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Seismic vulnerability assessment of bridges. The case of the Oran region, Algeria

Evaluación de vulnerabilidad sísmica de puentes. El caso de la región de Orán, Argelia

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ABSTRACT: The recent devastating earthquakes have revealed that bridges are one of the most vulnerable components of transportation systems. These seismic events highlighted the need to mitigate the risk resulting from the failure of bridges. This study aims to consider the seismic risk of an extensive heritage of existing civil engineering structures proceeding with prioritization. This imposes the need to consider the design of a geographic information system (GIS) based on the analysis of the different components of risk: hazard, vulnerability, and risk. The assessment of the seismic vulnerability of bridges integrates the various structural and non-structural components of bridges, taking into account their specificities in Algeria. The application of this approach to the Oran region has resulted in the development of a tool using a database to process as much geolocated information as possible, thus contributing to more efficient crisis management, and making it possible to avoid bridge damage and failures that can result in loss of life and monetary losses. This tool could also be used for the inspection of bridges as well as the optimal prioritization of preventive and corrective measures necessary before a major earthquake hits the bridge network in the Oran Region.

RESUMEN: Los devastadores terremotos recientes han revelado que los puentes son uno de los componentes más vulnerables de los sistemas de transporte. Estos eventos sísmicos destacaron la necesidad de mitigar el riesgo derivado de la falla de los puentes. Este estudio tiene como objetivo considerar el riesgo sísmico de un extenso patrimonio de estructuras de ingeniería civil existentes procediendo a la priorización. Esto impone la necesidad de considerar el diseño de un sistema de información geográfica (SIG) basado en el análisis de los diferentes componentes del riesgo: peligro, vulnerabilidad y riesgo La evaluación de la vulnerabilidad sísmica de los puentes integra los diversos componentes estructurales y no estructurales de los puentes, teniendo en cuenta sus especificidades en Argelia. La aplicación de este enfoque a la región de Orán ha dado como resultado el desarrollo de una herramienta que utiliza una base de datos para procesar la mayor cantidad posible de información geolocalizada, contribuyendo así a una gestión de crisis más eficiente y evitando daños en puentes y fallas que pueden resultar en pérdida de vidas y pérdidas monetarias. Esta herramienta también podría utilizarse para la inspección de puentes, así como para la priorización óptima de las medidas preventivas y correctivas necesarias antes de que un gran terremoto golpee la red de puentes en la región de Orán.

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1. Introduction

Bridges are a substantial and vital part of any transportation infrastructure system. Bridges, in particular, play an important role in modern transportation. They represent fundamental nodes of various road networks and the central mechanisms of

urban traffic [1, 2].
The earthquakes that hit the United States (San Fernando 1971, Loma Prieta 1989, Northridge 1994), Japan (Kobe 1995), and other regions around the world (El Asnam 1980, Costa Rica 1990, Kocaeli 1999, Taiwan 1999, Chili 2010) caused very significant damage to bridge structures, demonstrating their vulnerability to major earthquakes [3–7]. Because of these earthquakes, a large number of reinforced concrete and steel bridges were severely damaged or collapsed.

Among the major damage suffered by bridge structures during earthquakes, one reports, among other things [8]:

- The damage to bearings,
- The failure of the bents and piers,
- The rupture of the abutments serving as retaining walls,
- The collapse or subsidence of the embankment located at the bridge accesses.
  Various methods have been adopted to assess the seismic vulnerability of bridges:

1) Judgment methods based on the bridge response data obtained from expert opinions [9].
2) Empirical methods based on the damage statistics from past earthquakes, such as the study of bridge damage associated with earthquakes in Loma Prieta and Northridge [10].
Some studies used the earthquakes of Northridge and Kobe [11, 12], but other studies, only considered the Kobe earthquake [13, 14].
3) Analytical methods based on the development of the analytical bridge models. The ground motions with different levels of intensity are considered for the seismic simulation of bridge damage by performing numerous analyzes.

The results of the analysis are used to develop analytical fragility curves by determining the probability of exceeding a specified limit state of damage under a given intensity of ground motion. Various analytical procedures were followed in the development of fragility curves [15–25], ranging from the elastic analysis of equivalent systems with a single degree of freedom to the nonlinear time history analysis of 3D bridge models.
Several methods for assessing the seismic vulnerability of bridges have been developed around the world, such as:

- The American "CALTRAN" [26, 27] method developed by the California Department of Transportation, and "NYSDOT" developed by the same New York State Department in 1995. They use an algorithm for classifying bridges and viaducts to group structures according to their structural characteristics.
- The method of the Ministry of Transport of Quebec "MTQ-95". It allows calculating a numerical vulnerability index between 0 and 100 taking into consideration the seismic hazard.
- The "SISMOA" method developed by Roads Department, Roads and Motorways Technical Study service of France. This method called SISMOA consists in empirically determining the seismic risk of a bridge or viaduct [28].

