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Probabilistic Seismic Damage for Existing RC Buildings Used for Educational Purposes

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Abstract: The objective of this research is to evaluate the seismic vulnerability of a collection of 55 reinforced concrete educational establishments, comprising approximately 516 buildings, located within the urban area of Mostaganem. Among them, 328 constructions were built in compliance with Algerian seismic regulations (Date > 1980 = 328 constructions), while 188 constructions were constructed prior to the implementation of seismic design codes (Date < 1980 = 188 constructions). This classification corresponds to the introduction and enforcement of the regulations following a significant earthquake in Chlef (El Asnam) in 1980.Using the RISK-UE lm1 method, the vulnerability index was determined through visual inspections of each building. An on-site inventory form was utilized to identify the main sources of seismic vulnerability, considering factors such as building typology, structural system, code adherence, maintenance condition, number of floors, plan and elevation irregularities, soil characteristics, and more. This approach allowed for the prioritization of buildings based on their specific vulnerabilities. The results obtained from this methodology were integrated into a Geographic Information System (GIS) environment, enabling a comprehensive understanding of the seismic behavior of the structures and facilitating the estimation of seismic risk levels. This integration also supports simulations and efforts to implement concrete preventive measures aimed at strengthening existing educational buildings, thereby reducing the potential negative consequences of future earthquakes.

Keywords: Seismic scenarios, Vulnerability, RISK-UE, Damage, Reinforced concrete buildings

Introduction

Mostaganem, a significant city in Northwestern Algeria, has undergone distinct phases of urban development throughout its history, including antiquity, Arab-Turkish influence, colonial era, and post-independence (Belhamissi, 1982). This historical context has resulted in a diverse range of building typologies within the city. The objective of this article is to present the outcomes of a comprehensive preliminary study focused on evaluating the seismic vulnerability and anticipated damage (seismic scenario analysis) of 45 reinforced concrete educational facilities, encompassing a total of 516 buildings situated within the urban boundaries of Mostaganem. This research is executed in two main stages:

1) Field investigations involved visual inspections of the school buildings to identify general sources of seismic vulnerability for the 516 existing reinforced concrete school structures (Giovinazzi & Lagomarsino, 2002). A diagnostic record was created for each building, containing information on building typology, technical design, topographical conditions, construction type, age of the building, number of floors, number of basements, history of structural damage and repairs, expansion projects, and other relevant data (Giovinazzi, 2005).

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2) The estimation of the average damage index for each structure was achieved using a semi-empirical relationship that correlates seismic hazard data with the estimated seismic vulnerability analysis. This research is grounded in the RISK-UE methodology and results in the definition of eight seismic scenarios representing the potential damage to buildings based on the European Macroseismic Scale EMS-98 (Grunthal, 1998).

With the aim of preserving the educational infrastructure in Mostaganem, this study focuses on assessing seismic risk by estimating the seismic vulnerability of reinforced concrete buildings. In this context, the RISK-UE method offers significant advantages, particularly concerning the expected functional damage. These findings should undoubtedly raise concerns among local authorities and prompt the initiation of rehabilitation and strengthening efforts for school buildings (Sabeur et al., 2023). The results obtained through this approach form a database detailing the potential damages to school structures, which are presented and integrated within a GIS environment.

Methodology for Estimating Vulnerability 'APPROCHE RISK-UE'

The RISK-UE lm1 method, also referred to as the macroseismic approach at level 1, is centered on the evaluation of a vulnerability index for a specific building. This index takes into consideration the building's construction type and various factors that can influence its behavior (CETE Méditerranée, 2008). Utilizing this index, vulnerability curves can be established based on the macroseismic intensity in accordance with EMS-98 (European Macroseismic Scale). This, in turn, allows for the assessment of the probability distribution of damage for the building. This method involves the identification of various states of deterioration for the structure and the evaluation of the likelihood of the structure being in different damage states at a given level of seismic ground motion (Mouroux & Le Brun, 2006; Mouroux et al., 2004).

Study Area

Our research is centered within the urban boundaries of Mostaganem and encompasses two distinct urban zones. One of these areas is the historic core, which includes historical structures, while the other area represents the city's expansion post-independence. The study area encompasses a total surface area of 20 square kilometers and extends with an average radius of 2.50 kilometers, as depicted in Figure 2.

