Development of a seismic damage assessment methodology for building in Algeria

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SUMMARY
Algeria is one of the countries that have experienced several strong to moderate earthquakesduring the last three decades. These earthquakes have caused considerable damages especially in the urban areas close to the epicentres. These damages can be reduced in urban areas prone to earthquakes if we proceed to estimate the seismic risk in sufficient time in order to take adequate preventive measures. In this paper is presented a seismic damage loss estimation methodology of buildings in Algeria based on the "Capacity Spectrum Method" using HAZUS(Hazard-United States) capacity and fragility curves adapted to the Algerian built context.This methodology gives an estimation of the seismic damage probabilities. A data-processing code was developed for this purpose to analyse the whole data and damage assessment. This methodology was validated with the observed damages induced by the May 21st,2003 Boumerdès earthquake.

Key words: Algerian buildings, HAZUS, Boumerdès earthquake, Algerian Seismic Code.

1. INTRODUCTION

The historical seismicity (Loauami et al., 2006) shows that Algeria is one of the countries where the seismic activity is high. It knew several strong earthquakes during the three last decades. Since El Asnam earthquake (October 10, 1980, Ms 7.3) which caused more than 2600 deaths and destroyed or damaged more than 60 000 buildings, several moderate but destroying earthquakes occurred in Constantine (October 27, 1985; Ms 5.7), Chenoua (October 29, 1989; Ms 6.0), Mascara (August 8, 1994; Ms 5.6), Algiers (September 4, 1996; Ms 5.6), Ain Temouchent (December 22, 1999; Ms 5.6) and Beni Ourtilane (November 10, 2000; Ms 5.5). Recently, the region of Boumerdès (50 Km East of Algiers) was struck by a magnitude Mw 6.8 earthquake on May 21st, 2003, (Belazougui, 2008), which caused considerable damage and more than 2300 deaths. The experience of these last earthquakes showed that the relief interventions have taken place only after the return of the first investigators, which may take a long time to give the information and therefore decreasesthe chance to find survivors. This delay is due to the non-fast localization of the affected zones and to the ignorance of the level of alarm to be given.

Just after a destroying earthquake, the catastrophe managers must take urgent decisions to mobilize the necessary means, according to the damages and their geographical distribution. This requires a preparation and installation of seismic risk reduction strategies in order to reduce the human and economic losses by the development of decision making tools.

The seismic damage estimation studies are a very useful tool to develop preparation and emergency management plans (Agrawal, 2004). The risk assessment process began at the end of the 19th century, by the systematic recording of the weather, stream heights and then earthquakes Charles, 2005). The first to draw up the benefit of the risk reduction studies was John R. Freeman, in his work "*Earthquake Damage and Earthquake Insurance"*, realised in 1932 (Charles, 2005), where it reviewed the catastrophes history. During the 1990's, the loss estimation models saw a significant and fast development (Clark, 2002), following several storms in Europe, the Andrew hurricane in 1992, the Northridge earthquake (USA, 1994) and the Kobe earthquake (Japan, 1995) which caused catastrophic losses to the world insurers and reinsurers who recognized the utility of such models. Indeed, these models allow a better quantification of the covered risks and thus a better knowledge of their exposure.

In this work, we elaborated a seismic damage estimation methodology for Algerian buildings based on HAZUS approach whose capacity and fragility curves of related typologies were adapted to corresponding typologies of the Algerian building context.

2. ELABORATION OF A SEISMIC DAMAGE ESTIMATION METHODOLOGY FOR ALGERIAN BUILDINGS

The seismic damage assessment process adopted (see Fig. 2.1) is based on HAZUS methodology (Hazard-United States), which relies on the capacity spectrum method resulting from various scientific researches(Mahaney et al, 1993; ATC-40, 1996; Comartin et al., 1999; Chopra and Goël, 1999; Fajfar, 1999).