Like countries with high seismicity, Algeria has a significant heritage of bridges whose operating period dates back several years. Most of these structures were built before the advent of earthquake-resistant calculation and design rules [29].

In addition, Algeria is characterized by a complex seismotectonic context and moderate seismic activity associated with the convergence between the African and Eurasian plates [30]. The region has experienced several destructive earthquakes in history, including the 1716 earthquakes in Algiers (the epicenter of the intensity, Io X), 1825 in Blida (Io IX), 1790 in Oran (Io XI), 1889 in Mascara (Io IX)), recently 1980 in El Asnam (Ms 7.3), 1989 in Tipasa (Ms 6.0), 1996 in Algiers (Ms 5.7), 1999 in Ain Temouchent (Ms 5.8), and more recently 2003 in Boumerdes (Ms 6.8) [31].

In Algeria, few studies on the vulnerability to earthquakes of bridges have been realized. However, it is clear that in the eventuality of another major earthquake in Algeria, the structural integrity of several bridges could not be ensured, especially since these structures of a certain age present very similar geometric and mechanical configurations to those damaged in earthquakes in California (San Fernando, 1971, San Francisco, 1989, and Northridge, 1994). However, it must be recognized that the Californian situation cannot be transposed directly to northern Algeria, because of differences in geological conditions and soil motions. Nevertheless, according to [32], numerous bridges can present deficiencies against significant seismic solicitations.

This article aims to develop a simple model to assess the seismic risk of existing bridges in Algeria. Due to the superior capabilities of spatial data processing, geographic information systems (GIS) technology is increasingly being considered for the implementation of infrastructure planning and management systems, including bridge management systems. A good seismic risk assessment of existing bridges is a necessary action to identify the most critical areas and assess the priorities for the reinforcement of bridges.

This article describes the use of a model to support the development of a system for assessing bridges against seismic risk, based on a geographic information system (GIS). The vulnerability index method was applied to assess the seismic risk of bridges in Oran city.

2. Methodology for assessing seismic risks and the vulnerability of bridges in Algeria

2.1 Methodology overview

The proposed Equation (1) conforms to the definition of seismic risk [33].

$$\text{IVS} = F_{\text{hazard}} * F_{\text{sogil}} * \text{vulnerability} \tag{1}$$

This formulation is inspired by the Canadian method MTQ2013 and adapted to the contexts and specificities of bridges in Algeria.
The seismic risk assessment of bridges in this method is based on the following steps (Figure 1):

1. Definition of the seismic hazard
2. Definition of the soil amplification effects
3. Definition of the global vulnerability of bridges

2.2 Seismic hazard and site effects

Seismic hazard is commonly defined as the probability of occurrence of a given seismic intensity during a certain period. A hazard factor is therefore calibrated according to the relative seismic hazard level. Table 1 gives the values of the hazard factor.
Three levels of relative seismic hazard are defined:

- Low if PGA ≤ 0.1 g;
- Moderate if $0.1\text{ g} < \text{PGA} \leq 0,4\text{ g}$
- High if PGA $> 0.4g$

Table 1 Definition of the hazard factor

PGA	F_{hazard}
≤ 0.1 g	1
$0.1\text{ g} < \text{PGA} \leq 0,4\text{ g}$	$1.75 + ((\text{PGA} - 0.1)/0.3) * 0.5$
$> 0.4g$	2.5

In general, when designing or evaluating a structure, the amplification effect is considered by an amplification factor applied to the design spectral acceleration or the seismic hazard parameter. The amplification effect of the seismic wave depending on the category of seismic location, is taken into account by a soil factor. The Soil factor is therefore calibrated according to the category of the site. Table 2 gives the values of the Soil factor.

Table 2 Definition of the soil factor

Site Category	Description	F_{Site}
S1	Rock	1
S2	Stiff soil	1.1
S3	Soft soil	1.15
S4	Very soft soil	1.25

2.3 Global vulnerability of bridges

Combined vulnerability factors $\mathrm{V}_{\text{General}}$, $\mathrm{V}_{\text{Superstructure}}$ and $\mathrm{V}_{\text{Infratructure}}$, respectively, represent the vulnerability related to the general characteristics of the structure, to the superstructure, and to the infrastructure, as shown by Equation 2.

$$\begin{aligned} \text{Vulnerability} &= V_{\text{General}} * \\ &(8 + V_{\text{Superstructure}} + V_{\text{Infrastructure}}) \end{aligned} \tag{2}$$

General vulnerability

The general vulnerability factor depends mainly on the type of structure to which the coefficient $\mathrm{C}_{\text{Struct}}$ (type of structure), the date of construction of the C_{Age} bridge, and its state of damage $\mathrm{C}_{\text{Endom}}$ are associated and shown in Equation 3

$$\begin{aligned} \mathrm{V}_{\text{General}} &= \mathrm{C}_{\text{struct}}\,\mathrm{X} \\ &[1 + \alpha_{\text{Age}} \times \mathrm{C}_{\text{Age}} + \alpha_{\text{Endom}} \times \mathrm{C}_{\text{Endom}})] \end{aligned} \tag{3}$$

The characteristics of bridges in Algeria are associated with the distinct periods described below, as shown in figure 2.