The current study specifically focuses on 55 reinforced concrete educational facilities, which are part of a larger total of 516 buildings situated in the urban fabric of Mostaganem. This diverse area comprises buildings with various purposes, including 30 primary schools, 11 middle schools, 8 high schools, 3 universities, 2 vocational training centers, and 1 paramedical center.

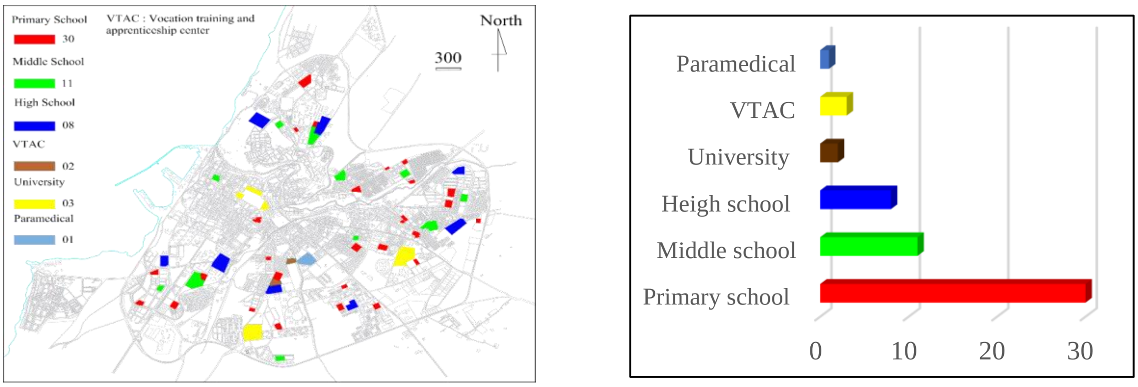


Figure 2. Spatial distributions/uses of educational buildings: (a) Localization of reinforced concrete (RC) existing buildings in the study area, (b) Categories of existing RC School Buildings.

The distribution of buildings in the study area, categorized by type, is visualized in Figure 2, revealing a notably high percentage of primary schools compared to other categories. These identified buildings span the entirety of the urban area within the city of Mostaganem. As a result, a comprehensive database has been constructed from this spatial distribution, addressing the educational requirements in the province of Mostaganem.

Results and Discussion

Estimation of Vulnerability Index

Based on visual assessment, the vulnerability index is calculated by considering 11 modifying factors of the studied buildings (Giovinazzi and Lagomarsino, 2004):

$$\overline{V_I} = V_I^* + \Delta V_R + \Delta V_m \tag{1}$$

The vulnerability index is associated with the building class (as shown in Table 4). ΔVR is a factor utilized to consider the characteristics of specific typologies at the regional level and is considered negligible in this study. ΔVm represents modifiers that depict how various typological parameters influence the seismic behavior of the building. Through visual assessment, four vulnerability typologies were examined for the reinforced concrete buildings in the study area (RC3.1, RC3.2, RC4, and RC5), with RC3.1 being the predominant category at 93.60%. This assessment of construction vulnerability (as presented in Table 1) can now be employed to evaluate and map the vulnerability of these structures using the RISK-UE methodology.

Table 1 presents the typology of RC buildings according to RISK-UE (Giovinazzi 2005).

RISK-UE type		Description	Number	(%)	∑(%)
RC Buildings	RC3.1	Regularly infilled walls	483	93,60	
	RC3.2	Irregular frames	14	2,71	
	RC4	RC Dual systems (RC frame and wall)	4	0,78	100
	RC5	Precast Concrete Tilt-Up Walls	15	2,91	
Total			516	100,00	

For a single building, the overall vulnerability index can now be obtained by summing up all the scores of modifying factors.

$$\Delta V_m = \sum V_m \tag{2}$$

Furthermore, surveys conducted in the study area in accordance with the requirements of the RISK-UE approach (Milutinovic and Trendafiloski (2003)) affect 52.13% of buildings with a vulnerability index of 0.30 < VI < 0.54 to vulnerability class D, 16.09% of buildings belonging to vulnerability class C (0.46 < VI < 0.70), and 40.70% of constructions are assigned to vulnerability class B (0.46 < VI < 0.70). Figure 3 shows the spatial distribution of the vulnerability index for pre-diagnosed educational buildings.

