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RAPID EARTHQUAKE LOSS ASSESSMENT MODEL FOR ALGERIAN BUILDING CONTEXT

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Abstract

Algeria is one of the countries that have experienced several strong to moderate earthquakes during the last decades. The experience of these events showed that the elaboration of adequate intervention measures was done after the first in situ inspections, which may take long time to provide information and therefore decreases the chance to find survivors. This delay is due to the lack of different means to locate quickly, at the early hours, the affected areas and due also to the uncertain alarm level to be given. In order to enhance the rapid response and emergency operation, disaster mitigation measures can be done.

The present work consists on a development of an integrated rapid earthquake loss assessment model. The main motivation through this development is the ability to estimate the probable seismic damage and their spatial distribution in an affected area by a potential earthquake, according to the existing building context in Algeria. This framework based on the Algerian building seismic damage assessment approach is integrated in a data-processing code developed for this purpose. In the implementation of this framework, a Geographical Information System (GIS) is used. The elaborated concept allows the automation of calculation and the quick data treatment with the generation of the seismic damage maps. It is used, in one hand, to make a predictive estimating of the earthquake damage which can occur in an urban area subjected to the seismic risk, through a probable earthquake scenario, enabling to take the adequate preventive measures. In the other hand, it can be used to give in real time, an estimating of the post-seismic damage, after a disaster occurrence, once the epicentre localised and the magnitude known, as it allows a quick survey of the disaster extends in the more affected areas, which would help to know the level of alarm to be given and the necessary emergency facilities to be mobilised. This model arises as a decision-making tool which constitutes a contribution in the urban planning field and crisis management in Algeria. A case study of the implementation of the developed model in the urban centre of Blida city is presented.

Keywords: Algerian buildings, loss assessment model, GIS, seismic risk mitigation, decision-making, Blida, preparedness.

1. Introduction

The assessment of damage that can be caused by a major earthquake, constitute a key step for the seismic risk reduction in subjected areas which requires to understand and to know the situation which will occur after the phenomenon. Several worldwide loss estimation models related to seismic risk have been developed and updated during the last decades, such as Hazus-MH model (Hazard-United states) [1, 2], RADIUS tool (Japan) [3], the European model Risk-EU [4], the Istanbul Earthquake Rapid Response System [5], the Seismic Alert System developed for Mexico city (SAS-Mex) [6], the SISMAN-LISA developed for the city of Manizales in Colombia [7], the Natural Hazards Electronic Map and Assessment Tools Information System (NHEMATIS) developed in Canada [5]. More recently, other models were developed like CAPRA (Central American Probabilistic Risk Assessment) Model [8], Global Earthquake Model (GEM) [8] and SYNER-G Model [9].

In Algeria, the experience of past earthquakes, such as those of El-Asnam in 1980 and Boumerdès in 2003, showed that the quantification of the damage extent in the affected areas and the elaboration of adequate intervention measures was done after the first in situ inspections, which may take long time to provide information and therefore decreases the chance to find survivors. In addition, considerable financial losses can be generated in mobilizing emergency resources and crisis management in case of delay to locate the affected areas and to the uncertain level of alarm to be given.

Therefore, it proves to be necessary to have seismic risk mitigation strategies and to develop a seismic damage prediction and assessment process in Algeria, as a decision-making tool for public authorities, civil protection managers, planning and urban or regional development managers, etc. in order to avoid disasters in the human and economic levels during a possible earthquake which could affect this region.

As part of this work, we focus on the development of a rapid earthquake loss assessment model according to the Algerian building context.

On the one hand, this model allows the prediction of the damage that can occur in an urban area exposed to seismic risk, assuming a probable earthquake scenario; the results may constitute the rigorous and objective support allowing to take suitable preventive measures for risk mitigation.

And in other hand, in the post-seismic assessment step, it can give an evaluation of the post-seismic damage in real time, in a few moments after a real earthquake, when the epicentre is located and the magnitude is known. The results would then make out the most affected areas, which would help to define the alarm level to be given and be able to mobilise adequate emergency means. These results are posted on Web site and sent in near real-time to emergency responders, civil protection and decision makers by email.

An application of the tool thus developed will be performed to estimate plausible seismic damage may occur in the urban centre of Blida city potentially exposed to seismic risk in Algeria.

2. Development of the Model

The development of the rapid earthquake loss estimation model for building in Algeria was performed in programming language (Dotnet), it uses the database management system (Microsoft Access) as read data platform of existing buildings, analyses and displays the results of seismic damage (see Fig.1).