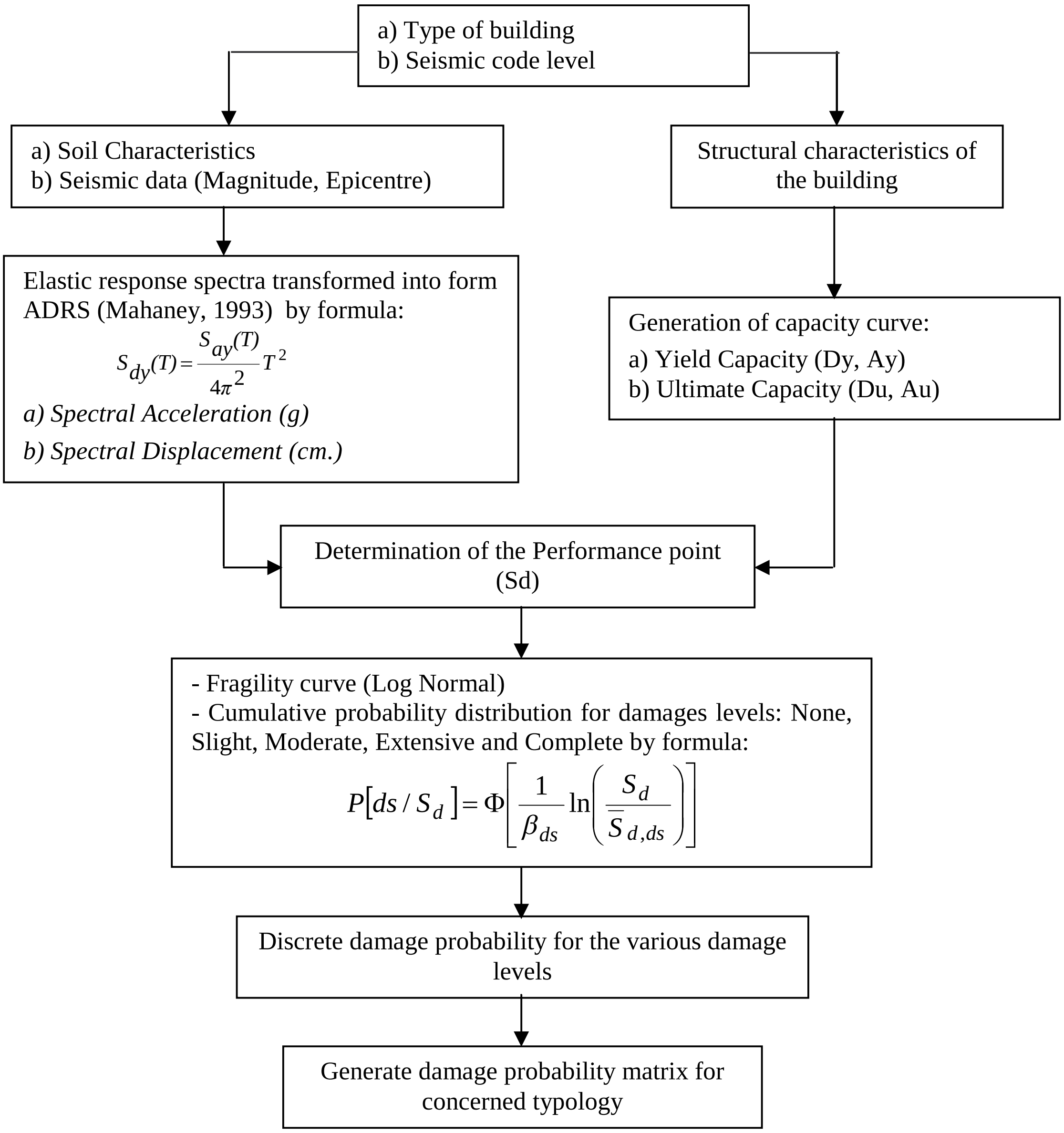


Figure 2.1. General flowchart of seismic damage evaluation procedure

The innovative character of the used approach mainly lies in the use of parameters directly related to the ground motion for damage estimation.The main parameters are the seismic solicitation represented in the form of response spectrum and the structure behaviour represented in the form of a capacity curve. The performance point, which is the intersection between the capacity curve and the seismic input, represents the behaviour of the building subjected to a given earthquake, see Fig. 2.1.According to its location on the fragility curves, it permits to calculate the damage probabilities for each damage level and thus described the damage level of the considered structure under the given seismic input.