- Before 1980: This period is characterized by the construction of masonry bridges, steel bridges, and reinforced concrete bridges without any earthquake design.
- Between 1980 and 2008: This period is characterized by the introduction of earthquake-resistant design. The El-Asnam earthquake of October 10, 1980 is the main reason for its application. During this interval, the earthquakes that occurred in Algeria did not have an important intensity and did not significantly affect the structures. It was considered that the new Algerian Seismic Regulations RPA for the seismic calculation of the structures was satisfactory.
- After 2008: Bridge construction has come in a new period. The public works sector has been provided with specific seismic regulations (RPOA) for the design of engineering structures.

Superstructure vulnerability

The vulnerability factor of the superstructure depends on the length of support availablen $C_{Support\_length}$, the bearing type $C_{Bearing}$, the discontinuities numbers of C_{Joint} and the beams numbers C_{Beam} and some design peculiarities. $V_{Superstructure}$ is given by the following

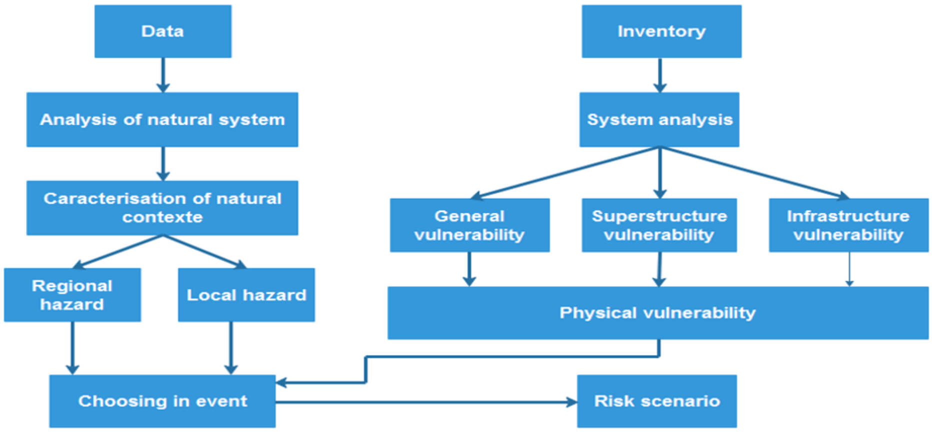

Figure 1 Flowchart of the methodology for conducting a seismic scenario

Figure 2 Typical bridges in Algeria

Equation (4).

$$\mathrm{V}_{\text{Superstructure}} = [\alpha_{\text{Support\_length}} \times \mathrm{c}_{\text{Support\_length}} + \alpha_{\text{Bearing}} \times \mathrm{c}_{\text{Bearing}} + \alpha_{\text{Joint}} \times \mathrm{c}_{\text{Joint}} + \alpha_{\text{Beam}} \times \mathrm{c}_{\text{Beam}} + \alpha_{\text{Part}} \times \mathrm{c}_{\text{Part}}] \quad (4)$$

Infrastructure vulnerability

The vulnerability factor of the infrastructure considers that the loss of a bent or abutment can lead to taking the bridge out of service. $V_{Infrastructure}$ is therefore established as the maximum value between the vulnerability factors of abutments $\mathrm{V}_{\text{Abutement}}$ and piers V_{Piers} as given in Equation (5).

$$\mathrm{V}_{\text{Infrastructure}} = \mathrm{Max}\,(\mathrm{V}_{\text{Abutement}}\, \mathrm{V}_{\text{Piers}}) \quad (5)$$

The vulnerability factor of the abutments depends on the abutment type, $C_{abutment\_type}$, the abutment foundation type, $C_{abutment\_foundation}$ and the soil nature below the abutment, $C_{Soil\_abutement}$. $V_{abutment}$ is given by the following Equation (6).

$$\mathrm{V}_{\text{Abutement}} = [\alpha_{abutment\_twpe} \times \mathrm{C}_{abutment\_tape} + \alpha_{abutment\_foundation} \times \mathrm{C}_{abutment\_foundation} + \alpha_{Soil\_abutement} \times \mathrm{C}_{Soil\_abutement}] \quad (6)$$

