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Assessment of seismic fragility curves for existing RC buildings in Algiers after the 2003 Boumerdes earthquake

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Abstract. The main purpose of this paper is to develop seismic fragility curves for existing reinforced concrete, RC, buildings based on the post earthquake field survey and the seismic performance using capacity design. Existing RC buildings constitute approximately 65% of the total stock in Algiers. This type of buildings, RC, was widely used in the past and chosen as the structural type for the future construction program of more than 2 millions apartments all over Algeria. These buildings, suffered moderate to extensive damage after the 2003 Boumerdes earthquake, on May 21st. The determination of analytical seismic fragility curves for low-rise and mid-rise existing RC buildings was carried out based on the consistent and complete post earthquake survey after that event. The information on the damaged existing RC buildings was investigated and evaluated by experts. Thirty four (34) communes (districts) of fifty seven (57), the most populated and affected by earthquake damage were considered in this study. Utilizing the field observed damage data and the Japanese Seismic Index Methodology, based on the capacity design method. Seismic fragility curves were developed for those buildings with a large number data in order to get a statistically significant sample size. According to the construction period and the code design, four types of existing RC buildings were considered. Buildings designed with pre-code (very poor structural behavior before 1955), Buildings designed with low code (poor structural behavior, between 1955-1981), buildings designed with medium code (moderate structural behavior, between 1981-1999) and buildings designed with high code (good structural behavior, after 1999).

Keywords: reinforced concrete; existing building; post earthquake survey; seismic damage assessment; seismic index method; capacity design; fragility curves

1. Introduction

The 2003 Boumerdes earthquake, which is considered as one of the most damaging earthquake in Algeria, caused huge damage and economic losses to buildings in many areas. The city of Boumerdes hit by a 6.8 magnitude earthquake widespread damage to many existing RC buildings. In terms of seismology, the epicentre of the main shock, which was felt within a 250-km radius from the epicenter (Laouami *et al.* 2006), was located at 36.91° N and 3.58° E, as provided by the Algerian Research Center of Astronomy, Astrophysics, and Geophysics (CRAAG). The Algerian Council of Ministers reported that the 2003 earthquake caused 2,278 deaths and 11,450 injuries,

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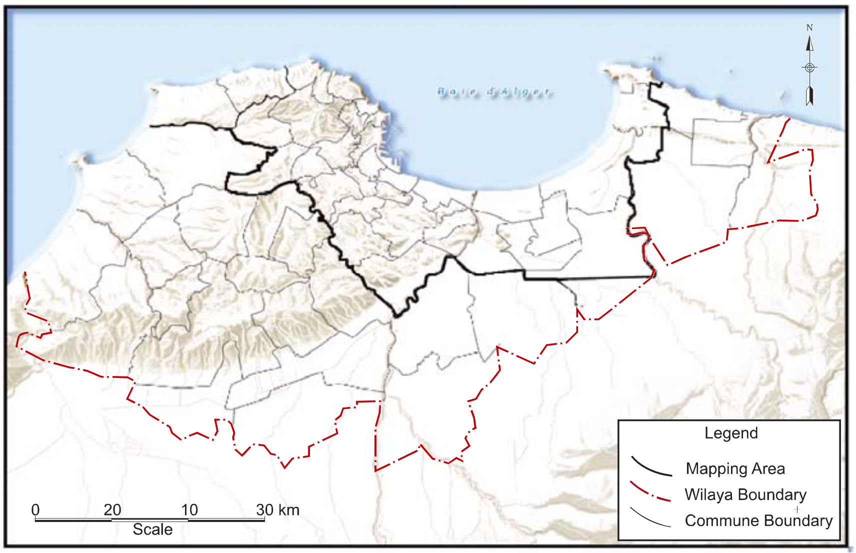


Fig. 1 Map of the concerned study area (225 km²)

and left an estimated 250,000 people (i.e., about 40,000 families) homeless (D.L.E.P. 2004). Accordingly, 17,000 structures were demolished and 116,000 were repaired. The direct economic loss was estimated to be U.S. $5 billion (Ousalem and Bechtoula 2005, Meslem *et al*. 2012).

