Seismic risk assessment
of Constantine City (Algeria)

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SUMMARY:
Located at the North-East of Algeria, Constantine has an important administrative, economic, scientific and cultural position and knew a significant urban evolution during the different periods of its history. This city is located in active seismicity area of Algeria and has been stricken in the past by several moderate to strong earthquakes where the most recent took place on October 27th, 1985 with a magnitude Ms = 6.0. Because of its dense housing and high concentration of population (2374 hab/km²), Constantine presents a very high seismic risk which requires an assessment in order to take preventive measures to reduce losses in case of major event. In this context an earthquake scenario was performed using the HAZUS methodology adapted to the Algerian context and using a wide inventory of buildings built. The main results obtained from this scenario are presented in this paper.

Keywords: Constantine, Seismic risk, Earthquake scenario

1. INTRODUCTION

Recent earthquakes (Chlef 1980, Constantine 1985, Oued Djer 1988, Tipaza 1989 Mascara 1994, Ain Benian 1996 and more recently still Boumerdès 2003) (Yelles et al., 2003) show that there is an important seismic activity in Algeria. This activity affects essentially the Northern part of the country where the big cities are located for which the seismic risk is growing with the economic development and population growth.

Protect a city against earthquakes is, first, trying to understand and know the situation which will happen after the earthquake struck, which leads to the following questions: what will be the appearance of the city after earthquake? How to deal with the disaster? How to organize relief? Can limit losses? What should be done?

These questions can find answers after making scenarios with probable earthquakes that could hit an urban area and its surroundings. The authorities of the city thus will have elements that will enable them to know and to estimate the losses in advance, with an acceptable error, and to take the necessary measures before (prevention by generalizing vulnerability studies), during (development of an emergency plan with all the concerned sectors) and after (reconstruction) earthquake.

In this work, we propose to conduct a seismic scenario in Constantine city, see Fig. 1.1, which is located in a zone of active seismicity of Algeria which was shaken by several moderate to strong earthquakes, the last dates of October 27, 1985 (Ms = 6.0). Because of a high concentration of economic, scientific, cultural infrastructures and population (2374 hab/km²) (RGPH 2008), Constantine city requires special attention to protect it, in an acceptable level, against earthquake which can strike at any time.

Constantine city experienced a significant urban change during the different periods of its history (Boussouf, 2002). It knew the transit of many civilizations which each was marked by particular urban development.

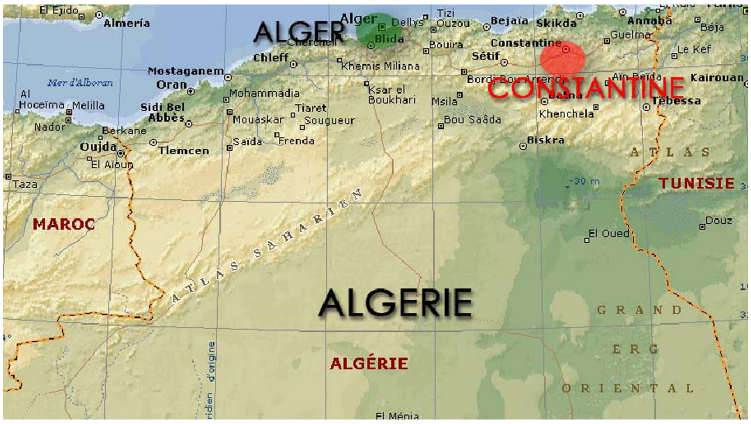


Figure 1.1: Location of the Constantine city map

This seismic scenario to estimate the probable seismic damages is done with a computer code that has been developed for this purpose for the calculation and processing of all data to estimate the damages and their spatial distribution. This computer code also allows to make a classification of constructions according to five (05) degrees of damage, (D1: Negligible damage, D2: Slight, D3: Moderate, D4: Extensive and D5: Complete) and thus identify the most affected areas by the earthquake.