2.1. Building Classification

The building inventory and its classification constitute the main step for seismic damage assessment in an urban area. The selected building classification is based on the type of lateral-bracing, number of stories as well as the period of construction. We chose the constructions types defined in the Algerian seismic code (RPA99/Version 2003), most widespread in Algeria, i.e. Reinforced Concrete structures (up to more than eight stories), Steel structures (up to more than eight stories) and Non Confined Masonry structures (up to more than three stories). This distinction is roughly homogeneous with the most existing classifications in the world earthquake loss estimation and particularly that used by the HAZUS methodology (FEMA, 2002). Thus, eleven (11) standard building classes were analysed representing four (04) categories of lateral-bracing systems as illustrated in Table 2.1.

Table 2.1. Building Typologies used for the methodology

N°	Typology	Type of lateral-bracing	Height (m)	
			Stories	
			Name	Number
1	RC1-B	Reinforced Concrete moment frame Structures (Beam-Columns)	Low-rise	1 – 3
2	RC1-M		Medium	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	4 – 7
6	RC2-H		High-rise	8 and more
7	S-B	Steel Structures	Low-rise	1 – 3
8	S-M		Medium	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	3 and more

2.2. Capacity and Fragility Curves

In this study, we used capacity and fragility curves developed and used in the HAZUS methodology(FEMA, 2002) which take account of the American seismic design level (high code, moderate code, low code and pre-code). This choice was made by taking into account the Algerian building context. Indeed, we used the capacity and fragility curves of the existing building types in Algeria, while trying to make closeness between the application levels of the American seismic code, UBC (FEMA, 2002) and the Algerian seismic code, RPA, in order to use these curves. Hence, we defined four (04) seismic design levels according to evolution periods' of the various versions of the Algerian seismic code bringing a change in the design level, see Table 2.2.

Table 2.2. Seismic design levels according to evolution periods' of the Algerian seismic code (RPA)

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

3. VALIDATION OF THE METHODOLOGYWITH THE BOUMERDESCITY CASE (ALGERIA)

In order to test and calibrate the seismic damage estimation methodology elaborated for the Algerian buildings, we applied it to the case of the Boumerdès urban area (located at 50 km East of Algiers city), see Fig. 3.1, which was stricken on May 21, 2003 by a destructive moment magnitude 6.8 (Mw) earthquake (Boukri et al., 2008).

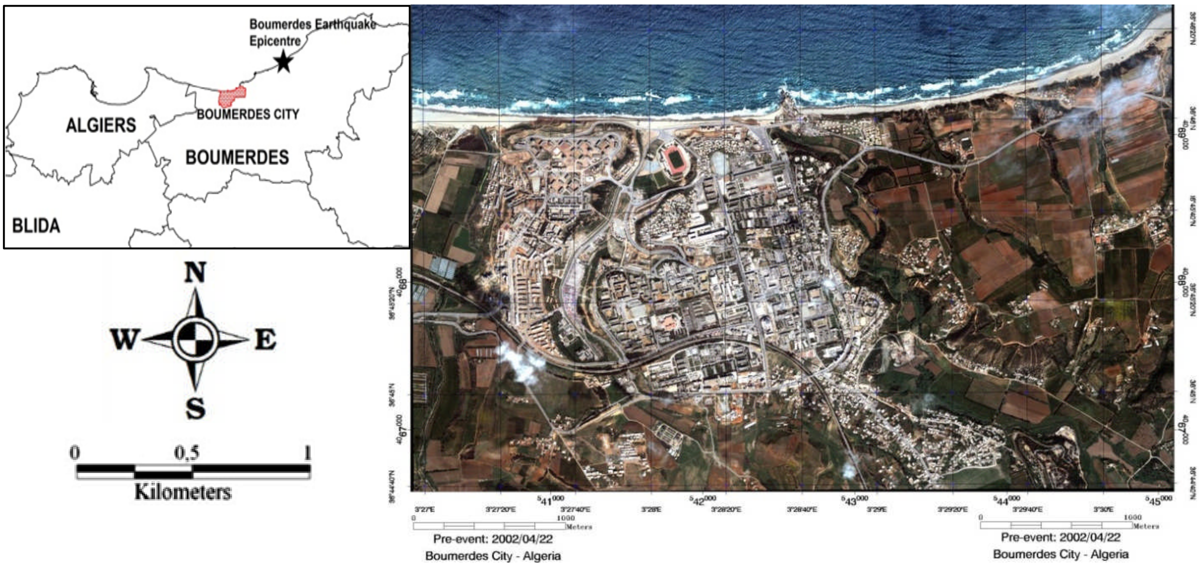
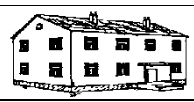
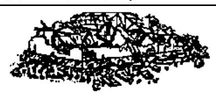