Expert survey teams investigated the field and conducted post-earthquake survey on selected buildings that suffered various degrees of damage. The data collected was analyzed in order to establish a set of earthquake fragility curves for existing RC buildings and to use these tools in evaluating the seismic vulnerability of RC frames that are representative of the building inventory in the capital Algiers. Hereafter, the main results of the study such as fragility curves using the Japanese seismic index methodology are presented.

2. Description of the urban study area

2.1 Area study

The study area covers almost all the Wilaya (Province) of Algiers, capital of Algeria. This zone is one of high seismic potential with many active faults around. Urban development has been rapidly progressing in Algiers without the development of proper disaster prevention systems against potential earthquakes. After the great 2003 Boumerdes earthquake, it became urgent and necessary to prepare a master earthquake disaster prevention plan in order to mitigate possible future seismic damages in Algiers (JICA-CGS 2006). The seismic micro zoning mapping covers a total area of approximately 225 km2 and a population of 2624428 inhabitants including the surrounding urbanized area. Thirty four (34) communes of fifty seven (57), the most populated and built areas were concerned by this study done jointly between the Japanese International Cooperation Agency (JICA) and the National Earthquake Engineering Research Center (CGS). Fig. 1 shows the map of the concerned study area delimited by the solid bold black line.

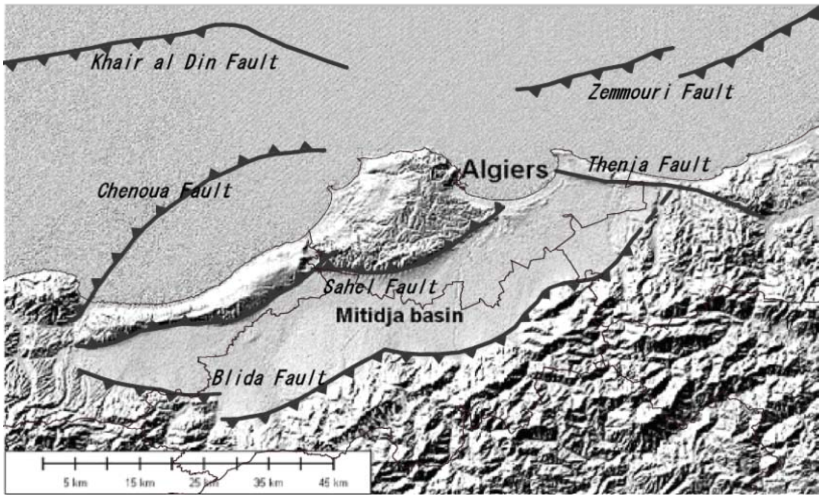


Fig. 2 Identified active faults around the capital Algiers

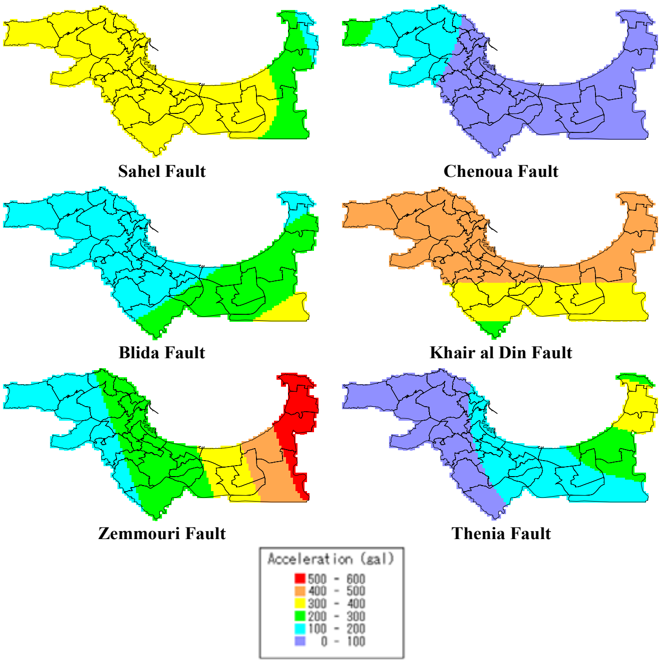


Fig. 3 Acceleration distribution at Bedrock

2.2 Seismic hazard assessment

Many seismic hazard investigations and research projects were achieved for the northern part of Algeria by the CRAAG and CGS using the seismic instrumentation network (Devechère *et al*. 2005). Based on the observed damage and the post earthquake survey, taking in consideration the current situation and the past experience of Algeria from previous earthquakes, possible scenarios were drawn up. In total, six major active faults have been identified and chosen at the periphery of