2. SEISMIC DAMAGE ESTIMATION METHODOLOGY FOR BUILDING

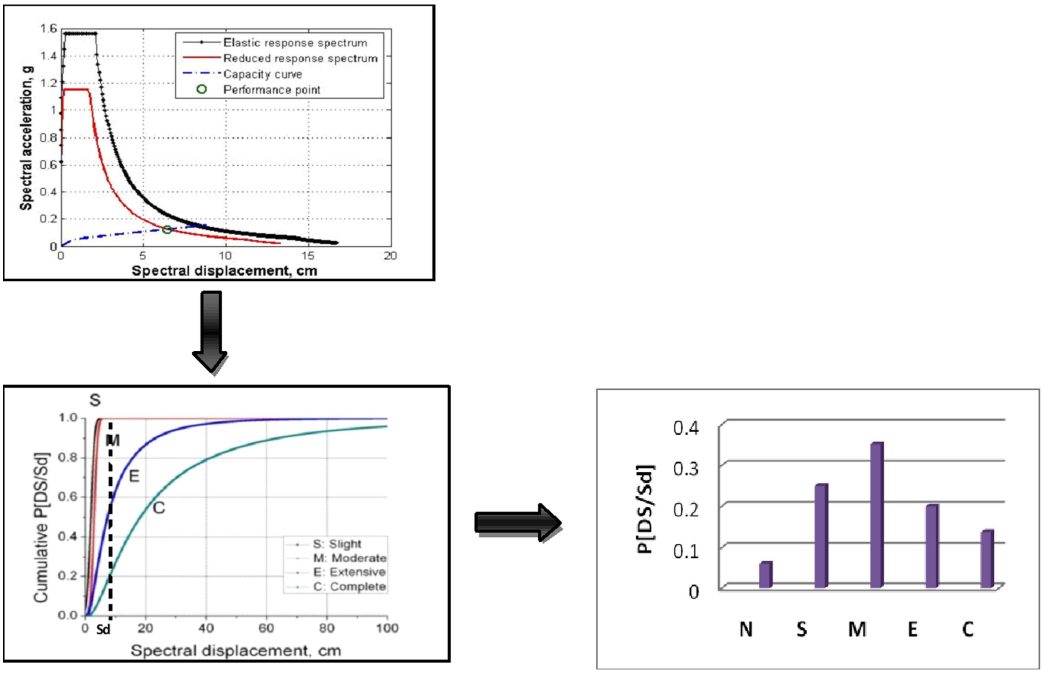
The seismic damage estimation process for building which was used to perform the earthquake scenario of Constantine city is based on the HAZUS approach (The FEMA Tool Estimating Earthquake Losses) (FEMA, 2002) which uses the capacity spectrum method developed by several research studies (Mahaney et al., 1993; ATC-40; 1996; Comartin et al, 1999; Chopra and Goël, 1999; Fajfar, 1999). The main parameters are the seismic solicitation represented by a response spectrum and the structure behavior represented by its capacity curve. The performance point, which is the intersection of the capacity curve and the response spectrum, represents the behavior of the building subjected to a given earthquake, see Fig. 2.1. This performance point allows to calculate the probability of damage for each damage level according to its location on the fragility curves and therefore describes the damage level of the structure.

Table 2.1: Buildings Types used in the methodology

NO.	Typology	Type of resisting system	Height (m)	
			Stories	
			Name	Number
1	RC1 - B	Reinforced Concrete Beam-Columns Structures	Low rise	1 - 3
2	RC1 - M		Medium rise	4 - 7
3	RC1 - H		High rise	8 and more
4	RC2 - B	Reinforced Concrete Shear Walls	Low rise	1 - 3
5	RC2 - M		Medium rise	4 - 7
6	RC2 - H		High rise	8 and more
7	S-B	Steel Structures	Low rise	1 - 3
8	S-M		Medium rise	4 - 7
9	S-H		High rise	8 and more
10	URM-B	Unreinforced Masonry (Bearing walls)	Low rise	1 -2
11	URM - M		Medium rise	3 and more

The building classification is based on the type of lateral resisting system, the number of stories (see table 2.1) and the period of construction (table 3.1). We have considered the most common building types defined in the Algerian Seismic Code (RPA99/Version 2003). These building types are reinforced concrete, masonry and steel structures.

This classification is approximately consistent with the most existing classifications used by several seismic damage estimation models in the world and particularly by HAZUS (FEMA, 2002) method.