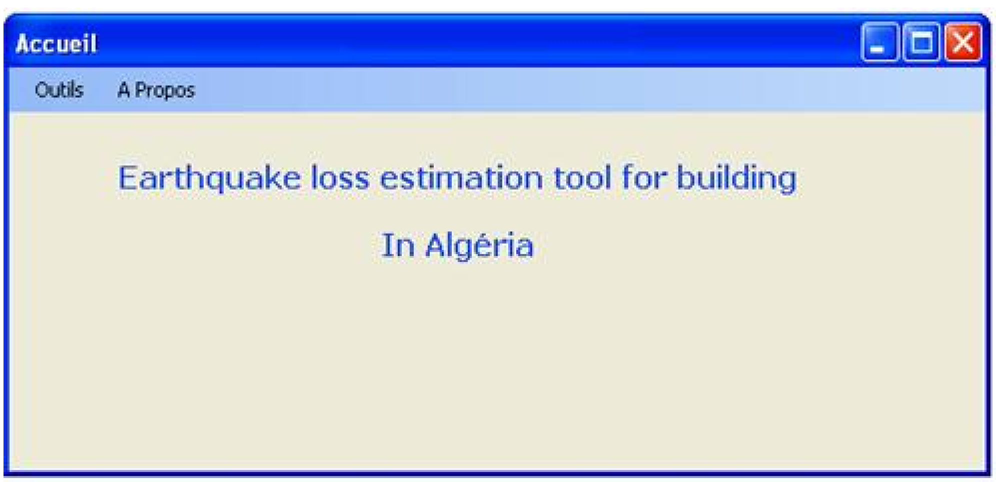


Fig. 1 – Main menu interface of the rapid earthquake loss estimation model for building in Algeria « RELEM-Algeria »

This model is based on the automation of the seismic damage assessment methodology developed according to the existing buildings context in Algeria [1, 2], the procedure is summarized in Fig.2.

The developed tool directly interacts with a geographical information system (GIS) to ensure the automatic display of results and generation of synthetic damage maps. These maps are a relevant and quantitative support and would be a great help for authorities and crisis managers as support for decision making. They allow to identify the most affected areas by a potential earthquake, buildings may have been seriously damaged, detection of industrial installations could be in danger or constitute a danger by cascade phenomenon and require rapid intervention to rescue the occupants and minimize induced effects (explosions, fires, etc.), identification of interventions centres and hospitals near the disaster areas in order to accelerate the victims rescue. They also give an overview of the roads to be taken to save time in the emergency intervention, etc.

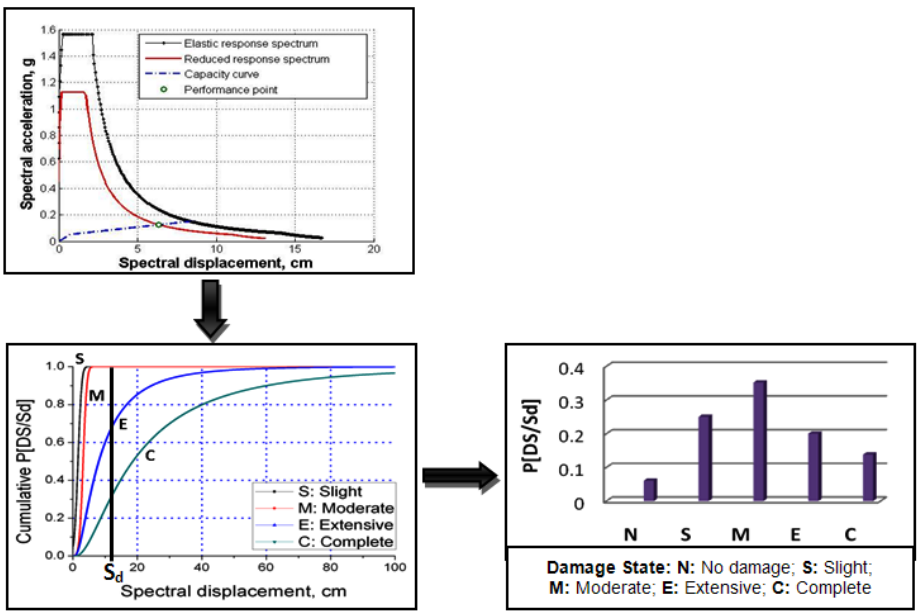


Fig. 2 – Schematization of the seismic damage estimation process of existing buildings in Algeria [1, 2]

This model is presented as a relevant support for decision-making, in terms of earthquakes and their effects in Algeria, which is a contribution in the field of urban planning and crisis management in Algeria.

The architecture of this model is organized into five interrelated categories (see Fig.3) which are described and detailed below.

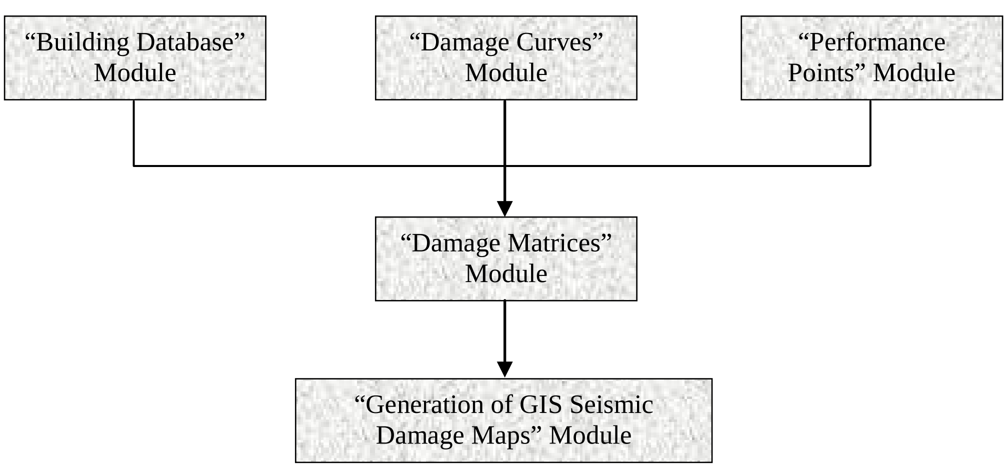


Fig. 3 – Flow chart of the Rapid earthquake loss estimation model for building in Algeria

2.1 Module "Building Database"

This module (see Fig.4) is dedicated to the digitization of buildings data collected on site, after an inventory campaign and pre-seismic survey using a building identification and evaluation form developed for this purpose, as shown in Fig.5.