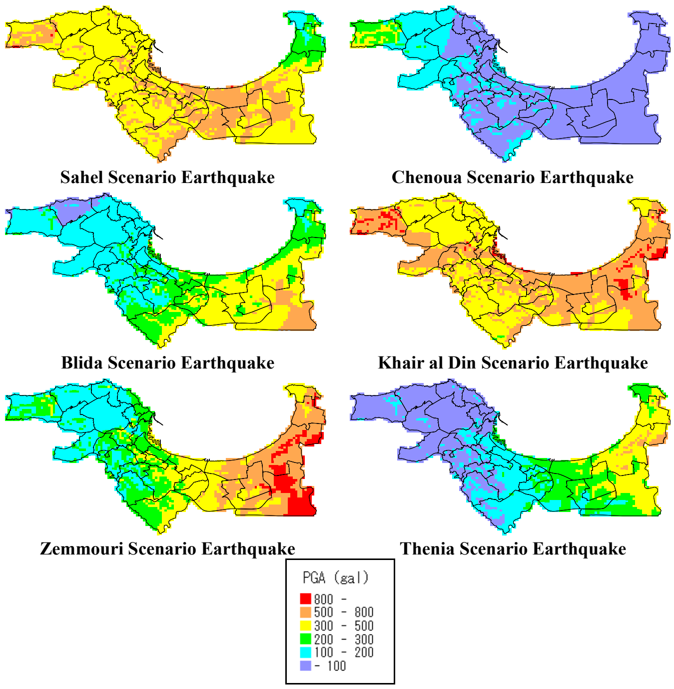


Fig. 4 Peak ground acceleration distribution at ground surface

the region subject to the survey and used to create a seismic scenario so as to estimate magnitudes of possible future earthquakes in consideration of recurrence periods. The Sahel, Chenoua, Blida, Thenia and Zemmouri faults, in addition to Khair Eddine offshore fault were considered in this study. Fig. 2 shows the location of each active fault. Expected magnitude at the bedrock and the soil surface associated with a 475 years return period for each active fault, are summarized in Fig. 3, and Fig. 4, respectively.

2.3 Post earthquake survey of existing RC buildings

The number of existing RC buildings in the thirty four (34) communes was estimated in accordance with the GIS data and the result of inventory survey. A total sampling number of 99688 existing RC buildings were investigated in the whole study area. The building inventory was conducted based on the ratio of the population and the survey was carried out by experts of CGS with the cooperation of JICA's experts (Japanese International Cooperation Agency). The distribution pattern of these buildings shows the characteristics of Algiers's urban growth. Fig. 5 shows the distribution of the existing RC buildings in Algiers. The post earthquake survey was conducted in order to estimate their damage and develop seismic fragility curves for the future seismic risk planning. In addition to a standard classification by structural type, it was necessary to group the buildings by other consistent characteristics and earthquake performance (Ertugul *et al*. 2008, Anastasia *et al*. 2012). The inventory of post earthquake surveyed buildings was classified in four different performance classes according to their characteristics in terms of:

· **Number of levels:** five types of levels were considered in this study (1 to 3 levels, 4 levels, 5