Damage State: N: No damage ; **S:** Slight ; **M:** Moderate ;**E:** Extensive ; **C :** Complete

Figure 2.1. Seismic damage estimation procedure

3. BUILDINGS INVENTORY OF CONSTANTINE CITY

To apply the seismic scenario for estimating the probable building damage in Constantine city, an inventory has been conducted in the study area using a form developed for this purpose, see Fig. 3.1. This sheet contains all of the parameters that can have an influence on the seismic response of the building (Boukri et al., 2008) according to its structural typology, period of construction, number of stories, etc. The data collected have been stored in a digital database as illustrated in Fig. 3.2, then each sheet has been associated with an entity "built" on the urban map of Constantine city, see Fig. 3.3.

NATIONAL CENTRE OF EARTHQUAKE ENGINEERING (CGS)

BUILDING INVENTORY FORM OF CONSTANTINE CITY

Name:........................

N° of inventory form:........ Date....../....../........

District:....................

Islet: ....

Adress: ....

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 ☐

If Masonry: Confined ☐ Non-Confined ☐

Date of construction (approximately):

Before 1980 ☐ 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 ,Nbof 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:

....

....

Figure 3.1. Building inventory form for Constantine city

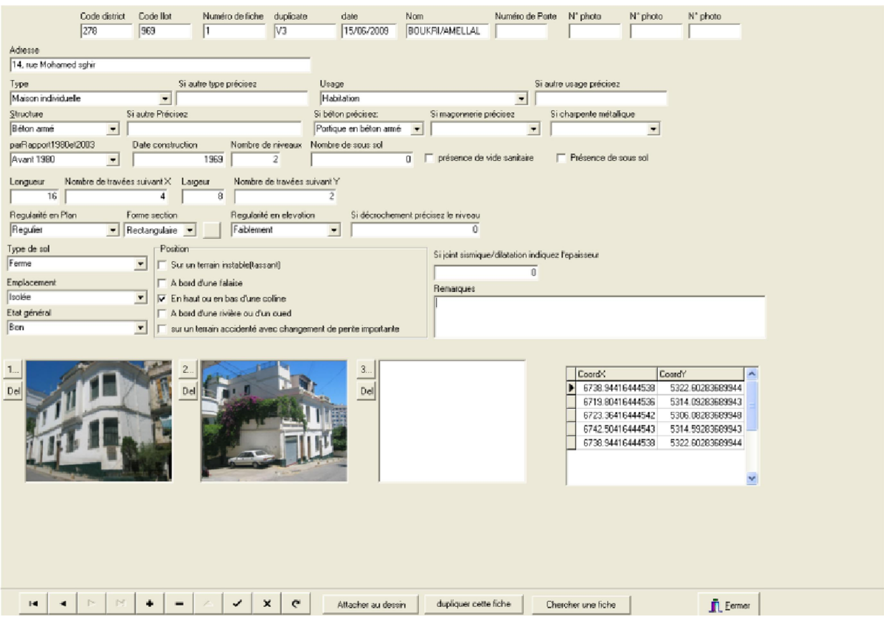


Figure 3.2. Computer Code interface of Building inventory form

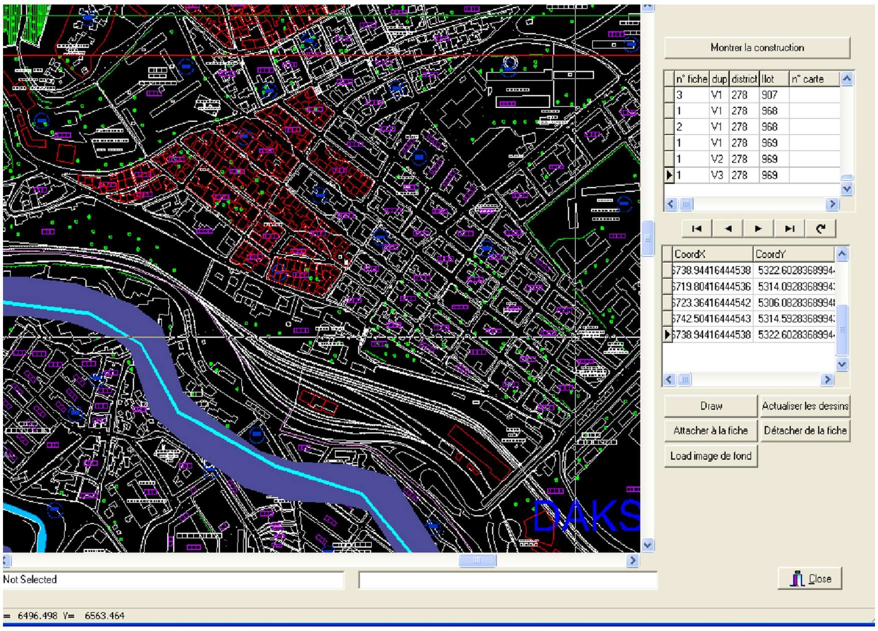


Figure 3.3. Example of building digitalization in Constantine city

The inventoried buildings have been also classified according to the updating periods of the Algerian Seismic Code (see table 3.1)