Figure 3.1. (a)-Quick-bird satellite image of Boumerdès city before the earthquake (April 22, 2002) provided by OYO corp.-(b)-Location of the May 21, 2003 Boumerdès earthquake epicentre (black star) (Bounif et al., 2004)

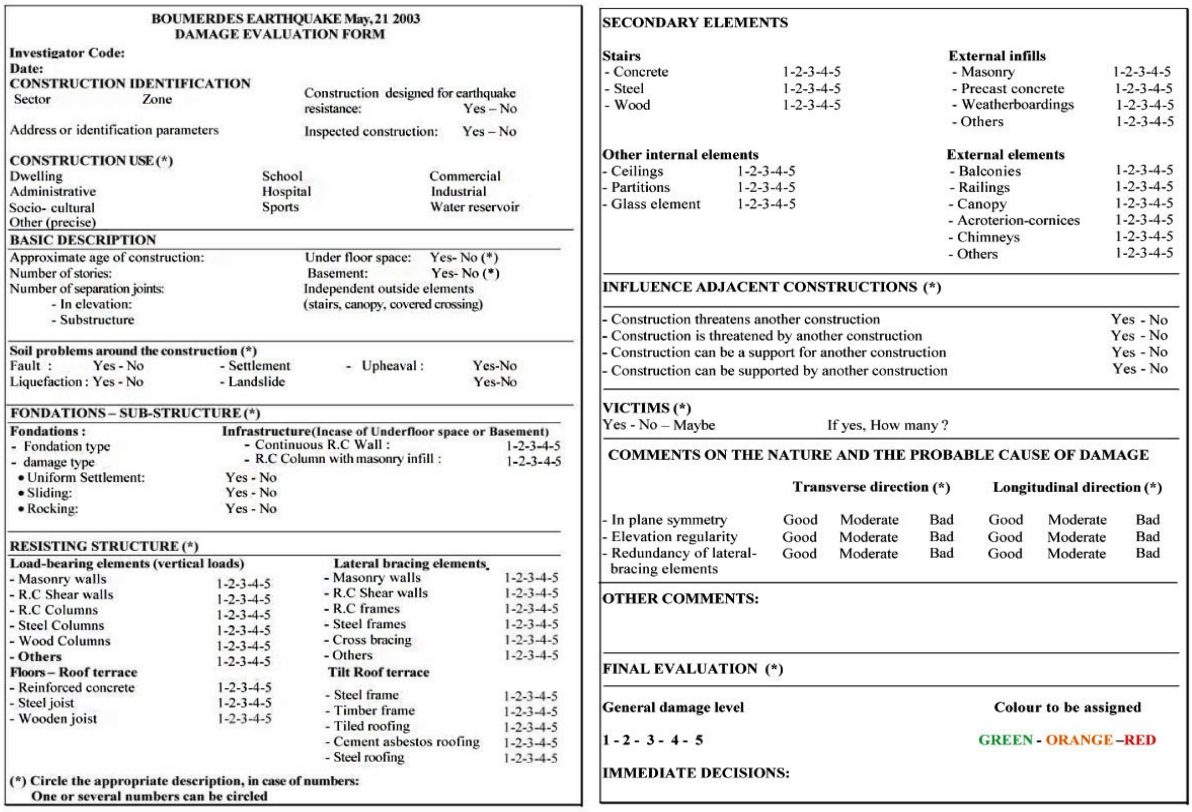
An interactive data-processing code was developed for this purpose gathering all the methodology steps to analyse the whole data and damage estimation process as illustrated in Fig. 2.1. The building seismic damages in Boumerdès city were estimated using the site elastic response spectrum derived from the accelerometer records obtained during the main shock of the May 21st, 2003 earthquake. The results are compared to the real observed damages.

