Towards Large Scale Seismic Risk Assessment in Algeria: Case Study to the City of Blida

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Abstract. In recent years, the use of large scale seismic risk assessment has become increasingly popular to evaluate the fragility of a specific region to an earthquake event, through the convolution of hazard, exposure and vulnerability. These studies focus on the vulnerability of the built environment of the region and the evaluation of the human social dimension, which has great importance when determining the ability of a community to attend to a disaster and to eventually resume normal activities. This study, developed within the scope of the EU-funded project ITERATE (Improved Tools for Disaster Risk Mitigation in Algeria), focuses on the development of a web-based framework for integrated seismic risk assessment in Northern Algeria, primarily focused on the city of Blida, chosen as first case-study. For this purpose, alliances with local institutions, web-based data mining techniques and specifically developed research were used to obtain: an updated seismic hazard model, and exposure and vulnerability models for local buildings and bridges, which are proposed and implemented in a web-based platform which allows the calculation of the seismic risk at a municipal level in terms of probabilistic losses. Furthermore, a social vulnerability assessment is implemented at the same level and combined with the physical vulnerability to enable the identification of the regions that are more vulnerable to earthquakes. Such framework will, in turn, empower Algerian stakeholders to perform the evaluation of earthquake scenarios at a regional scale and provide valuable information to decision makers for the implementation of risk mitigation measures in vulnerable areas.

1. Introduction
Following major disasters, it is evermore recognized that while their occurrence is often inevitable, reducing the associated risk through prevention measures should be a primary concern. Regions with a significant percentage of non-seismically designed buildings and where there is room for improvement in urban planning are particularly vulnerable to natural hazards.

In Algeria, earthquakes can have a devastating impact, as has been shown by past events in the northern part of the country like the El Asnam 1980 Mw 7.1 and Boumerdès 2003 Mw 6.8 earthquakes, which in each case have caused thousands of fatalities as well as billionare costs in damages, leaving the country in a state of emergency for extended periods of time. As a result of these events, the country adopted in 2004 the Law on Prevention of Major Risks and Disaster Management and the National Scheme for Land Use Planning, demonstrating its political will to promote disaster risk reduction (DRR). New seismic design regulations were also adopted, while in 2012 the National Delegate for Major Risks was established. However, these accomplishments in legislative and higher administration level have not been followed by an equally successful integration of the new regulations at the local level. Overall lack of coordination and awareness of the general public regarding seismic risk has
hindered the implementation of the conceived regulations. Acknowledging this reality, the project ITERATE was created as a part of the European Union initiative to reduce risk among its members, as well as is neighboring countries, for which Algeria qualifies. ITERATE has set out the goal to empower Algeria's capacity to enforce seismic risk reduction measures through a dual objective: address the lack of state-of-the-art tools for the seismic risk assessment throughout the country, all while engaging local authorities and increasing the awareness of local population and practitioners, making use of a privileged combination of expertise from Algeria, Portugal and Italy. Within this context, 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) will be collected from previous studies (when existing) or specifically developed. These models will be integrated within a web-based platform (WBP) that will provide seismic risk information and real-time loss estimates to the relevant public and private stakeholders.

2. Hazard

2.1. Tectonic Background

The Algeria–Morocco region is located at the margin of the African Plate as shown in Figure 1 and it has been determined that the convergence of the African and Eurasian Plates has an approximate N50°W–SSE direction. The region at the northwestern edge of the African Plate (called the Nubian Plate) is subdivided into the main structural domains, as shown in Figure 1. The Sahara domain, characterized by a lack of significant Mesozoic–Cenozoic deformation, forms part of the Precambrian areas of Africa; it is clearly cratonized and generally not affected by major later deformations and thus, it can be treated as tectonically stable [1].

The Tell–Rif system comprises mountains formed by sedimentary external zones (only weakly affected by metamorphism) that were thrust southward toward the Moroccan Meseta, the High Plateau, and the Internal Zones [2].

2.2. Seismicity of the Region

An earthquake catalogue was compiled and homogenized which covers the seismic events above a moment magnitude Mw of 4.0 present in the region from A.D. 856 until A.D. 2017. These events, shown in the inset of Figure 1, lead to the conclusion that the studied region has a very shallow seismicity, since most of the earthquakes reported are located in the crust, with only a few scattered events having depths between 30 and 120 km.