Table 3. Seismic design levels according to evolution periods' of the Algerian seismic code (RPA)

Code version	**After 2003**	**1999ï 2003**	**1981-1999**	**Before 1981**
Code level	High-code	Moderate-code	Low-code	Pre-code

30706 constructions have been inventoried. Analysis of this data shows that masonry constructions represent 12% (3712 construction) of the total identified buildings and is the part of the former City (old rock site) and the sites around it built during the colonial period (before 1962). In terms of structural typology, reinforced concrete constructions predominate (21186 units, 69%) divided between frames and shear walls (19385; 63.13%, and 1801, 5.85%), this situation is explained by the development of the city from 1930 using the Reinforced Concrete and the strong urbanization post-independence. The steel frame structures represent about 5% (1589 constructions) and are mainly in the industrial zone built the form of hangars and small industrial buildings and a few other hangars in schools and educational institutions. Wooden structures are almost non-existent. There are other typologies representing about 14% of the total of constructions divided between temporary constructions made of sandwich panels conducted after the 1985 earthquake and precarious constructions.

Most of the buildings (89%) are residential; the second part is academic institutions with 1068 constructions (3.48%). The rest of the buildings is divided between hospital, commercial, industrial, administrative and socio-cultural (mosques, sport halls, etc.) occupancy. The number of constructions built between 1980 and 2003 (13268; 43.21%) close approximately the number of buildings dating from before 1980 (15893; 51.76%). This is mainly due to the strong urbanization from the 1980s. This percentage is much lower for the period post 2003 (short period between 2004 and the date of the Census as well as the lack of constructing sites in the study area). These structures are divided into three categories according to the number of stories. Most are those of low height (1 to 3 stories) represent 77%, constructions of average height (4 to 7 stories) are more than 22% of total buildings. The number of high rise buildings (8 stories and more) is low (227; 0.74%) and represents housing buildings.

4. SEISMIC SCENARIO IN CONSTANTINE CITY:

4.1 Seismic Hazard

To estimate the maximum acceleration (PGA) at the bedrock, we took into account the results of the seismic hazard study carried out in Constantine city (CGS, 2011b).The nearest fault which may affect the city is Ain Smara fault with a maximum magnitude Mw 7±0.23.

Using the Ambraseys attenuation law represented by Eqn.4.1 below (Ambraseys et al., 2005), considering a magnitude Mw = 7 and an average Epicentral distance of 4 Km, the calculation yields a PGA in Constantine city of **0.45 g**. The choice of this law (Eqn 4.1) is due to the fact that it was established on the basis of 595 strong motion records from Europe and the Middle East including 3 records from Algeria caused by shallow crustal earthquakes with magnitudes *M*w Ó5 and distance to the surface projection of the fault less than 100 km.. This attenuation law is the best one to apply it to Constantine context.

$$\log\ y = a_1 + a_2 M_W + (a_3 + a_4 M_W)\log\sqrt{d^2 + a_5^2} + a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_T + a_{10} F_0 \qquad (4.1)$$

Where: 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.a_1 to a_{10}**:** Coefficients derived for evaluation of the horizontal peak ground acceleration and the spectral response acceleration for 5% damping.
d**:** Epicentral distance

4.2 Geotechnical Context

According to the study performed by the National Centre of Earthquake Engineering (CGS, 2011a), analysis and interpretation of parameters from physical and mechanical tests performed on the geological formations Constantine site, show that the urban area of Constantine city is classified S1 (Hard soil) according to the classification given by the Algerian Seismic Code updated in 2003 (RPA99/ 2003).