The developed database of existing building is automatically organised hierarchically in order to respect the building classification developed in the seismic damage assessment methodology according to the existing buildings in Algeria [1, 2].

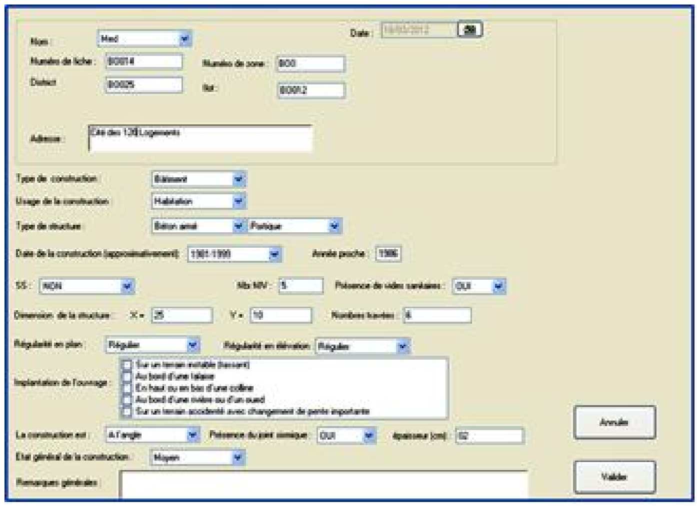


Fig. 4 – Building data-base Module Interface

National Earthquake Engineering Research Centre (CGS)

BUILDING INVENTORY FORM

Name:…………………… Date……/……/…….
N° of inventory form:……..
District:………………..
Islet: ……………….
Address: …………………………………………

Construction Type:
Building ☐ Single house☐ Hangar ☐ Mosque ☐ Precarious ☐
Other (precise) ………………

Construction Use:
Dwelling ☐ Hospital ☐ Commercial ☐ Administrative ☐ Sports ☐
Industrial ☐ School ☐ Socio-cultural ☐ Hydraulic ☐
Other (precise)………………

Structure Type:
Reinforced concrete ☐ Masonry ☐ Steel ☐ Wood ☐
Other (precise)………………
If Reinforced concrete: Moment frame ☐ Shear wall ☐ Dual ☐

Date of construction (approximately):
Before 1981 ☐ 1981-1999 ☐ 1999-2003 ☐ After 2003 ☐
Number of stories: Number of basement:
Existence of under floor space: Yes ☐ No ☐
Dimension of the structure: X =………m, Y=………m, Nb of bays:…
Plane regularity: Regular ☐ Light irregularity ☐ Irregular ☐
Elevation regularity: Regular ☐ Light irregularity ☐ Irregular ☐

Building implantation:
- On an unstable ground (settlement) Yes ☐ No ☐
- At the edge of a cliff Yes ☐ No ☐
- At top or bottom of a hill Yes ☐ No ☐
- At the border of a river Yes ☐ No ☐
- On a rough ground with break of significant slope Yes ☐ No ☐

Construction is at: Corner ☐ Middle ☐ Isolated ☐
If existence of seismic joint:………… (Thickness):………cm

General state of the construction:
Good ☐ Average ☐ Bad ☐

General observations:

Fig. 5 – Building inventory form used

The digitised data for each building are stored in a Microsoft Access database format and are linked with the graphic entities of buildings on a Geographic Information System (GIS) platform as shown in Fig.6.

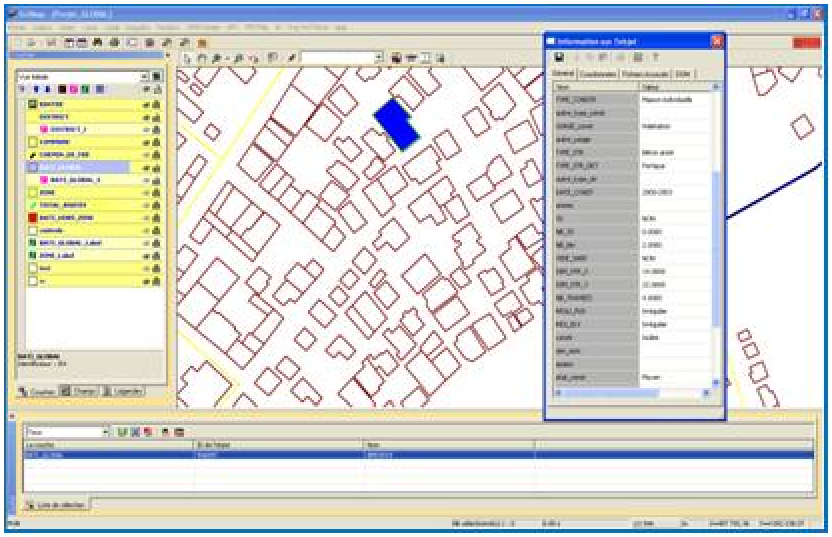


Fig. 6 – Example of the building database built in GIS format

2.2 Module “Damage curves”

This module generates the fragility curves values , as illustrated in Fig. 7, of all the building types described in the methodology described previously [1, 2]. These values are used to calculate the damage probability to each building typology.