In northern Algeria, the Tell Atlas seems to be the most efficient and, accordingly, the most dangerous area in this part of the contact between the Eurasian and African plates. Events with magnitudes above 6.0 mainly cluster in the central part of the Tell Atlas which includes the Ech-Chlef region, the Algiers-Blida region and the Bouira-Batna region. The released energy in the Saharan Atlas, far from the plate contact, is clearly less than that in the Tell Atlas, although it is slightly higher in its central-eastern part.

2.3. Characteristics of the Seismic Hazard

The currently available hazard model for Algeria was developed in 2006 and provides results in terms of PGA and SA, and not just magnitude forecasts. This model used an attenuation equation for spectral accelerations. Owing to the rate of great earthquakes in northern Algeria as well as to the non-existence of an available strong motion regional database, they adopted the spectral acceleration attenuation relationship for Europe damped at 5% by [3].
Seismic hazard maps in terms of PGA and SA at different periods for rock soil damped at 5% and for return periods of 100 and 475 years, were generated [5]. Figure 2 shows results for PGA for rock, damped at 5%, and for a return period of 475 years.

Figure 1. Global tectonic sketch for the studied region including seismicity [4]

Figure 2. Seismic hazard map for PGA at rock with 10% probability of exceedance in 50 years (i.e. 475 return period) taken from [5]
As expected, most of the hazard is concentrated in the Northern part of the country, which also coincides with the highest populated areas. An updated model is being developed for the ITERATE project, using the Global Earthquake Model OpenQuake platform with updated ground motion prediction equations, but the results of this model are still in process.

3. Exposure

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 fundamental to reliably evaluate physical vulnerability and economic losses due to earthquake hazard. For this purpose, such dataset was created for the city of Blida, chosen as first case study, since it is a major population, economic and cultural center, which is considered representative of the Northern Algeria construction practices.

Four main building typologies 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

Given that in Algeria, there is no updated cadaster database that can be used to determine the amount and characteristics of the building inventory; census data along with other datasets to approximate building distribution, such as population datasets, were used as a reliable source for the development of the exposure model. Using the official census has three main advantages: First, the census captures both formal and informal construction, which allows for risk assessment in regions with low social development indexes; second, it is performed to the smallest administrative level which allows, to some extent, a detailed risk assessment on a province scale and; third, the census inquiry captures dwelling attributes using a significant number of variables, thus allowing appropriate building class identification.

Different attributes have been used herein to define a set of building classes which are the material of construction, type of lateral load resisting system, date of construction (which has a direct relation with the design code level) and number of storeys (height of the building). The first and second attributes are organized in 4 categories: Reinforced concrete moment resisting frames (RC MRF); dual reinforced concrete system: moment resisting frames and shear walls (RC MRF-SW); reinforced concrete shear walls (RC SW); and unreinforced masonry (UM).

The year of construction plays an important role in classifying the building portfolio according to the level of seismic design. In Algeria, the first design code that contained provisions regarding the consideration of seismic action was released after the earthquake of El Asnam in 1980 (Mw 7.1) entitled RPA81 (1981) [6]. The latest version is RPA99 (1999) [7] which was amended after the earthquake of Boumerdes in 2003 (Mw 6.8) and named RPA99 version 2003 (2003) [8]. Thus, buildings constructed before 1981 are categorized as pre-code (PC), while those built during the period ranging from 1981 to 1999 are termed medium-code (MC). The buildings constructed after 1999 are classified as post-code (C). Regarding the number of floors, three categories are considered herein: up to three storeys as low-rise (LR), between four and seven storeys as mid-rise (MR) and more than seven storeys as high-rise (HR). 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.

Combining the classification from Table 1 with the data from the Building Census survey of 2017, a municipality-based exposure model containing the number of buildings for each vulnerability class was
created. For the purposes of computing the seismic hazard for each asset, it will likely be assumed that all the building locations will be located at the centroid of the associated municipality area, which is a common assumption when performing seismic risk assessment at a large scale.

Table 1. Taxonomy defined for Exposure Modelling of Buildings

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

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

Since the Algerian national census provides an aggregated number of dwellings for each municipality, for the present model, the disaggregation of the number buildings for each type of dwelling was carried out by dividing the number of dwellings by the average number of dwellings per story times the average number of storeys.

The dwelling fractions computed include the range of number of storeys for each building type, and through expert judgment the average number of storeys in each typology and the average number of dwellings per story were defined. Table 2 presents a summary of the assumed values.