The vulnerability factor of the bents depends on the bent type, C_{Peir_type}, the bent foundation type, $C_{Fondation\_Peir}$, and the soil nature under the bent, C_{soil_Peir} and the vertical irregularity, C_{Irreg}. V_{Peir} given by the next Equation (7).

$$\mathrm{V}_{Bent} = [\alpha_{Peir\_type} \times C_{Bent\_type} + \alpha_{Fondation\_Peir} \times C_{Fondation\_Peir} + \alpha_{soil\_Peir} \times C_{soil\_Peir} + \alpha_{Irreg} \times C_{Irreg}] \quad (7)$$

3. Application of the proposed methodology

3.1 The study area

Oran, Algeria's second city after the capital Algiers, is located in the northwest of the country on the shores of the Mediterranean Sea, as shown in Figure 3. Oran is an important economic and industrial pole, rich in history and architecture.

This study takes into account local hazard data immediately available through the geological map. This is a first-level microzoning, as shown in Figure 4.

3.2 Seismic hazard and classification soil

Seismic hazard is a function of two factors, the intensity of ground motion and soil amplification, that represent the seismicity of a region and the Geotechnical site characterization of the bridge site, respectively. Hence, the

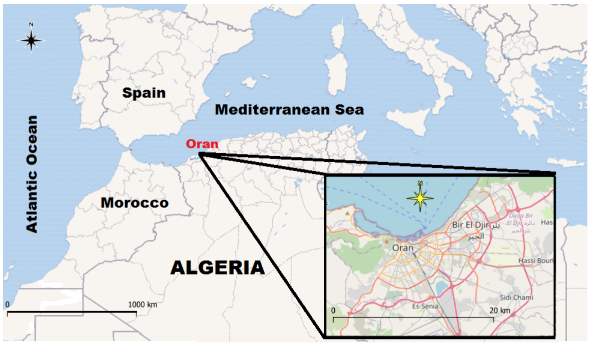

Figure 3 Study area identification

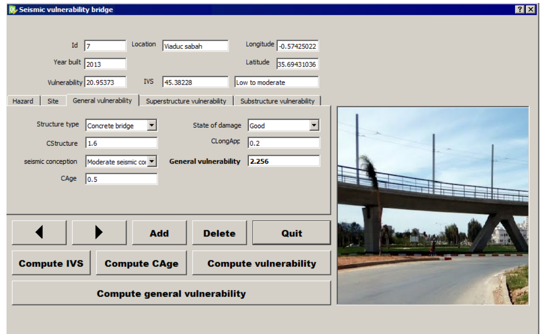

Figure 5 Typical structural performance form for the bridges

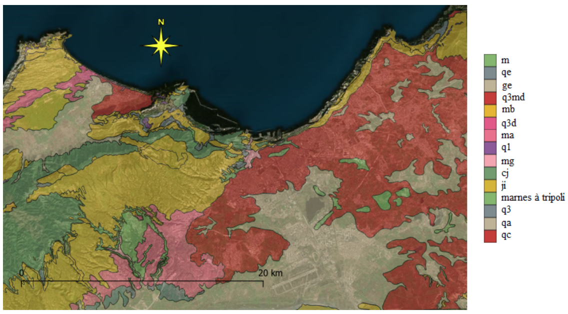

Figure 4 Geology-based zonation for the sub-regional area

peak ground acceleration (PGA- rock) for the bridge site (A) is defined to measure the seismic hazard. It is modified by the site coefficient (S) to express soil amplification effects.

3.3 Developed database and bridge information model

To perform the analysis of the seismic vulnerability, information on the bridge stock is necessary. The data for each bridge contains the following information: General information (localization, age, etc.); Seismic Design:

- Number of spans: single vs. multiple span bridges
- Structure type: concrete, steel others
- Pier type: multiple column bents, single column bents and wall piers
- Abutment type and bearing type

Data on these bridges have been digitized in a database through the investigation forms. The methodology can be applied in digital form, as shown in Figure 5. Survey information is stored in a table database. It is accessed by programs to calculate load factors for each bridge. Then we chose the combination of factor index. Finally, we calculate the vulnerability class.

The objective is to centralize all the bridge information in a database that allows the management of all the elements of the infrastructure throughout its entire lifecycle. The designed application can, like BIM tools, provide a robust platform for communication and information sharing among all stakeholders [34]. The survey of the inventory of existing bridges aims to obtain data on the distribution of bridge types (Figure 6). The results of this survey are:

- Most of the bridges are made of reinforced concrete;
- Most reinforced concrete bridges were built according to a pre-code without any seismic consideration.

A GIS was used to perform a comprehensive seismic vulnerability analysis of the bridges. The relational database containing the bridge inventory is integrated into the designed GIS.

