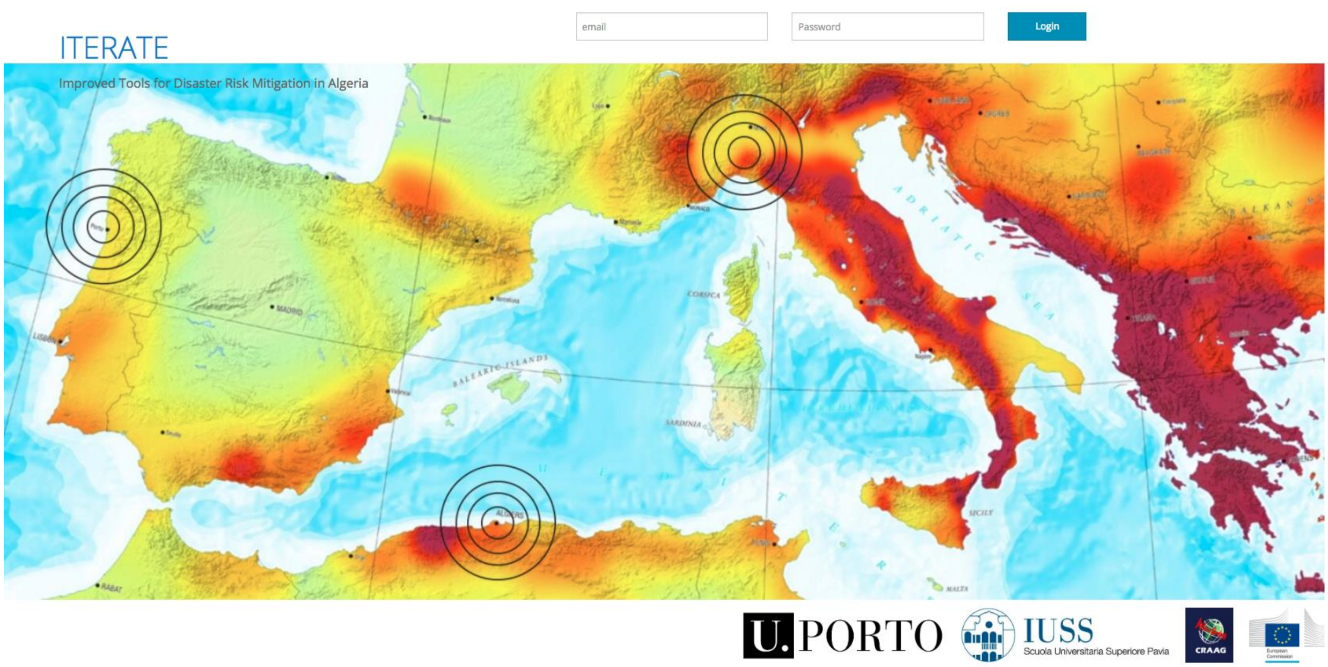


Figure 6. Homepage of the WBP.

Testing scenario

Several seismic scenarios have been performed with a view to test the derived models and WBP implementation. In this section, a recent seismic event in Algeria is considered, the Boumerdès earthquake of 2003 (Ms ≈ 6.8). In this investigation, the areas with the highest risk in the province of Blida, the building typologies contributing the most to the economic losses are identified. The results have been discussed between the three partners of the ITERATE project and were also presented in the workshop that took place in Blida on the 9th of December 2018 that marked the release of the WBP. This analysis is performed using OpenQuake [6], the open source software for hazard and risk analysis of the Global Earthquake Model initiative.

Figure 7 shows the location of the epicentre of the Boumerdès earthquake as well as the active faults in Northern Algeria where the results of hazard and risk analyses for the event are ready to be visualized.