The map in Figure 3 shows a proposal of the building fractions for 2017 in each municipality per each of the building typologies defined in Table 1. This was derived based on official census data (the total number of dwellings recorded in 2017) together with the disaggregation proposed on Table 2 which is based on previous research and by local experts.

Table 2. Average number of storeys as a function of building height and dwellings per storey

| No. of storeys | Avg. # of storeys | Comments on number of storeys | Dwellings per storey |
|----------------|-------------------|--------------------------------|----------------------|
| H: 1-3a        | 1.25              | 60% of 1 storey and 30% of 2 storeys and 10% of 3 storeys | 1                    |
| H: 1-3b        | 2                 | 20% of 1 storey and 60% of 2 storeys and 20% of 3 storeys | 1                    |
| H: 1-3c        | 2.5               | 50% of 2 storeys and 50% of 3 storeys | 1                    |
| H: 4-7         | 5                 | Common practice in the country (up to 5 storeys is not mandatory to have a lift) | 2                    |
| H: >7          | 10                | Common practice in the country | 4                    |
Figure 3. Map for Blida at municipality level showing with pie charts the building fractions (2017)

A smartphone application has been developed specifically for the surveying of buildings in Algeria, to refine and update the information collected from the census with more parameters which will aid in the definition of the fragility of the inventory. This application, which is available from the project website, is based in a building collection form which was developed in paper format to assist in the information gathering process, allowing all individuals to use a single format with pre-defined fields which can be correlated to the performance of a specific building. Both the application and the paper forms are available in English, French and Arabic.

4. Vulnerability

4.1. Physical Vulnerability

Physical vulnerability is a measure of how prone a building is to damage for a given severity of the ground shaking. The aim of most research works dedicated to this subject is to give a mathematical formulation to vulnerability. One of the most widely used formulations for the quantification of vulnerability is with the use of fragility curves which describe the conditional probability of exceeding a certain damage limit state in terms of the selected intensity measure of the ground motion.

Fragility curves are calculated when the vulnerability studies are mechanics-based, i.e. the seismic behaviour of structures is modelled. Different levels of complexity for the mechanical models of the buildings are available and usually the selection of the model typology is chosen as a function of the level of knowledge of the building stock.

In the case of Algeria, several authors have already generated fragility curves for most of the identified building typologies in the Algerian inventory, which represents a great advantage for the
project. However, given that different authors used very different methodologies to obtain such fragility curves, the resulting curves can show different results for similar levels of ground shaking for the same typologies, making the reliability of these studies questionable for the its direct use in the project.

For this purpose, capacity curves available from Algerian literature are collected and sorted among the building typologies defined. These capacity curves will be used to capture the single degree of freedom (SDOF) equivalent average behaviour of a specific typology as well as the variability of each point in the simplified curve. This information will be used to generate a synthetic SDOF inventory as shown in Figure 4(a), which will be subjected to different levels of ground shaking through non-linear time-history analysis.

![Figure 4](image)

**Figure 4.** a) Family of synthetic SDOF models generated after a specific average and variance of parameters (taken from [9]). b) Fragility curves derived from the performance of a synthetic SDOF typology to NLTHA for different levels of ground shaking (taken from [9]).

The performance of each synthetic SDOF to each earthquake record will be evaluated and classified, assessing therefore the probability of exceeding a specific damage state for a specific level of ground shaking. The ultimate product of this process is the generation of capacity curves for each building typology as exemplified in Figure 4(b).

The resulting fragility curves have the advantage of accounting for building-to-building variability through the generation of the equivalent SDOF families which are representative of buildings with different configurations and construction qualities, as well as accounting for record-to-record variability through the response of each SDOF to multiple earthquake records via non-linear time-history analysis.

4.2. Social Vulnerability

The overall seismic risk of a population is not only a matter of hazard and physical vulnerability, but also about the ability of the exposed society to cope with the results of a disastrous event. These social effects are largely ignored in seismic risk assessment, mainly because of the difficulty to quantify the human dimensions within a hazard zone.

Social vulnerability assessment is the calculation of the differential impacts that communities can undergo after being exposed to similar levels of hazard, based on the conditions of each community’s social dimension, evaluating the capacity of groups to prepare for, respond to, and recover from disasters [10].
In order to quantify these effects objectively, a methodology is defined in which indicators derived from census information will be combined with a questionnaire that will be applied directly to the people in different communities of Algeria.

In the case of the census-based indicators, the approach will be based on the Social Vulnerability Index (SoVI) \[1\] methodology in which some specific observable variables are collected and processed in order to characterize the broader, non-observable dimensions of social vulnerability.