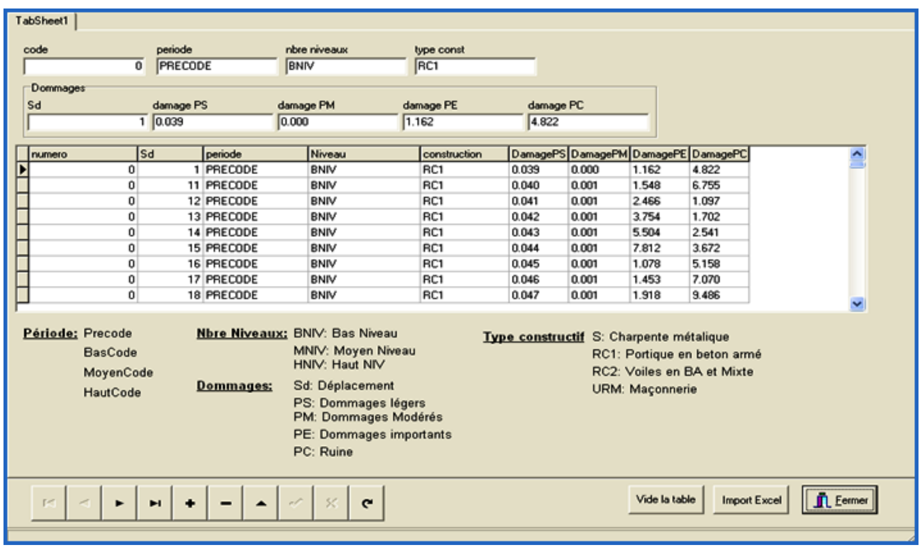


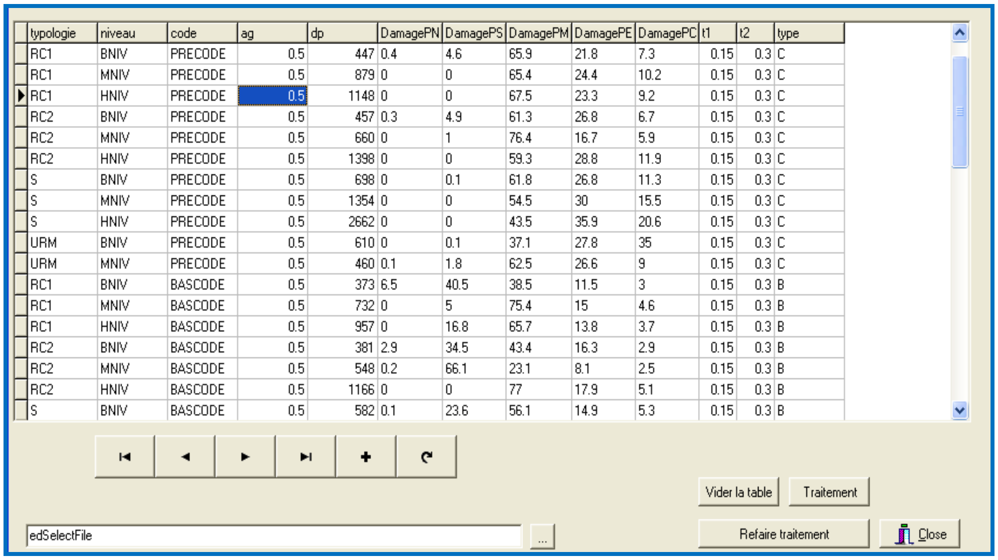
Fig. 7 – Generation of damage curve values

2.3 Module “Performance points”

This module includes a program for the automatic calculation of performance points "S_d" for all the existing building types in the database carried out (see Fig. 8), according to the procedure detailed in [1, 2].

2.4 Module “Damage matrices”

This module of the developed model, as shown in Fig. 8, allows the calculation of the damage probability matrices of each relevant typology, according to the classification of 05 damage levels described in the methodology developed by Boukri et al. 2013 [1], as illustrated in Fig. 2. These results are assigned to all the buildings stored in the database.