The post-seismic evaluation forms drawn up by experts moved on the affected areas by the earthquake were used on the one hand to consider the damage undergone by constructions and, on the other hand, to make a building classification of Boumerdès city.

Table 3.1. Structural and non-structural damages: Classification for Reinforced Concrete and Masonry structures equivalent to EMS 98 (CGS, 2003; Grünthal and Levret, 2001)

Masonry structures	Reinforced Concrete structures	Damage description
		**Level 1: No damage** (none : structural damage)
		**Level 2: Light damage** (light structural damages, moderate non-structural damages)
		**Level 3: Moderate damag**e (moderate structural damages, important non-structural damages)
		**Level 4: Important damage** (important structural damages, severe non-structural damages)
		**Level 5: Severe** damage Collapse or about to(severe structural damages) **Partial or total collapse**

This evaluation form (see Fig. 3.2) gathers information of each inspected constructions (CTC, 1981) allowing to consign its damage state according to a 5 damage categories classification (Meslem et al., 2010; Meslem et al., 2012) close to the European Macroseismic Scale, EMS 98 (Grünthal, 2001 and CGS, 2003) as shown on the Table 3.1



(a) (b)

Figure 3.2. Post-quake damage evaluationform for Algeria (CTC, 1981; CGS, 2003)

3.1. Building Characteristics of Boumerdès City : Post-Quake Damage Estimation

The 3663 inspected damaged constructions in Boumerdès city were analysed by the National Centre of Earthquake Engineering (CGS, 2003) and occupancy classified as residential, industrial, commercial, educational, administrative, etc. The Reinforced Concrete structures are prevalent and represent the three quarters of the total buildings. This type of construction has been built after 1962 and is concentrated especially in the Western part of the city between the two rivers crossing the city, namely Corso and Boumerdès Rivers. The buildings having the "beam-column" frame system (RC1) represent approximately 71% (2596 constructions), while those built using the reinforced concrete shear walls system (RC2) represent 3.66%. The majority are collective buildings for residential, commercial or administrative use. Nevertheless, Masonry structures which the majority date from the colonial period (before 1962) represent approximately a quarter (25%) of the inspected constructions, located essentially in the secondary and dispersed agglomerations in the Eastern and Southern part of the city and are mainly individual constructions. There are also some steel (for industrial use) and wood constructions (12 and 15 constructions respectively, not included in the 3663 constructions). These two (02) typologies (steel and wood) represent only less than 1% of the total buildings in Boumerdès, so they are excluded from the data base. The buildings are also classified according to the constructive system, number of stories, construction periods and damage levels caused by the May 21, 2003 earthquake. This classification respects the seismic damage estimation procedure to be applied.

This classification emphasizes that some typologies retained for the analysis, see table 2.1, do not exist in Boumerdès city, like RC1-H, RC2-H and URM-M (Pre-code), RC2-B, URM-M (Low-code) and RC1-H (Moderate code). For the period before 1981, the number of constructions is about 1443 whose the half is in masonry system. During this period, Boumerdès city was only a small locality belonging to the municipality of Thénia (Dunand, 2005), the urban expansion started with the materialization of the town-planning of 1970. The number of constructions is more significant (1866 units) during the low-code period (1981-1999) of which nearly 90% are built in Reinforced Concrete. During this period, Boumerdès became Wilaya (province) in 1984 and knew a strong urbanization and transformed at the same time into an industrial pole represented by the Algerian oil company SONATRACH and an academic pole with the construction of the University containing several faculties and institutes. For the 3rd period (2000-2003), all constructions are built using the RC1 or RC2 systems with various heights, but their number is very small considering the short duration of this period.