Initially, a set of socio-economic independent variables are chosen and separated into groups. Once these variables are collected from census information at the desired geographical level (municipal for this case), they are normalized and processed using factor analysis to determine how each of them represent the variability of its corresponding group (factor).

Each one of the underlying social dimensions is quantified by these factor scores (sub-indexes) which in turn are placed in an additive model to produce the composite social vulnerability index score SoVI \[1\].

The current study considers a core set of indicators which past research and practice lead to associate to vulnerability dimensions: population, education, economy, health, infrastructure, habitat and governance/institutional capacity. The selection of relevant variables for an index is done though expert opinion, considering: the aim of the study, the theoretical framework, availability and accuracy of social vulnerability data and statistical results for the Algerian territory.

Additionally, given that the census information available is often outdated or incomplete, a “Scorecard approach” \[12\] is adopted in which participatory assessment is implemented through the use of a questionnaire which is organized in the six themes shown in Table 3.

This Scorecard is built with specific questions and answer schemes for each key area, it has been adapted to Algerian background to meet it peculiarities and will be spread among population and the municipal representatives and an evaluation of potential gaps will be assessed especially for critical areas where further analysis is needed.

| Theme                                      | General Question                                                                 |
|--------------------------------------------|----------------------------------------------------------------------------------|
| Awareness and advocacy                     | What is the level of awareness and knowledge of earthquake disaster risk?         |
| Social Capacity                            | What are the capacities of the population to efficiently prepare, respond and recover from a damaging earthquake? |
| Legal and institutional arrangements        | How effective are mechanisms to advocate earthquake risk reduction in your quarter? |
| Planning, regulation and mainstreaming risk mitigation | What is the perceived level of commitment and mainstreaming of disaster risk reduction through regulatory planning tools? |
| Emergency preparedness, response and recovery | What is the level of effectiveness and competency of disaster management including mechanisms for response and recovery? |
| Critical services and public infrastructure resiliency | What is the level of resilience of critical services to disasters? |
5. Web-Based Platform Development

A web-based and open-source platform (WBP) can be an easy and effective way to apply large-scale risk assessments in regions prone to earthquakes, especially with a significant percentage of assets that are vulnerable to this natural hazard and where a large density of population exists such as the case of Algeria. This platform aims to provide stakeholders with accurate and reliable information regarding the true seismic risk that the Algerian society is exposed to, allowing stakeholders to produce, visualize and share information effectively to reduce risk.

Two major analyses will be implemented to assess the seismic risk in Algeria: 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 virtual event created by the user; or a probabilistic-based analysis, that assesses the probable seismic risk in Algeria.

These modules are intended to be incorporated in the WBP, and their outputs disseminated through several decision makers and the general Algerian society, in order to increase the awareness of the population and to reduce their risk and potential losses. Moreover, the Civil Protection of Algeria will be a special end-user of the WBP to manage the available resources in case of emergency, and to increase the preparedness for an earthquake event.

In terms of outputs, the platform will represent 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); human (fatalities, injured and homeless people) losses, damages in structures and economic losses. Likewise, the exposed assets, collected from the building inventory mobile app will also be represented

6. Conclusions

This paper provides a general overview of the development of an integrated seismic risk model for the Northern Algeria territory, using the municipality of Blida as first case study. A detailed framework including considerations around the different risk components: hazard, exposure and vulnerability, was presented.

The seismic hazard in Algeria is concentrated in the north of the country which is a predominantly active shallow crustal region. An updated model is currently being developed with the use of an earthquake catalog which contains earthquake events from A.D. 856 to 2017, which will be implemented with significant detail and using up-to-date tools.

The exposure model is created considering information from census data, as well as the use of a smartphone application which is used to obtain detailed and updated characteristics of the building inventory.

The physical vulnerability of the exposed assets will be calculated through the evaluation of the performance of synthetic sets of structures, represented by SDOF systems, subjected to multiple earthquake events through NLTH analysis. This process will allow the generation of fragility curves per building typology, which will in turn allow the assessment of the probability of occurrence of a damage state, given a level of ground shaking at a site.

The social vulnerability of the different social groups will be accounted for through the convolution of census-based indicators and the results obtained by the collection of a questionnaire, which will be applied to multiple individuals and stakeholders at the municipal level.

All the information derived for this risk model will be implemented in a WBP which will allow the calculation, visualization and storage of results of hazard and loss estimation scenarios.
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