4.3 Response Spectrum for the Seismic Scenario

The seismic damage estimation methodology is applied using the elastic response spectrum (ɕ = 5%) of the Algerian Seismic Code (RPA99/2003) which is given by the following formula, Eqn 4.2:

$$\frac{Sa}{g} = \begin{cases} 1.25A\left(1+1.5\dfrac{T}{T_1}\right) & 0 \le T \le T_1 \\ 2.5(1.25A) & T_1 \le T \le T_2 \\ 2.5(1.25A)\left(\dfrac{T_2}{T}\right)^{2/3} & T_2 \le T \le 3.0s \\ 2.5(1.25A)\left(\dfrac{T_2}{3}\right)^{2/3}\left(\dfrac{3}{T}\right)^{5/3} & T \ge 3.0s \end{cases} \qquad (4.2)$$

The developed computer code automatically generates the elastic response spectrum for 5% damping in ñAcceleration-Displacementò format of the studied site. The following parameters are taken into consideration:

- Bedrock S1
- T_1 = 0 15 s and T_2 = 0 30 s
- Calculated site acceleration: A = 0. 45 g

4.4 Seismic Damage Estimation and Generation of Damage Maps

Inventoried buildings considered in this study (28486 among 30706 buildings) are classified according to the following typologies: RC1 (20201), RC2 (1801), RDU (4910) and S (1574). The remaining buildings (2220) no corresponding to any classification and are excluded from data. The seismic damage probabilities of each type (see table 4.1) are estimated according to five (05) damage levels (D1 to D5) and are spatially distributed. Each damage level is associated with a color (see table 4.2).

Table 4.1. Damage probabilities by typology for of Constantine city

Damage degree / Typology	D1	D2	D3	D4	D5
RC1	2.77%	18.53%	56.64%	16.86%	5.2%
RC2	0.21%	28.29%	52.28%	14.56%	4.66%
URM	0.02%	0.44%	42.38%	27.70%	29.46%
S	0.08%	18.45%	57.34%	17.57%	6.56%

Table 4.2. Associated colour to each damage degree.

Damage degree	*Colour*
D1	Light green
D2	Dark green
D3	yellow
D4	Orange
D5	Red

The spatial distribution of the damages is done on the basis of the city map (subdivision of the city into 10 sectors grouping 496 districts) adopted during the General Census of Population and Housing of 2008 (RGPH, 2008). The damage ratio in the 10 sectors as well as the damage rate calculated considering only Extensive damage (D4) and Complete damage (D5) are given in table 4.3 and Fig. 4.1. Generated damage maps, as illustrated in Figs 4.2 and 4.3, allow to locate the districts which suffered the highest damage (damage D4 + D5 rate).