typologie	niveau	code	ag	dp	DamagePN	DamagePS	DamagePM	DamagePE	DamagePC	t1	t2	type
RC1	BNIV	PRECODE	0.5	447	0.4	4.6	65.9	21.8	7.3	0.15	0.3	C
RC1	MNIV	PRECODE	0.5	879	0	0	65.4	24.4	10.2	0.15	0.3	C
RC1	HNIV	PRECODE	0.5	1148	0	0	67.5	23.3	9.2	0.15	0.3	C
RC2	BNIV	PRECODE	0.5	457	0.3	4.9	61.3	26.8	6.7	0.15	0.3	C
RC2	MNIV	PRECODE	0.5	660	0	1	76.4	16.7	5.9	0.15	0.3	C
RC2	HNIV	PRECODE	0.5	1398	0	0	59.3	28.8	11.9	0.15	0.3	C
S	BNIV	PRECODE	0.5	698	0	0.1	61.8	26.8	11.3	0.15	0.3	C
S	MNIV	PRECODE	0.5	1354	0	0	54.5	30	15.5	0.15	0.3	C
S	HNIV	PRECODE	0.5	2662	0	0	43.5	35.9	20.6	0.15	0.3	C
URM	BNIV	PRECODE	0.5	610	0	0.1	37.1	27.8	35	0.15	0.3	C
URM	MNIV	PRECODE	0.5	460	0.1	1.8	62.5	26.6	9	0.15	0.3	C
RC1	BNIV	BASCODE	0.5	373	6.5	40.5	38.5	11.5	3	0.15	0.3	B
RC1	MNIV	BASCODE	0.5	732	0	5	75.4	15	4.6	0.15	0.3	B
RC1	HNIV	BASCODE	0.5	957	0	16.8	65.7	13.8	3.7	0.15	0.3	B
RC2	BNIV	BASCODE	0.5	381	2.9	34.5	43.4	16.3	2.9	0.15	0.3	B
RC2	MNIV	BASCODE	0.5	548	0.2	66.1	23.1	8.1	2.5	0.15	0.3	B
RC2	HNIV	BASCODE	0.5	1166	0	0	77	17.9	5.1	0.15	0.3	B
S	BNIV	BASCODE	0.5	582	0.1	23.6	56.1	14.9	5.3	0.15	0.3	B

Fig. 8 – Performance points and damage matrices Module

2.5 Module “Generation of GIS Seismic Damage Maps”

The generation of seismic damage maps is done in a Geographical Information System (GIS) platform, automatically associated with the database of "RELAM-Algeria" model, where all the buildings data and the results of the seismic damage probabilities are calculated and stored. The displayed information can be updated instantly. This topic generates the damage maps in multiple forms and themes providing interactivity to the concerned institutions in relief for the interpretation of results and identification of the most damaged buildings and areas. This allows to easily quantifying the damage extent and their space situation in the first consecutive times to the earthquake occurrence.

2.5.1 Generation of damage maps by buildings

This theme can generate the damage maps for whole buildings, which helps to diagnose their condition in the area affected by the earthquake and locate those with significant and severe damage probabilities, in order to quickly orientate the intervention. These constructions can be classified, also, according to the average preponderant damage ratio, as shown in Fig. 9, for which is associated a colour, as shown in Table 1. The generated maps can be exported as an image to be sent quickly to authorities involved in relief, by using electronic network, so to locate and identify the most damaged buildings, their number, etc.

Table 1 – Colour associated to tag each building according to its level of damage

Damage degree	**Colour**	**Damage category**
D1	Light green	*Noor Negligible*damage “***N***”
D2	Dark green	*slight* damage “***S***”
D3	Yellow	*moderate* damage “***M***”
D4	Orange	*important and extended* damage “***E***”
D5	Red	*complete* damage “***C***”

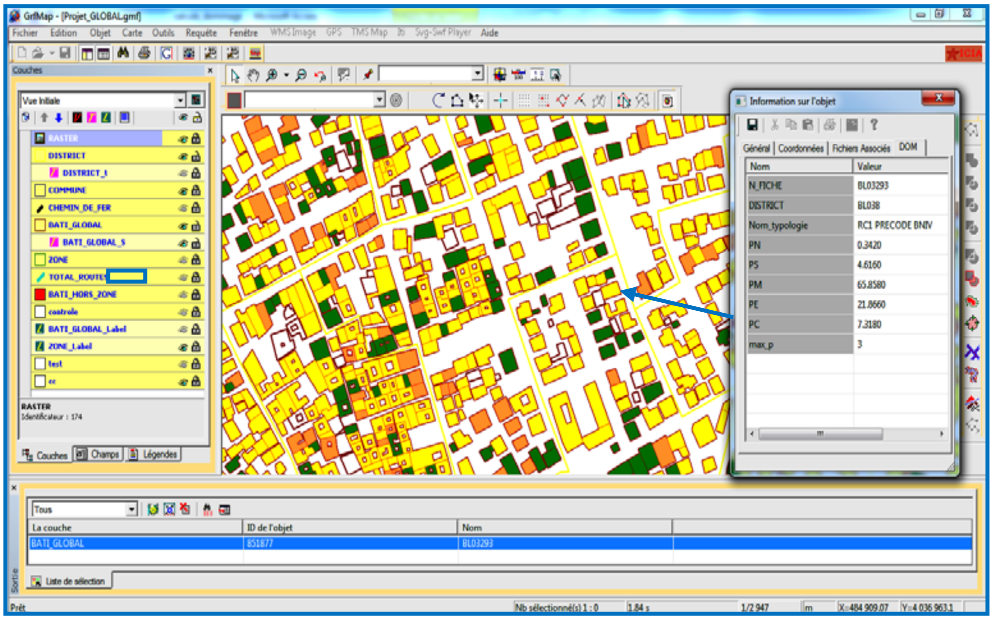


Fig. 9 – Generation of a GIS damage map (classification of the building according to the preponderant damage level)