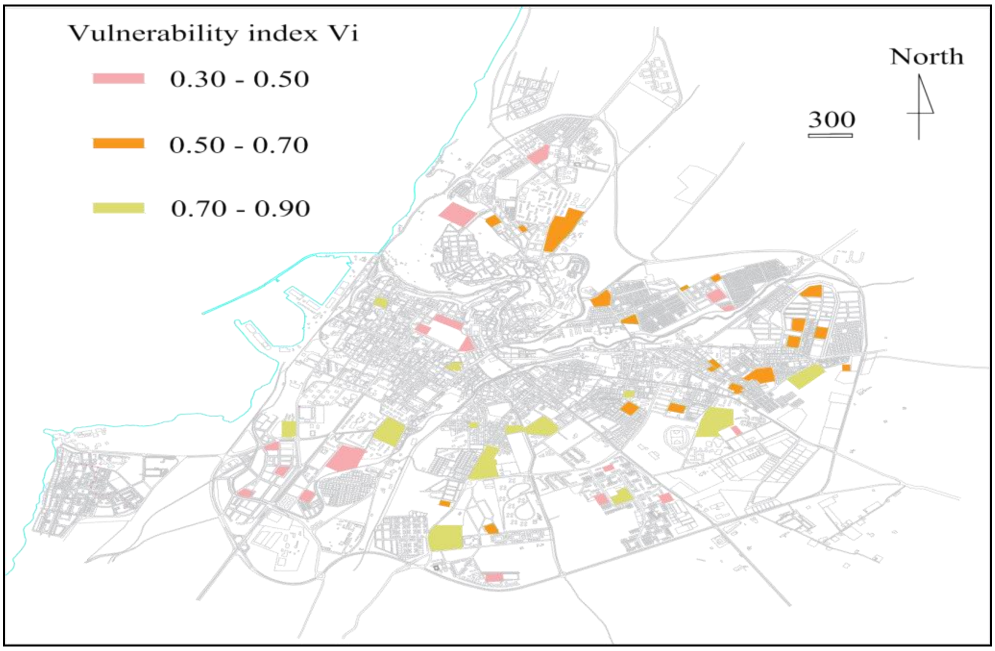


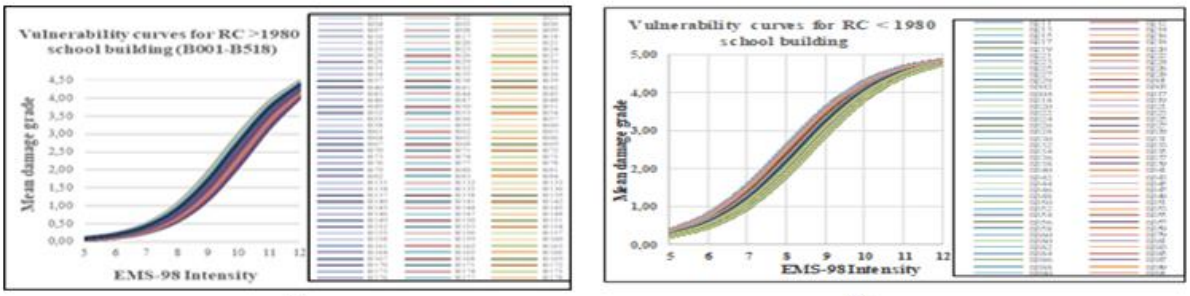
Figure 3. Spatial distribution of the vulnerability index using the RISK-UE method.

Estimation of average damage to educational buildings

The corresponding average damages, denoted as μD, are subsequently calculated by considering the macroseismic intensity I according to the EMS-98 scale and the vulnerability index V (as per Equation 3). μD falls within a range from 1 to 5, following the EMS-98 scale, which is divided into five classes (Giovinazzi 2005).

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I+6.25V_I-13.1}{2.3}\right)\right] \tag{3}$$

The fragility curves depicted in Figure 04 are produced using Equation N03, which correlates seismic hazard data (seismic intensity I) with the results obtained from the seismic vulnerability analysis (V).