4. Results and discussions

Figure 7 shows the soil classification map. The interest of this map appears in the preliminary classification of all the bridges in the study area, which can be easily performed, using the site classification system.

The statistical analysis of the results obtained in Figure 8 shows that 77 bridges out of the 120 bridges studied were built on soft soil (S3). In addition, the results show that there are two bridges built on S1 sites. Thirty -nine bridges were built on stiff soil (S2). Three bridges were built on very soft soil (S4). This is due to the soil composition of the city of Oran, mainly composed of unconsolidated deposits, as shown in Figure 2 (recent alluvial formations). The nature of the soil and the effects of resulting sites significantly contribute to increasing the seismic vulnerability of structures. The behavior of the 120 bridges is estimated for two scenarios of earthquakes characterized by their Mean PGA values [30] in Oran city:

Earthquake for 100 years of the return period (PGA= 0.068g)

Earthquake for 475 years of the return period (PGA=0.138g)

The variation of the IVS index for the different bridges built on the soft soil is analyzed according to the level of seismic hazard as shown in Figure 8. The distribution of IVS indexes also analyzed according to the number of spans.

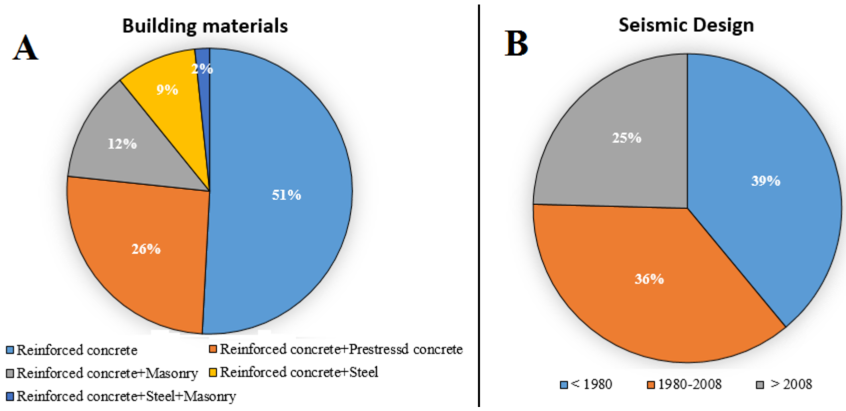

Figure 6 (A) Building materials and (B) seismic design of the bridges in the study area

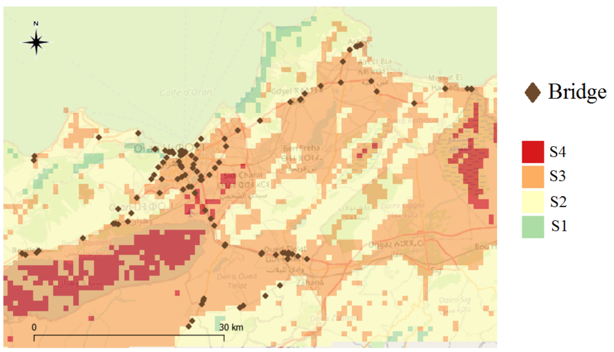

Figure 7 Bridges inventory and classification of soil in the study area

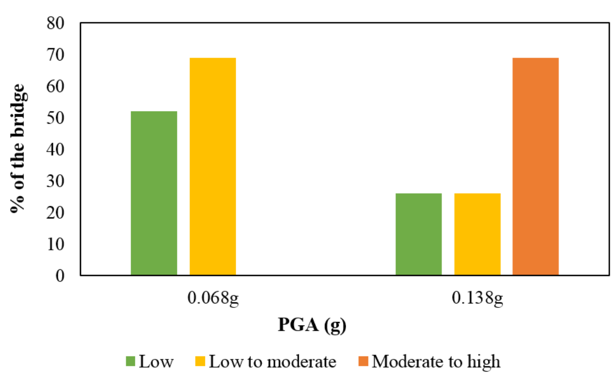

Figure 8 The distribution of the index vulnerability of the bridges for 100 and 475 years return periods

Following the used methodology, in the case of an earthquake for a 100 years return period (PGA = 0.068g), 100% of the structures have an IV index less than 50. It varies from 6.76 to 34.99 for the different bridges built.
- The IVS index ranges from 6.76 to 31.67 for single-span bridges and from 7.17 to 34.88 for multi-span bridges 6.78 to 34.99.
Figure 9 indicates that the seismic vulnerability of the analyzed bridges varies from low to moderate for a return period of 100 years.