2.5.2 Damage map by districts or by areas (large urban subdivisions)

This theme allows to display the damage by districts or by sectors (large urban subdivisions) of the area affected by an earthquake either in the form of an average preponderant damage level (mean D1 to mean D5) or according to the damage rate calculated considering only “Extensive damage (D4)” and “Complete damage (D5)”, which will allow to the authorities to delimit the delimit the most damaged areas in order to provide an initial estimate of their damage states to focus and devote the main efforts by mobilizing the necessary emergency resources in order of priority and to know the adequate damage level to be given.

3. Application

In this work, we propose to apply the concept developed previously, "RELAM-Algeria", to analyse its implementation for the theoretical seismic damage estimation of existing buildings in an urban site in case of a major earthquake occurrence.

For that, we chose the urban site of Blida city located at North Centers Algeria (see Fig. 10) and which extends on the Mitidja plain over 260 m above the sea level, sheltering a high population density of about (3,070 inhabitants/km²). This city is potentially exposed to seismic risk, because it is located in a region that has experienced strong earthquakes during the last centuries generating intensities between X and XI [10]. Earthquakes severely affected the city of Blida and its surroundings [11] are those of February 3rd, 1716 March 17th, 1756, May 16th, 1760 and the most destructive one, which occurred on March 2nd, 1825 causing near total destruction of the old city of Blida with 3,000 dead and about 7,000 dead across the region affected by the earthquake. During the instrumental period, the strongest earthquake recorded in the Blida region is that of November 7th, 1959 with a magnitude Ms = 5.6. From these past earthquakes, the mean maximum intensity in the Blida region is estimated between VIII and X [12].

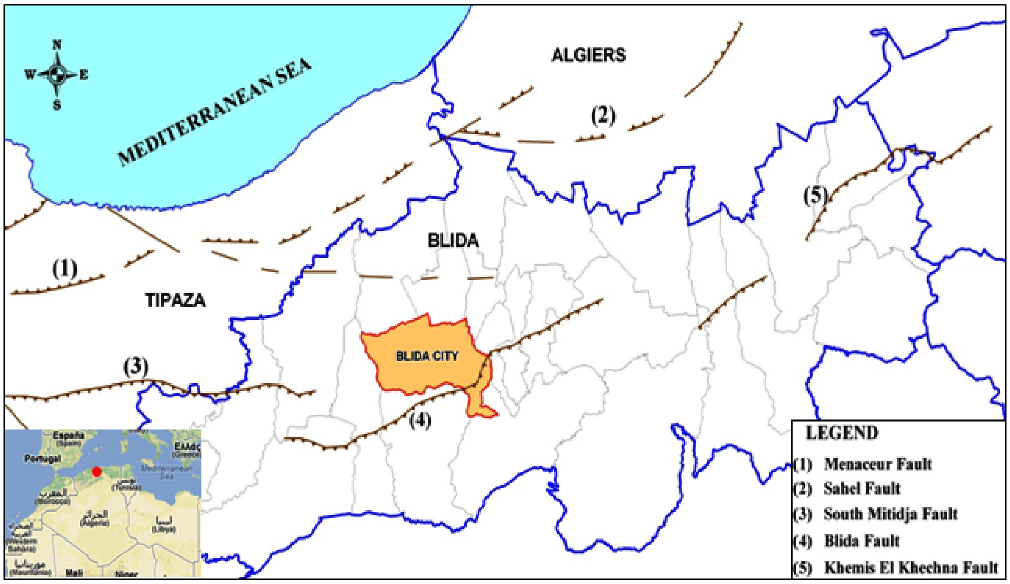


Fig. 10 – Location of Blida city in Algeria (see red circle); b) Map of active faults in Blida region [13, 14]

3.1 Building database

To create the building database in the perimeter of the urban site of the Blida city a comprehensive and systematic inventory was carried out for all buildings located in the study area. This inventory was conducted by the National Earthquake Engineering Research Centre (CGS) using a specific identification and evaluation form as shown in Fig. 5. To constitute this database, each sheet representing a building unit has been stored in the "RELAM-Algeria" model using the "building Database" Module (see Fig. 4) and linked with the corresponding graphical entity in the integrated GIS platform based on the Geo-Eye satellite image of very high resolution (50cm) acquired within the framework of this project (see Fig. 11).

Fig. 11 – Example of the digitised buildings of Blida city in GIS platform using high-resolution Geo-Eye satellite imagery

The total number of buildings, in the urban perimeter of Blida city, digitized and recorded in the database is about 24,673 units. Among these buildings, we selected 24,627 units whose types are supported by the seismic damage estimation of existing buildings in Algeria methodology [1] included in the developed model.

From the building database carried out, the developed model range the inventoried buildings according to the seismic damage estimation of existing buildings in Algeria methodology [1], as illustrated in Table 2.