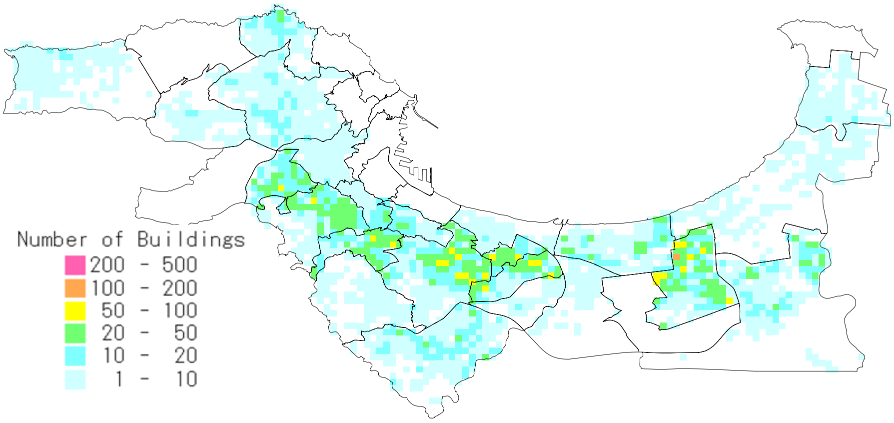


Fig. 5 Distribution of the existing RC buildings

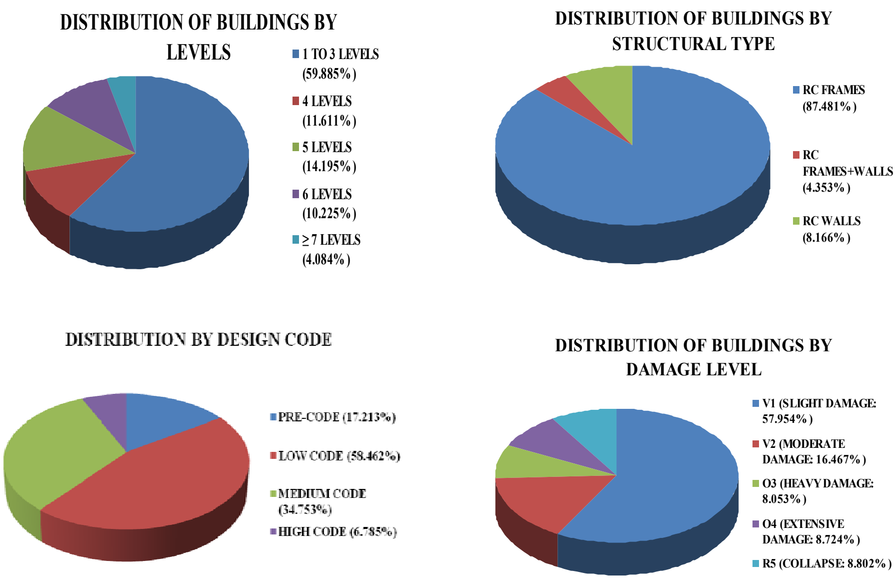


Fig. 6 Characteristics of the existing RC buildings

levels, 6 levels and 7 and more levels).

· **Structural type:** three structural types were considered (resisting moment frame systems, dual systems and shear wall systems).

· **Design code:** four types of design codes were considered according to the age of the construction (pre-code code: concerns buildings built before 1955, low code: concerns buildings built between 1956 and 1980 -AS55 recommendations and PS69 code, medium code: concerns buildings built between 1981 and 1999 -RPA81, RPA83, RPA88, and high code: concerns buildings built after 1999 -RPA99 and RPA99/Version 2003).

· **Damage level:** five grades of damage level were considered, V1 (no structural damage and minor damage for non structural elements, the building is fully operational), V2 (no structural damage and slight damage for non structural elements, the building needs some reparation and can be operational), O3 (moderate structural damage and heavy damage for non structural elements, building must be evacuated), O4 (heavy structural damage and extensive damage for non structural elements, building must be evacuated and is near to collapse), R5 (total collapse of building).

Fig. 6 summarizes the distribution ratio of buildings according to their different characteristics.