In the case of an earthquake for a 475 years return period (PGA=0.138g), 42.97 % of the structures have an IVS lower than 50. It varies from 13.53 to 69.98 for the different bridges. IVS index ranges from 13.53 to 63.34 for single-span bridges and from 13.57 to 69.98 for multiple-span bridges.
Note that all the bridges with an IVS index exceeding 50 were built before 2008.

Figure 10 indicates that 57.02% of the bridges analyzed have a vulnerability varying from moderate to high for a return period of 475 years.

5. Conclusion

The estimation of the seismic risk of the existing bridges in Oran city was the opportunity to design a GIS based on the analysis of the different components of the risk: the seismic hazard, the effects of the lithological site, and the vulnerability of the various structures. This can be an important element in setting up crisis prevention and management plans in a more efficient manner, thereby avoiding errors that are difficult to repair in the future.

The data necessary for the application of the method are simple and scalable, allowing a rapid estimate of the seismic risk of bridges, but the result involves a large uncertainty that is difficult to quantify. The limitation of the method lies in the fact of considering only the PGA of the earthquake defined either in a deterministic or probabilistic manner instead of the full spectrum of the movement of the ground, whereas the resonance phenomena observed during the earthquake are at specific frequencies, depending on the site and the bridges.

Nevertheless, the study presented here gives a first

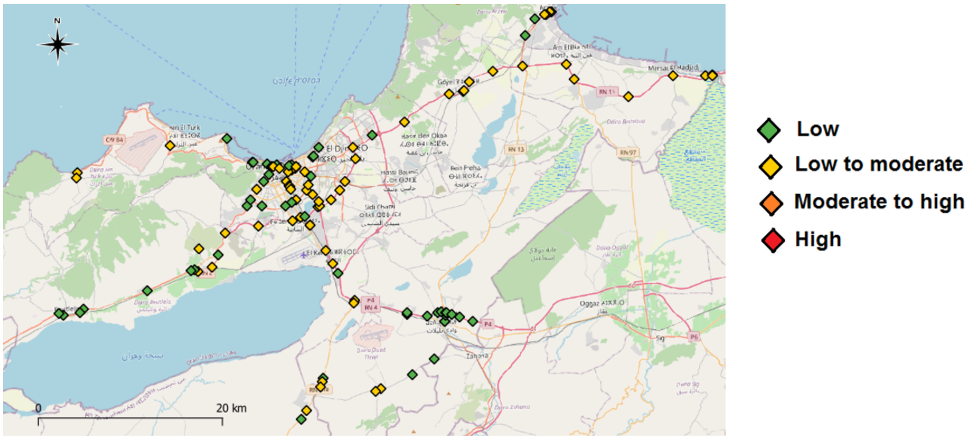

Figure 9 Map of seismic vulnerability of bridges for 100 return period

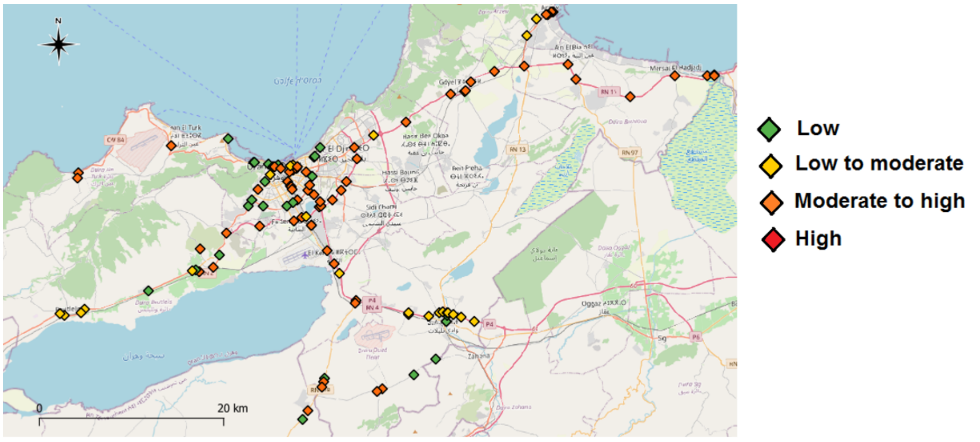

Figure 10 Seismic vulnerability of bridges for a return period of 475 years.

idea of what an earthquake could cause in the city of Oran for return periods of 100 years and 475 years. The results revealed that most bridges are built on soft soil, causing an increase in their vulnerabilities due to the amplification of the seismic action.

A more thorough analysis would make it possible to estimate the seismic risk on a large heritage of existing bridges by a process of prioritization. Knowing that the decision to reinforce the road itineraries, and therefore the structures that compose them, in the face of earthquakes, is usually based on the comparison between the cost of reinforcement and the losses resulting from an earthquake.

6. Declaration of competing interest

We declare that we have no significant competing interests, including financial or non-financial, professional, or personal interests interfering with the full and objective presentation of the work described in this manuscript.