Table 2 – Building distribution according to their type

Type	**Number of building according to the type**	**Number of buildings according to the lateral resisting system**	**Percentage (%)**
RC1-L	14,483	15,355	62.4
RC1-M	848		
RC1-H	24		
RC2-L	1,118	1,682	6.8
RC2-M	507		
RC2-H	57		
S-L	609	611	2.5
S-M	2		
S-H	--		
URM-L	6,877	6,979	28.3
URM-M	102		

3.2 Earthquake scenario

3.2.1 Seismic hazard

Based on the analysis of active faults models in the Blida region (see Fig. 1), it appears that the most threatening seismic source for Blida city is the Blida fault which across the Atlas Mountains and the plain. This fault extends from the South of El affroun chain eastward about 45 Kms [14]. The studies carried out by BOUDIAF [11] show that the eastern section of this fault about a 20 kms of length was at the origin of the destructive earthquake of March 2nd, 1825 causing the ruin of Blida city and its surroundings [11].

In the current study, the earthquake scenario of Blida city is performed by considering Blida fault with a maximum magnitude Mw 7 as most severe seismic input, being the nearest and the more threatening seismic source to Blida city and its surroundings.

The peak ground acceleration (PGA) was calculated using the Ambraseys et al. attenuation law [15] given by Eq. (1), assuming a magnitude Mw = 7 and an average epicentral distance of 1 km. Therefore, the average Peak Ground Acceleration value (PGA) estimated in Blida city is about 0.5g.

$$\log A_h = a_1 + a_2 M_W + (a_3 + a_4 M_W)\log\sqrt{d^2 + a_5^2} + a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_T + a_{10} F_0 \quad (1)$$

Where, A_h represents the horizontal PGA [unit: ms^{-2}], S_S=1 for soft soil sites and 0 otherwise, S_A=1 for stiff soil sites and 0 otherwise, F_N=1 for normal faulting earthquakes and 0 otherwise, F_T=1 for thrust faulting earthquakes and 0 otherwise and F_0=1 for odd faulting earthquakes and 0 otherwise.

3.2.2 Geotechnical conditions

According to the study performed by the National Earthquake Engineering Research Centre within the framework of the microzoning study of the Wilaya (department) of Blida [16], the local soil classification for each district or small area of the urban site of Blida city, following the prescription of the Algerian Seismic Code updated in 2003 [17] is given in Fig. 12.

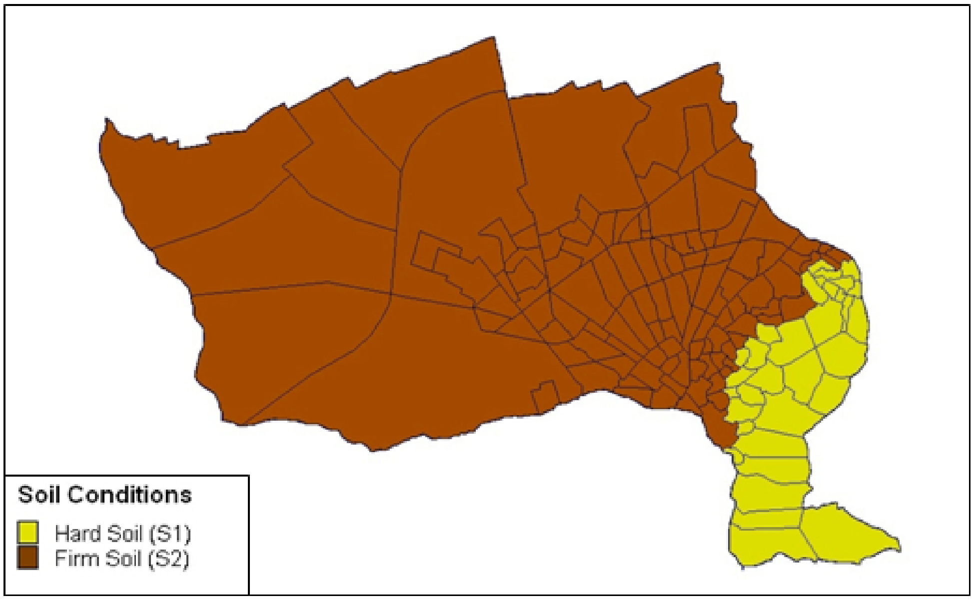


Fig. 12 – Soil Conditions in Blida City

3.2.3 Building damage assessment and generation of GIS damage maps

The model developed in this work has enabled the automatic seismic damage calculation for whole building units considered in the urban site of the Blida city and the generation of GIS damage maps allowing the space localisation of areas that would be most damaged in case of the earthquake adopted as reference. For that, the study area is divided into 14 urban subdivisions (sectors) grouping 139 districts, as adopted during the General Census of Population and Housing of 2008 [18].

One specifies that these results are given as an indication according to the building inventory carried out and the adopted earthquake scenario.

Table 3 summarises the damage probabilities according to the building type, while the results presented in Table 4 and Fig. 13 give the mean probable damage ratio in the defined urban areas, considering only "Extensive damage (D4)" and "Complete damage (D5)", i.e (D4 + D5).