The analysis of the assessed damages in Boumerdès city (see table 3.3 and figure 3.4), shows that a significant percentage of masonry buildings have suffered a several (extended and complete) damage, because these constructions are unreinforced masonry built without any design standard. Concerning RC1 buildings which are prevalent in Boumerdès city, although their half was slightly damaged, they represent the greatest number severely damaged (574 units classified between D4 and D5). This is due mainly to the poor quality of concrete and the bad reinforcement of column-beam joints (no stirrups). The more very slightly damaged construction system is RC2 (shear wall), which is used essentially for the buildings belonging to the public inheritance such as the dwelling residences like "Cité 800 logements". This system showed that it is more appropriate in high seismicity zones if it is well designed. The total building classification according to their damage categories is given in table 3.2

Table 3.2. Classification of the observed buildings according to their typology and the relative damages they have suffered

Damage level	D1	D2	D3	D4	D5	Total number of constructions
Number of constructions	57	1766	975	658	207	3663
Pourcentage (%)	1.56	48.21	26.62	17.96	5.65	

3.2 Damage Estimation Using the Developed Methodology and Comparison with the Observed Damages

Because of the defection of the accelerometer station, located at Boumerdès city (36.75N, 03.47E), 18 Km from the epicentre, during the mains hock of the May 21, 2003 earthquake, which could represent better the generated seismic excitation, the Keddara station (36.65N, 03.41E) located at the south-west of the disaster area (29 km of epicentral distance) has provided the accelerometer record which was used for the construction of the elastic response spectrum for this study. The choice to use this record is due to the fact that this station is closest to the defective station of Boumerdès and the study area. The H/V spectral ratios (Farsi et al., 2004) measurements performed by (Meslem et al., 2010), show the existence of hard surface layers at Keddara station site. This argues for an absence of amplification.

3.2.1. Development of the elastic response spectrum ($\zeta = 5\%$)

The normalized mean elastic response spectrum used in this case (see figure 3.3) was built from the two (02) horizontal components (E-W and N-S) of the accelerogram recorded at Keddara station.

From this response spectrum, we extracted the limit characteristic periods of the constant spectral acceleration branch T1 and T2 which have as respective values 0.088s and 0.227s. These two periods are used to plot the corresponding normalized elastic spectrum (see figure 3.3) given by the 1999 Algerian seismic code (RPA, 2000), see Eqn 3.1.

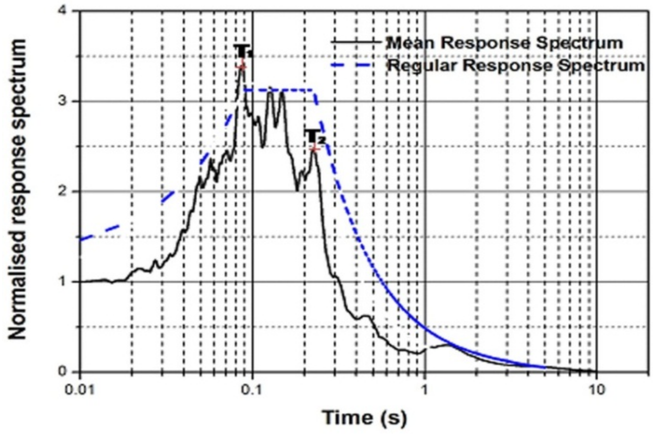


Figure 3.3. Normalized elastic response spectrum for 5% damping

$$\frac{S_a}{g} = \begin{cases} 1.25\left(1+\frac{T}{T_1}\left(2.5\eta\frac{Q}{R}-1\right)\right) & 0 \le T \le T1 \\ 2.5\eta(1.25A)Q/R & T1 \le T \le T2 \\ 2.5\eta(1.25A)\left(\frac{Q}{R}\right)\left(\frac{T_2}{T}\right)^{2/3} & T2 \le T \le 3.0S \\ 2.5\eta(1.25A)\left(\frac{Q}{R}\right)\left(\frac{T_2}{3}\right)^{2/3}\left(\frac{3}{T}\right)^{5/3} & 3.0S \le T \end{cases} \tag{3.1}$$