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9. Author contributions

Fatima Zohra BABA HAMED built the design, data analysis and writing of the article. Farid RAHAL built the design and writing of the article. Farida GUENANOU was responsible for data collection.

10. Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article [and/or] its supplementary materials.

References

[1] C. A. Riveros-Jerez, "Structural health monitoring methodology for simply supported bridges: numerical implementation," *Revista Facultad de Ingeniería Universidad de Antioquia*, no. 39, Mar. 2007. [Online]. Available: http://www.scielo.org.co/scielo.php?pid=S0120-62302007000100004&script=sci_arttext&tlng=en

[2] E. Eduardo, "Estudio de las causas del colapso de algunos puentes en colombia," *Ingeniería y Universidad*, vol. 6, no. 1, pp. 33–47, Ene-Jun 2002.

[3] D. L. Anderson, D. Mitchell, and R. G. Tinawi, "Performance of concrete bridges during the hyogo-ken nanbu (kobe) earthquake on january 17, 1995," *Canadian journal of civil engineering*, vol. 23, no. 3, Jun. 1996. [Online]. Available: https://doi.org/10.1139/l96-884

[4] D. Mitchell, R. Tinawi, and R. G. Sexsmith, "Performance of bridges in the 1989 loma prieta earthquake–lessons for canadian designers," *Canadian Journal of Civil Engineering*, vol. 18, no. 4, Aug. 1991. [Online]. Available: https://doi.org/10.1139/l91-085

[5] D. Mitchell, S. Huffman, R. Tremblay, M. Saatcioglu, D. Palermo, and *et al.*, "Damage to bridges due to the 27 february 2010 chile earthquake," *Canadian Journal of Civil Engineering*, vol. 40, no. 8, Jun. 06, 2012. [Online]. Available: https://doi.org/10.1139/l2012-045

[6] M. Yashinsky, "Performance of bridge seismic retrofits during northridge earthquake," *Journal of Bridge Engineering*, vol. 3, no. 1, Feb. 1998. [Online]. Available: https://doi.org/10.1061/(ASCE)1084-0702(1998)3:1(1)

[7] M. N. Priestley, F. Seible, and G. M. Calvi, *Seismic design and retrofit of bridges*. New York, NY: John Wiley & Sons, 1996.

[8] M. J. N. Priestley, F. Seible, and C. M. Uang. (2011, Mar.) The northridge earthquake of january 17, 1994: Damage analysis of selected freeway bridges. University of California. San Diego, CA.

[9] A. T. Council. (1983) Seismic retrofitting guidelines for highway bridges. Applied Technology Council. United States.

[10] A. A. Kiremidjian and N. I. Basöz, "Evaluation of bridge damage data from recent earthquakes," *Bulletin NCEER*, vol. 11, no. 2, pp. 1–7, Apr. 1997.

[11] M. Shinozuka, Y. Murachi, X. Dong, Y. Zhou, and M. J. Orlikowski, "Effect of seismic retrofit of bridges on transportation networks," *Earthquake Engineering and Engineering Vibration*, vol. 2, Nov. 21, 2003. [Online]. Available: https://doi.org/10.1007/s11803-003-0001-0

[12] A. S. Elnashai, B. Borz, and S. Viachos, "Deformation-based vulnerability functions for rc bridges," *Structural Engineering and Mechanics*, vol. 17, no. 2, Oct. 01, 2003. [Online]. Available: https://tinyurl.com/37u94nfy

[13] F. Yamazaki, H. Motomura, and T. Hamada, "Damage assessment of expressway networks in japan based on seismic monitoring," in *12th world conference on earthquake engineering*, Japan, 2000. [Online]. Available: https://www.iitk.ac.in/nicee/wcee/article/0551.pdf

[14] M. Shinozuka, M. Q. Feng, J. Lee, and T. Naganuma, "Statistical analysis of fragility curves," *Journal of Engineering Mechanics*, vol. 126, no. 12, Dec. 2000. [Online]. Available: https://doi.org/10.1061/(ASCE)0733-9399(2000)126:12(1224)

[15] J. B. Jernigan and H. Hwang, "Development of bridge fragility curves," in *7th US National Conference on Earthquake Engineering*, Boston, MA, 2002.

[16] J. B. Mander, A. Dutta, and P. Goel, "Capacity design of bridge piers and the analysis of overstrength," Multidisciplinary Center for Earthquake Engineering Research (MCEER), Buffalo, NY, Tech. Rep. MCEER, 98-0003, Jun. 1998.

[17] J. B. Mander and N. Basöz, "Seismic fragility curve theory for highway bridges," in *Optimizing post-earthquake lifeline system reliability*, W. M. Elliott and P. McDonough, Eds. ASCE, 1999, pp. 31–40.