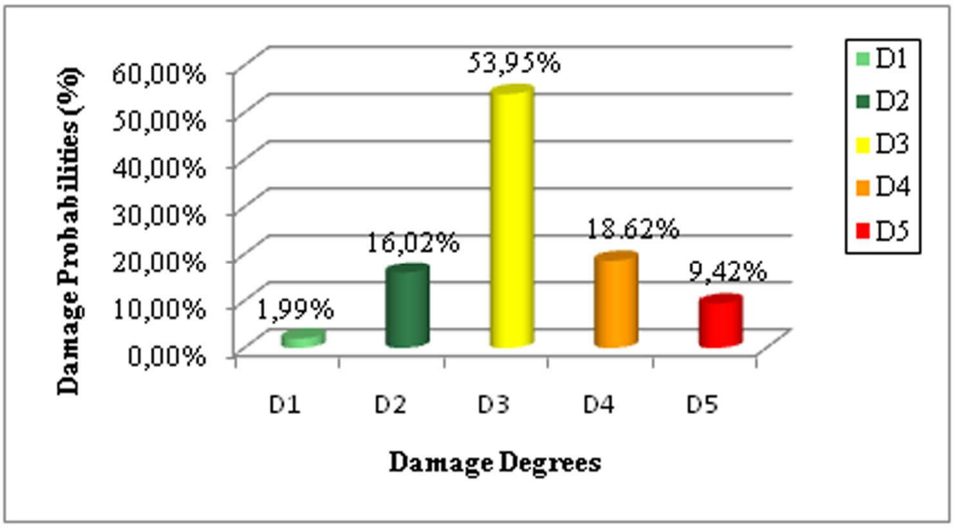


Figure 4.1. Total damage probabilities in Constantine city

Table 4.3. Damage probabilities by sector in Constantine city

Sector Name \ Damage Level	D1 (%)	D2 (%)	D3 (%)	D4 (%)	D5 (%)	Damage Ratio : D4+D5 (%)
Sidi M'cid	3.77	24.45	47.77	16.15	7.75	23.90
Martyrs	1.76	13.84	56.65	19.45	8.29	27.75
Boussouf	0.45	21.51	56.73	16.16	5.15	21.31
Rock-old city	0.66	5.55	53.22	23.70	16.88	**40.58**
University	0.80	8.96	64.44	19.26	6.53	25.79
Djebel el Ouahch	2.69	21.03	56.97	14.62	4.69	19.31
El Mansourah-SMK	1.61	11.54	51.75	20.72	14.38	**35.10**
Daksi	1.22	9.79	59.85	19.71	9.43	29.14
Gammas	3.93	25.91	48.93	15.30	5.93	21.23
Industrial zone	2.13	20.97	52.33	17.84	6.73	24.57
Total Area	**1.99**	**16.02**	**53.95**	**18.62**	**9.42**	**28.04**