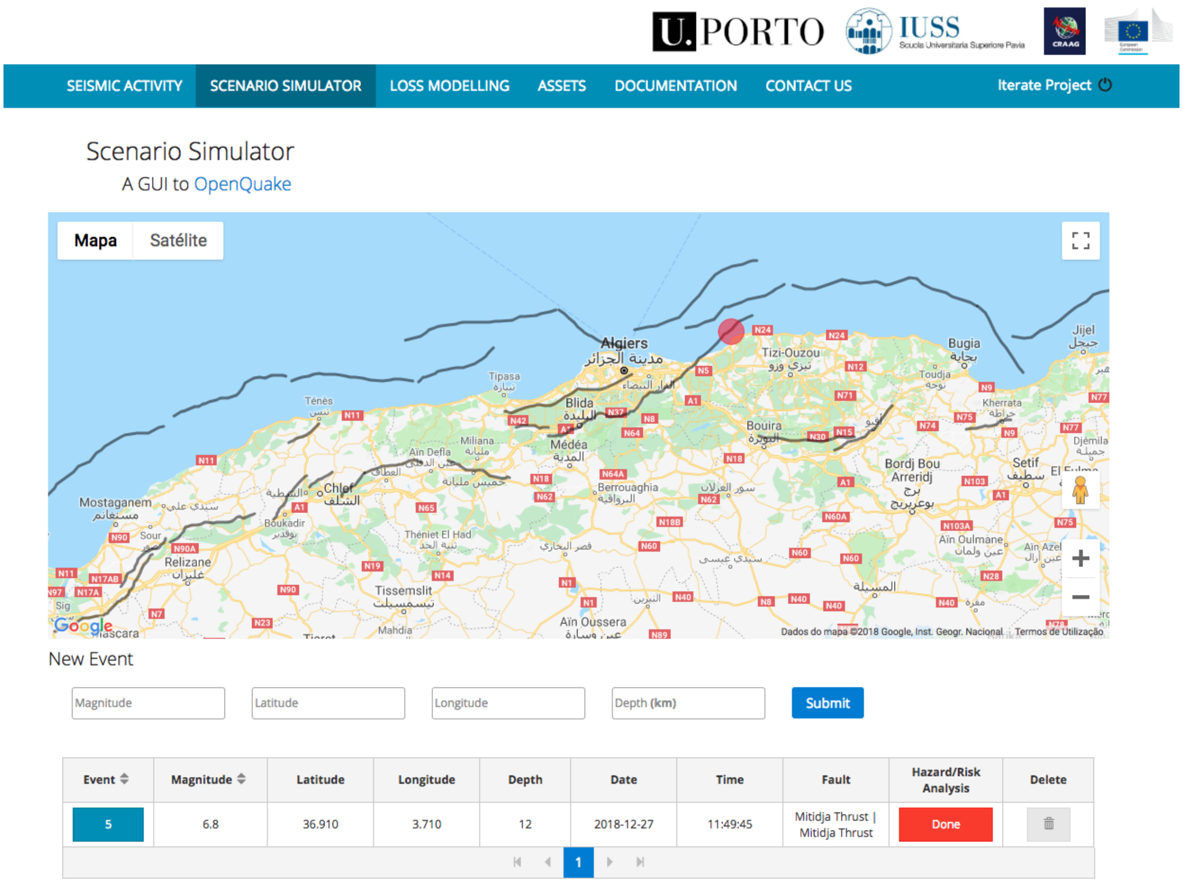
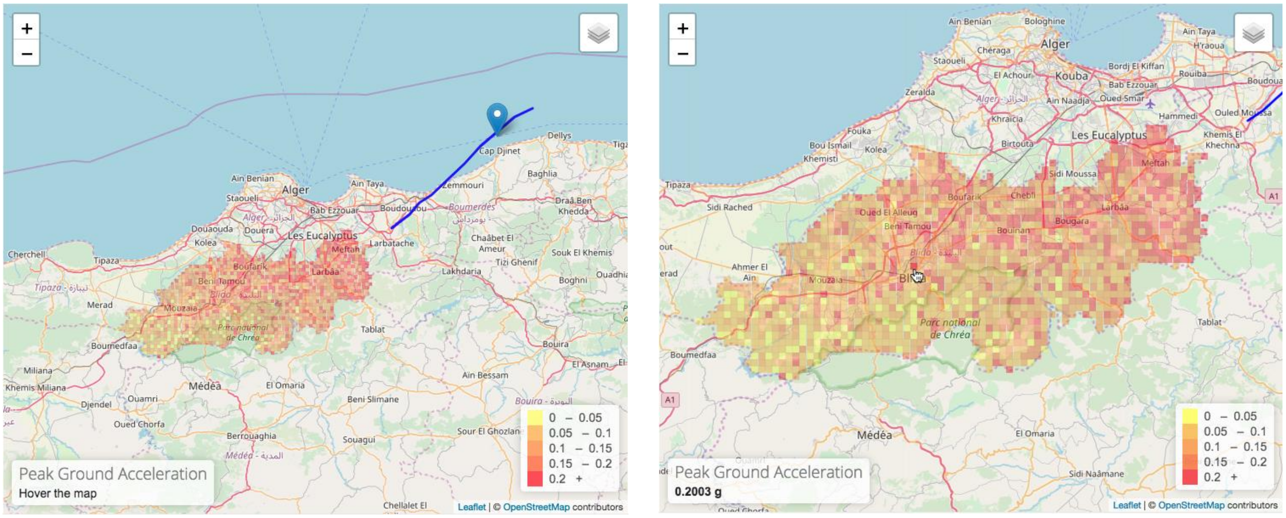


Figure 7. Scenario Simulator module of the WBP.