[18] J. B. Mander and C. T. Cheng, "Replaceable hinge detailing for bridge columns," *International Concrete Abstracts Portal*, vol. 187, Jan. 06, 1999. [Online]. Available: https://doi.org/10.14359/5599

[19] G. Monti and N. Nisticò, "Simple probability-based assessment of bridges under scenario earthquakes," *Journal of Bridge Engineering*, vol. 7, no. 2, Mar. 2002. [Online]. Available: https://doi.org/10.1061/(ASCE)1084-0702(2002)7:2(104)

[20] S. Banerjee and M. Shinozuka, "Nonlinear static procedure for seismic vulnerability assessment of bridges," *Computer AIDED Civil and Infrastructure Engineering*, vol. 22, no. 4, May 2007. [Online]. Available: https://doi.org/10.1111/j.1467-8667.2007.00486.x

[21] H. Hwang, J. B. Liu, and Y. H. Chiu, "Seismic fragility analysis of highway bridges," Center for Earthquake Research and Information, Memphis, TN, Tech. Rep. MAEC RR-4, Jul. 2001.

[22] K. R. Karim and F. Yamazaki, "A simplified method of constructing fragility curves for highway bridges," *Earthquake Engineering & Structural Dynamics*, vol. 32, no. 10, Aug. 2003. [Online]. Available: https://doi.org/10.1002/eqe.291

[23] D. H. Choi, S. G. Gwona, H. Yoo, and H. S. Na, "Nonlinear static analysis of continuous multi-span suspension bridges," *International Journal of Steel Structures*, vol. 13, Apr. 11, 2013. [Online]. Available: https://doi.org/10.1007/s13296-013-1010-0

[24] F. Nateghi and V. L. Shahsavar, "Development of fragility and reliability curves for seismic evaluation of a major prestressed concrete bridge," in *13th World Conference on Earthquake Engineering*, Vancouver, BC, 2004. [Online]. Available: https://www.iitk.ac.in/nicee/wcee/article/13_1351.pdf

[25] K. Mackie and B. Stojadinovic, "Fragility curves for reinforced concrete highway overpass bridges," in *13th World Conference on Earthquake Engineering*, Vancouver, BC, 2004. [Online]. Available: https://www.iitk.ac.in/nicee/wcee/article/13_1553.pdf

[26] *Seismic Vulnerability Manual*, New York State, Department of Transportation, New York, NY, 1995. [Online]. Available: https://tinyurl.com/2eucbs5t

[27] B. Maroney and J. Gates, "Seismic risk identification and prioritization in the caltrans seismic retroft program," in *4th U.S.-Japan Workshop on Earthquake Disaster Preventionfor Lifeline Systems*, Japan, 1992, pp. 55–75.

[28] D. Davi and P. Schmitt, "Sismoa: une méthode d'estimation rapide de la vulnérabilité des ponts aux séismes," in *Annales du bâtiment et des travaux publics*, Paris, 2003, pp. 19–27.

[29] A. Kibboua, M. Naïli, and D. Benouar, "Méthode d'estimation de la vulnérabilité sismique des ponts à poutres isostatiques en béton armé," in *9ème Colloque National AFPS*, Marne-La-Vallée, 2015.

[30] J. A. Peláez, M. Hamdache, and C. L. Casado, "Seismic hazard in terms of spectral accelerations and uniform hazard spectra in northern algeria," *Pure and Applied Geophysics*, vol. 163, May 10, 2005. [Online]. Available: https://doi.org/10.1007/s00024-005-0011-0

[31] F. Z. Baba-Hamed, D. D. Rahal, and F. Rahal, "Seismic risk assessment of algerian buildings in urban area," *Journal of Civil Engineering and Management*, vol. 19, no. 3, Jun. 14, 2013. [Online]. Available: https://doi.org/10.3846/13923730.2012.744772

[32] A. Kibboua, H. Bechtoula, Y. Mehani, and M. Naili, "Vulnerability assessment of reinforced concrete bridge structures in algiers using scenario earthquakes," *Bulletin of earthquake engineering*, vol. 12, Sep. 25, 2013. [Online]. Available: https://doi.org/10.1007/s10518-013-9523-7

[33] A. Khaled, M. J. Nollet, and A. Lemaire, "Étude de sensibilité des paramètres pour l'évaluation de la vulnérabilité sismique des ponts en vue de la calibration de la méthodee," Ministere des Transport Du Québec, Québec, Tech. Rep. R628.1, Mar. 2013.

[34] F. Rahal and Z. Hadjou, "Information system for parametric architecture, dedicated to spaces allocation," *Urbanism. Arhitectură. Construcții*, vol. 4, pp. 337–346, Sep. 2018.