(a) (b)

Figure 4. Mean Damage Grade Estimation School Building, (a) μD index for RC >1980, (c) μD index for RC<1980

Seismic Scenario Study

Seismic scenarios should be calculated using the beta distribution for each vulnerability class. This damage distribution function is defined as follows (basic equation of the beta distribution): The damage distribution is calculated using a beta distribution.
Probability density:

$$P_\beta(x) = \frac{\Gamma(t)}{\Gamma(t)\Gamma(t-q)}\;\frac{(x-a)^{q-1}(b-x)}{(b-a)^{t-1}} \qquad a \leq x \leq b \tag{4}$$

Cumulative distribution function:

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

Where: the beta distribution is parameterized by a, b, t, and q, and x represents the continuous random variable ranging between a and b. Γ is the gamma function. With the parameters: a = 0, b = 6, t = 8

$$q = t(\,0.007\,\mu_D{}^3 - 0.052\mu_D{}^2 + 0.28\mu_D) \tag{6}$$

Discrete probabilities: The probability pk associated with each damage degree k is expressed in the following form:

$$p_k = P_\beta(k+1) - P_\beta(k) \tag{7}$$

Fragility curve:
The fragility curve, which defines the probability of reaching or exceeding a damage level k, is directly obtained from the cumulative distribution function.

$$p(D \geq D_k) = 1 - P_k(k) \tag{8}$$

Seismic Scenarios for RC building

Analyzing Figure 5 for reinforced concrete structures built before 1980 reveals multiple seismic scenarios. In the first scenario, corresponding to an IEMS-98 intensity of 5.6, no significant damage is reported, and all structures remain intact at a D0 level of 100%. Subsequently, for an IEMS-98 intensity of 7, minor to light damage is expected, with 63.57% of constructions classified as D0 and 36.43% as D1. The seismic scenario resulting from an IEMS-98 intensity of 8 shows probable damage distributed across D0 (54.46%), D1 (9.11%), D2 (26.74%), and D3 (9.69%). The expected damage in this case ranges from negligible to moderate. As the seismic intensity reaches IEMS-98=9, moderate damage is predicted on the structural side, and heavy damage on the non-structural side, with 46.32% of the buildings classified as D1, 17.25% as D2, 13.57% as D3, and 22.87% as D4. The scenario assessed for an IEMS-98 intensity of 10 foresees heavy structural damage and very heavy non-structural damage, with a distribution of 21.71% in D2, 41.86% in D3, 10.85% in D4, and 25.58% in D5. As for the final scenario, which corresponds to an IEMS-98 intensity of 11, it is characterized by severe to total building damage, with 17.63% of structures classified as D3, 45.93% as D4, and 36.43% as D5. In the last scenario, corresponding to IEMS-98=12, all buildings experience total destruction (collapse), with 15.12% in D4 and 84.88% in D5.

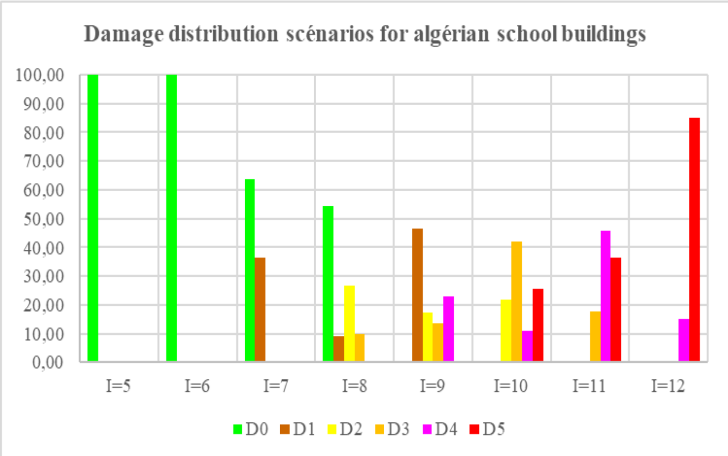


Figure 5. Synthesis of global damage scenarios for different EMS-98 Intensity

The key insight gleaned from the Geographic Information System, as depicted in Figure 5, is the significant variation in estimated damages across various intensities for all educational facilities.

Conclusion

The seismic scenarios obtained through the application of the RISK-UE method have been integrated and compared using a Geographic Information System (GIS). These scenarios will guide decision-makers in assessing the severity and extent of seismic risk for various types of existing buildings in Mostaganem or other cities in the country. This is aimed at implementing preventive measures and naturally reducing disaster risks by lowering vulnerability. Recommendations can be proposed to Algerian authorities to simulate and facilitate efforts aimed at taking concrete, specific prevention measures to enhance existing educational buildings, thus mitigating the adverse impact of future disasters.

Recommendations

At this juncture, we have arrived at the conclusion that it is of utmost importance for research to delve into how school buildings should function to ensure the safety of students in the aftermath of an earthquake. This research project represents just the initial phase and should be succeeded by further analysis, as we have pinpointed a substantial research avenue to explore based on the foundational findings from this initial phase of the work.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

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