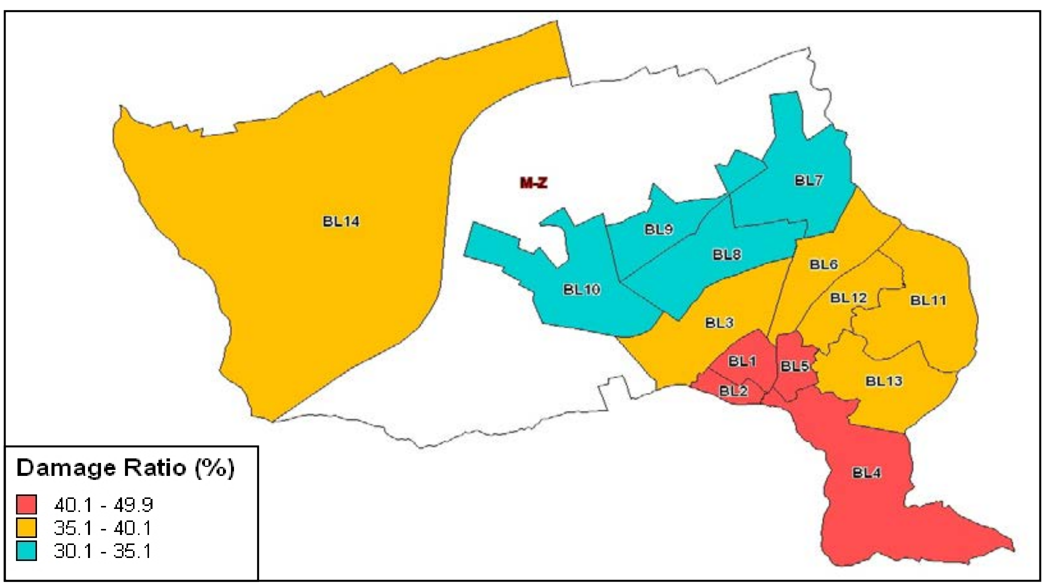


Fig. 13 – Mean damage ratio in each sector of Blida city

Table 3 – Damage probabilities according to the building type

Type	Damage probability (%)				
	PN (D1)	PS (D2)	PM (D3)	PE (D4)	PC (D5)
RC1	1.6	13.3	56.6	22.6	5.9
RC2	0.1	10.7	69.6	16.5	3.1
S	6.4	29.8	41.7	17.9	4.2
URM	0.0	0.1	38.3	28.0	33.6

Table 4 – Mean damage probabilities for each urban sector in Blida city

ID	Sector Name	Damage Category (%)					Damage Ratio “D4+D5” (%)
		N (D1)	S (D2)	M (D3)	E (D4)	C (D5)	
BL1	Blida city-centre	1.0	6.5	48.9	25.3	18.4	43.6
BL2	Bab Errahba-Sidi Yakoub	1.2	7.7	50.4	25.1	15.6	40.7
BL3	Bab Ezzaouia	1.2	9.2	51.3	24.0	14.4	38.4
BL4	Dardara - Sidi El Kebir	0.8	8.1	47.1	24.9	19.1	44.0
BL5	Ouled Soltane - Douiret	0.9	5.5	44.5	26.3	22.7	49.0
BL6	Kritli Mokhtar	1.3	10.4	50.7	23.7	13.9	37.6
BL7	Industrial zone of Benboulaid	2.6	14.5	48.4	22.4	12.1	34.5
BL8	Benboulaid-Bounaama	1.1	11.9	54.9	21.9	10.3	32.2
BL9	Sidi AEK-Bananiers	1.1	11.5	57.3	22.1	8.1	30.2
BL10	Zabana	1.0	8.7	59.3	22.4	8.7	31.0
BL11	Ben Achour-H'malit	1.5	13.8	47.3	23.8	13.6	37.4
BL12	Yousfi AEK	1.1	7.9	51.0	24.3	15.7	40.0
BL13	Road de Chréa - Agba El Hamra	1.0	13.7	49.8	22.8	12.6	35.4
BL14	Maramane	0.5	5.6	56.0	24.6	13.4	37.9

4. Conclusion

The Rapid Earthquake Loss Assessment Model for Algerian Building Context "RELAM-Algeria", developed in this work is presented as a relevant support for decision-making, in terms of earthquakes and their effects in Algeria, which is a contribution in the field of urban planning and crisis management in Algeria.

It is used for predictive seismic damage estimation that can occur in an urban area exposed to seismic risk through the implementation of a probable earthquake scenario, which will offer opportunities to decision-makers and public authorities to take appropriate preventive measures for the seismic risk management, to analyse the urban system and propose the most effective action plans for seismic risk mitigation; it allows also a real-time post-seismic damage assessment in the few moments following an earthquake (rapid post-seismic estimation) in an urban area affected, once the epicentre is located and the magnitude is known, which help to define the alarm level to be given in order to mobilise the emergency means with a considerable time saving in response and the rescue of human lives.

To analyse its implementation for the theoretical seismic damage estimation of existing buildings in an urban site in case of a major earthquake occurrence, this decision-making tool has been applied to estimate the probable seismic damage in the urban site of Blida city potentially exposed to seismic risk, the results are given as an indication according to the building inventory carried out and the adopted earthquake scenario.

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