Boumerdès earthquake of 2003

The 2003 Boumerdès earthquake occurred on the 21st of May at 19:44:21 local time in Northern Algeria. The shock had a moment magnitude of 6.8. The epicentre of the earthquake was located near the town of Thénia in Boumerdès province, approximately 60 km east of the capital Algiers. The earthquake was the strongest to hit Algeria in more than twenty years since 1980, when a magnitude 7.1 earthquake resulted in at least 2 633 deaths.

The consequences of this earthquake in terms of hazard (PGA distribution map) and in terms of risk (buildings and bridges damages) for the province of Blida are shown in Figures 8-10. It can be seen that the western part of the province is the most affected (PGA_{max} = 0.20 g) which is the closest to the epicenter of the event (see Figure 8).



(a) *(b)*

Figure 8. Hazard map: a) fault and epicenter location of the event and b) PGA distribution.

As far as the results in terms of risk are concerned, a uniform distribution of building damage (collapse state) throughout the territory of the province of Blida is shown in Figure 9 (left). In addition, the number of buildings that experienced different limit states (slight, moderate, extreme and collapse) is also shown in Figure 9 (right).

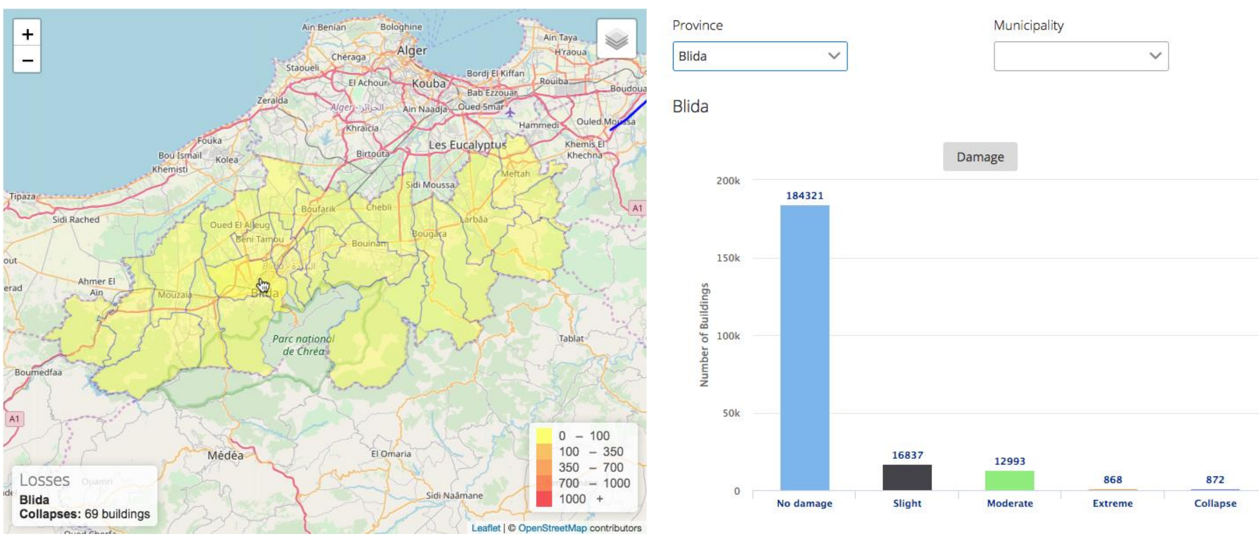


Figure 9. Damage distribution map (left) and number of buildings in different damage states.

In Figure 10, the disaggregation of the number of buildings per building class for collapse damage state is shown. It can be noticed that the building class "reinforced concrete moment-resisting frame mid-rise pre-code" contributes the most to the total number with no contribution of building classes "reinforced concrete shear wall mid-rise post-code, reinforced concrete shear wall high-rise post-code, reinforced concrete moment-resisting frame-shear wall low-rise post-code and reinforced concrete moment-resisting frame-shear wall high-rise post-code".