A: Acceleration coefficient (A=1)
T_1et T_2: Lower and Upper limit of the period of the constant spectral acceleration branch
η:Damping correction factor given by Eqn 3.2.

$$\eta = \sqrt{7/(2+\xi)} \tag{3.2}$$

ξ: Viscous damping ratio percentage of the structure,(ζ = 5%)

3.2.2. Site acceleration

The horizontal acceleration on the Boumerdès city was estimated from the 2 horizontal components (EW: 0.34g and NS: 0.26g) of the Keddara station record using the Ambraseys attenuation law (Ambraseys et al., 2005). The choice of this law (Eqn 3.3) 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 Mw ≥5 and distance to the surface projection of the fault less than 100 km. This attenuation law meets more the characteristics of the Boumerdès earthquake. So the peak ground acceleration value calculated in Boumerdès city is about 0.5g.

$$\log y = a_1 + a_2 M_W + (a_3 + a_4 M_W)\log\sqrt{d^2 + a_5^2} + a_6 S_S + a_7 S_A + a_8 F_N + a_9 F_T + a_{10} F_0 \tag{3.3}$$

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:Epicentraldistance

3.2.3. Geological and geotechnical context of Boumerdès city
The geological and geotechnical context of Boumerdès site (CGS, 2009) shows that the soil type is as firm (S2) according to the classification of the Algerian seismic code (400m/s≤Vs≤800m/s). Moreover, the H/V spectral ratios measurements performed on the urban site of Boumerdès city (Guiller et al., 2004) indicate that Vs≥500m/s. Other recent geophysical study performed by the National laboratory of habitat and construction in December, 2010 gives mean values of Vs≥490m/s.

Concerning the site amplification effect, the H/V spectral ratios measurements performed on this same site (Guillier et al., 2004; Hellal et al., 2010; Meslem et al., 2010) show its inexistence in Boumerdès city. This argues that the calculated acceleration value (A = 0.5g) on the Boumerdès station is fairly realistic and can be used to perform the elastic response spectrum for the whole Boumerdès city.

3.2.4. Damage estimation
The building damage estimation has been done using the methodology developed above. The obtained damages are compared to the real observed damages caused by the May 21st, 2003 earthquake as shown in Table 3.3, Figs. 3.4 & 3.5.

Table 3.3. Global damage probabilities comparison

Damage probability	PN (D1)	PS (D2)	PM (D3)	PE (D4)	PC (D5)
Estimated damages	3.31%	37.63%	43.23%	12.25%	3.58%
Observed damages	1.56%	48.04%	26.71%	18.02%	5.67%
PN: No damage probability, PS: Slight damage probability, PM: Moderate damage probability, PE: important or extensive damage probability and PC: Complete damage probability					

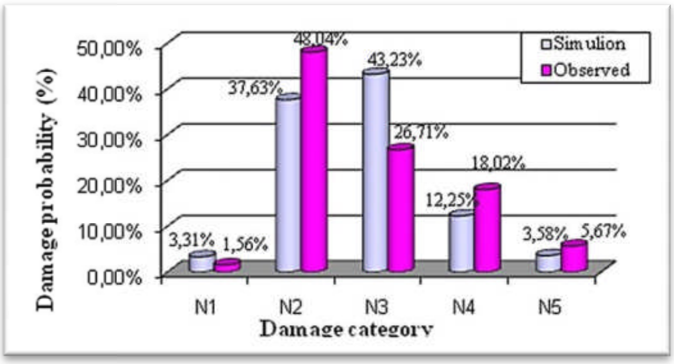


Figure 3.4. Histogram of the damages for 3,663 buildings in Boumerdès city: observed (CGS in situ evaluation), and estimated.