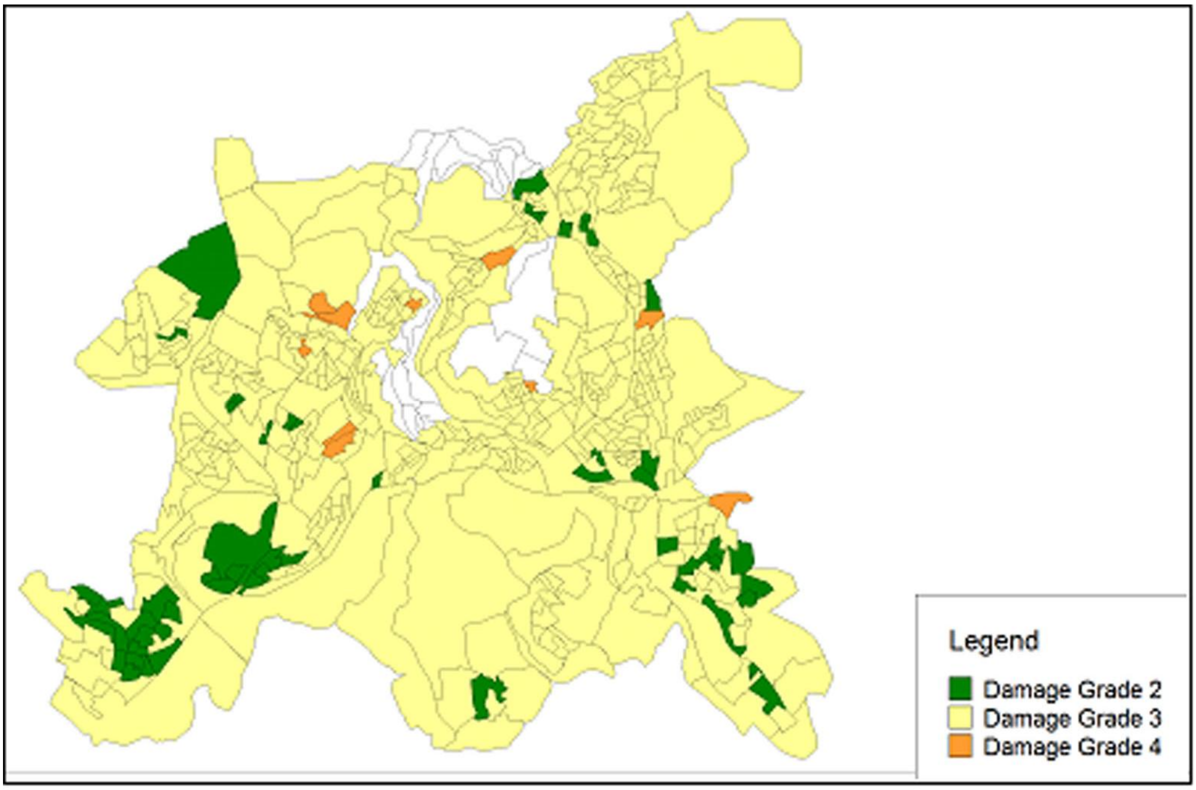


Figure 4.2: Average preponderant Damage level in districts of Constantine city

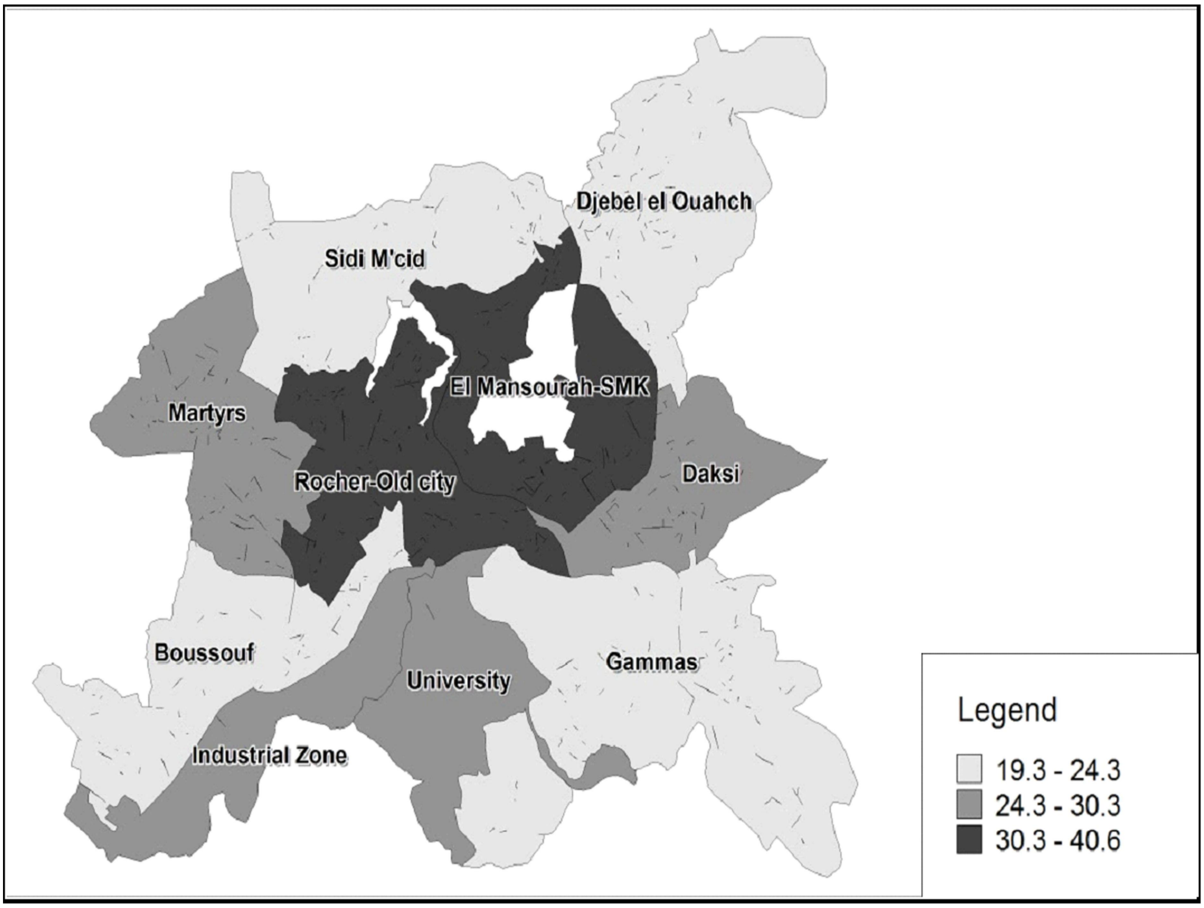


Figure 4.3: Damage ratio in each sector of Constantine city

5. CONCLUSION

A seismic scenario in Constantine city (Algeria) was presented. An important buildings inventory has been carried out by the National Centre of Earthquake Engineering (CGS), 31000 buildings have been inventoried and classified according to the lateral resisting system, occupancy, period of construction, number of stories, etc. This study was performed using a seismic damage estimation methodology developed on the basis of HAZUS approach. A computer code based on this methodology was developed to estimate the damages and to generate damage maps.

The results of this seismic scenario in Constantine city highlight that the ratio of likely damage (D4+D5) is approximately 28%. The higher damages are concentrated mainly in the sector of the old city containing the districts of the Casbah, Coudiat and Belle-Vue, and the sectors of El Mansourah and Sidi Mabrouk, where there is a concentration of old buildings.

These results may be overestimated, because we used as seismic event, in the absence of study area response spectrum, the response spectrum of Algeria Seismic Code (RPA99/2003) which overestimates the level of seismic hazard.

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