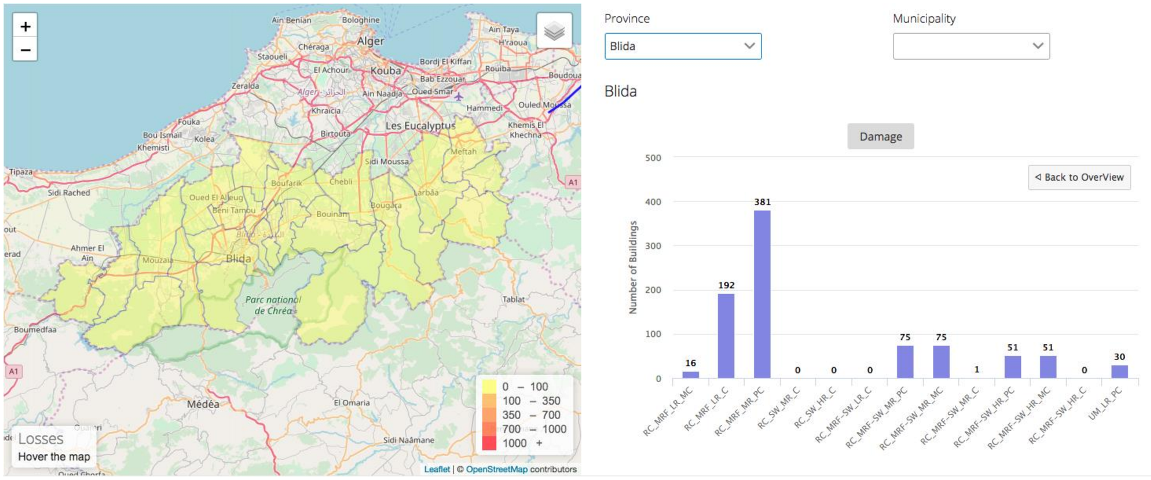


Figure 10. Number of buildings per building class associated to the collapse damage state.

CONCLUSIONS

In this paper, a user-friendly WBP which puts together all the necessary information of the different risk components (hazard, exposure and vulnerability) as an integrated tool for decision making was described. The exposure model is created considering information from census data, as well as the use of a smartphone application which has been adopted to obtain detailed and updated characteristics of the building inventory. The physical vulnerability of the exposed assets has been calculated through the evaluation of the performance of synthetic sets of structures, represented by SDOF systems, subjected to multiple seismic events through NLTH analyses. This process along with a consequence model allowed the generation of vulnerability curves for each building class.

Subsequently, the testing of the WBP that has been developed within the scope of the ITERATE project was presented. The WBP is powered by the OpenQuake engine that uses the three models to perform seismic hazard and risk analysis. The testing involved the analysis of the consequences of the major seismic event that affected Algeria in 2003 i.e., the Bourmerdès earthquake. Hazard and risk results have been presented in terms of PGA and damage distribution maps, respectively. The estimates obtained indicate a higher impact of the Bourmedès earthquake in the province of Blida. This is due to the higher proximity of the epicenter of the event to the province, as denoted by the higher levels of ground shaking predicted by the hazard model. The results presented in this paper were also subject of discussion during the workshop event, that took place in Blida (Algeria) on the 9th of December 2018 that marked the release of the WBP, with the aim of getting feedback from the local people who witnessed the 2003 Bourmedès earthquake. A calibration process of the WBP is ongoing.

ACKNOWLEDGMENTS

The research reported in this paper has been developed under the ITERATE project “ECHO/SUB/2016/740181/PREV23 ITERATE - Improved Tools for Disaster Risk Mitigation in Algeria” funded by DG ECHO - Humanitarian Aid and Civil Protection from the European Commission and SMARTER project - Seismic Urban Risk Assessment in Iberia and Maghreb (2017-2019), PTDZ/0002/2015, funded by the Portuguese Foundation for Science and Technology “Fundação para a Ciência e a Tecnologia”.

REFERENCES

[1] Silva, V., Crowley, H., Humberto, V., Pinho, R. (2015). “Seismic risk assessment for mainland Portugal”. *Bulletin of Earthquake Engineering*, 13, 429-457.

[2] Villar-Vega, M., Silva, V., Crowley, H., Yepes, C., Tarquea, N., and Acevedoa, A. (2017). “Development of a Fragility Model for the Residential Building Stock in South America”. *Earthquake Spectra*, 33(2), 581–604.

[3] Centre for Research in Astronomy Astrophysics and Geophysics (CRAAG), https://www.craag.dz/

[4] Hamdache, M., Pelaez, M.J., Yelles-Chaouche, A., Monteiro, R., Marques, M., Castro, J.M., Beldjoudi, H and Kherroubi, A. (2018). Preliminary Seismic Hazard Modelling in northern Algeria. In *the 1st Conference of the Arabian Journal of Geosciences*, Hammamet, Tunisia.

[5] Hamdache, M., Pelaez, J.A., Talbi, A., and Casado, C.L. (2010). “A unified catalog of main earthquakes for Northern Algeria from AD 856 to 2008”. *Seismological Research Letters*, 81(5), 732-739.

[6] OpenQuake, GEM OpenQuake Manual, http://www.globalquakemodel.org/openquake/