4. DAMAGE DISCUSSION

The comparison of the estimated and observed damages (see Table 3.3 and Fig. 3.4) according to the buildings typologies and seismic code periods' shows that they are more or less close in most cases and become almost the same if the damage categories 2 and 3 are merged**,** see Fig. 3.5**.** The diagnosis and classification of damaged buildings in these 2 categories (damage D2 and D3) require some qualification and an experience that some evaluators did not have unfortunately. This fact leads to different results between the observed damages and those predicted when making statistics by differentiating these damages, D2 and D3. The difference between the observed and estimated damages is also due to the use of American capacity and fragility curves even if a correspondence were made between American and Algerian building typologies. Furthermore, the origin of this difference has also other causes: the elastic response spectrum built from the record signal of Keddara station located at 12 km from Boumerdès site, the Poor quality of execution and structural material, lack of structural design (Belazougui, 2008), the aftershocks effect reaching a magnitude Mw = 5.8 on 27.05.2003, buildings orientation effect relatively to the fault (directivity effect) (case of Ibn

Khaldoun residence buildings) (Dunand, 2005), presence of many flexible stories (Ground floor) as well as the topographic effect in some places close to the rivers crossing the city (Meslem et al., 2012). These parameters influenced the effective damages suffered by the buildings in Boumerdès city.

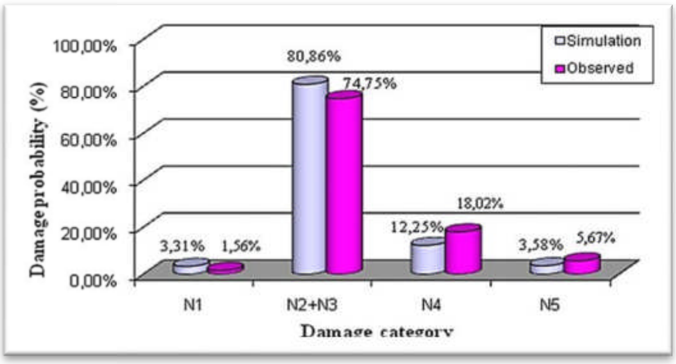


Figure 3.5. Comparison of the observed and simulated building damages in Boumerdès city.

5. CONCLUSION

In this paper, a seismic damage estimation methodology for Algerian buildings based on HAZUS approach (Hazard-United States) was elaborated whose related capacity and fragility curves were adapted to corresponding typologies for Algerian buildings. A data-processing code was developed for this purpose gathering all the methodology steps. This probabilistic methodology was calibrated with the case of Boumerdès city buildings struck by a destructive moment magnitude 6.8 (Mw) earthquake on May 21st, 2003. The seismic damage estimation was performed by representing the Boumerdès earthquake by the elastic response spectrum built from the accelerometer records obtained during the main shock. The results of this scenario in terms of damage were compared with the real observed damages which were assessed. This comparison showed that the theoretical and observed damages are close in the whole of the cases and present a more or less acceptable difference; the results become almost the same if the damage grades 2 and 3 are merged. The origin of the difference between the estimated and observed damages has several causes: adaptation of American capacity and fragility curves to Algerian building typologies, the use of a response spectrum built from the seismic records of free field Keddara station located 12 km from the Boumerdès city, the quality of the expertises and the errors which could be recorded in the damage classification of constructions, the earthquake characteristics, the location of Boumerdès city in the epicentral zone (strong ground motion zone), the poor quality of execution and structural material, lack of structural design, the aftershocks effect reaching a magnitude Mw = 5.8, the buildings orientation effect relatively to the fault (directivity effect), the presence of many flexible stories (Ground floor), as well as the topographic effect in some places close to the rivers crossing the city, etc. These parameters influenced the effective damages suffered by the buildings of the city. Furthermore, the local soil conditions should be known completely in order to provide accurate risk assessment.

The automatic probabilistic processing method by combining its results with GIS tools and GPS location is very helpful for decision making at early days and hours after the occurrence of a disaster as they allow a quick and easy real time survey of the disaster extent.

Finally, we suggest the development of capacity and fragility curves reflecting better the Algerian building context in order to have more precise results with the developed tool.

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