3. Damage functions of buildings

To establish the seismic fragility curves for existing RC buildings, the Japanese seismic index methodology based on the capacity design and the European Seismic Scale, EMS 98 were applied (Barbat *et al*., 2008). The results of the post earthquake survey building inventory after the 2003 Boumerdes earthquake were those provided by experts of CGS. The assessment of the seismic index, Is, concerned one thousand (1000) existing RC buildings and three structural types: resisting moment frame systems, dual systems and shear wall systems. The seismic capacity performance of the selected structures was carried using the second screening level. The one thousand (1000) existing RC buildings have been chosen using the GIS database, taking into account the specificities of the communes in terms of damage ratio, number of buildings, population density, age of buildings, number of levels and the structural types.

3.1 Seismic index method

Although the most reliable analytical method would be the use of complete nonlinear time history analysis, the present state of the art in general has been an increasing interest in the capacity design referred to nonlinear analysis procedures (Shinozuka *et al*. 2000a, Nour El-Din 2007, Borzi *et al*. 2013, Carlota *et al*. 2012). Two keys elements of the seismic index method are “Demand” and “Capacity”. Demand represents intensity of the ground motion to which the buildings are subjected, while capacity represents the building ability to resist the seismic demand. The seismic index method requires determination of the capacity in terms of displacements and resistance for resisting vertical structural elements individually, and then for the whole story (Ghobarah 2004, Moehle 2007, Rodriguez 2009, Polese *et al*. 2011).

3.1.1 Japanese methodology for seismic vulnerability of existing RC buildings

The methodology is available for existing RC buildings (JBDPA 2001). The seismic evaluation shall be based on both site inspection and structural calculation to represent the seismic performance of a building in terms of seismic index of structure, Is, and seismic index of non structural elements, In. the seismic safety of the building shall be judged based on standard for judgment on seismic safety wherein seismic performance demands are prescribed.

The methodology shall be applied for existing low-rise and medium-rise reinforced concrete buildings. Three levels of screening procedures may be used in accordance with the purpose of evaluation and the structural characteristics of the building. The second level is the most used and was applied in this study.

3.1.2 Guideline of the methodology

The guideline is based on several preliminary steps that are summarized hereafter:

1. Building inspection shall be conducted to check the structural characteristics which are necessary to calculate the seismic index of the structure, Is.

2. Appropriate methods for inspection should be selected in accordance with the screening level.

3. Material strengths and cross-sectional dimensions for calculation of strengths of structural members.

4. Cracking in concrete and deformations of structure.

5. Building configuration.

6. In detailed inspection, sampling tests of concrete cylinders extracted from the building shall be conducted for structural members (columns, beams, walls, etc.).

7. If the design drawings of the building are not available, inspections on the structure dimensions, diameters, and arrangements of reinforced bars shall be conducted on site which are necessary for seismic evaluation of the building in accordance with the screening level.

The seismic index of structure, I_s, shall be calculated at each story and in each principal horizontal direction of the building according to Eq. (1)

$$I_s = E_0 S_d T = C F S_d T \qquad (1)$$

where:

E_0: Basic seismic index of structure, function of C and F.
C: Lateral strength capacity index.
F: Ductility capacity index.
S_d: Irregularity index.
T: Time index.

For the second level screening procedure, only vertical members are considered and shall be classified into five (05) categories listed in Table 1.

Seismic index of non structural elements, I_n, is used to judge the safety of human lives or secure of evacuation routes against the fall-down or the spall-off of non structural elements, especially external walls. It is given by Eq. (2)

$$I_n = 1 - BH = 1 - (f + (1 - f)t)H \qquad (2)$$

Where:

B: Construction index.
H: Human risk.
f: Conformability index.
t: Deterioration index.

Seismic safety of structure shall be judged by comparing I_s to I_{S0} using Eq. (3):

$$I_s \geq I_{S0} = E_S Z G U \qquad (3)$$

where:

I_{S0}: Seismic demand index of structure.
E_S: Basic seismic demand index of structure, standard values of which shall be selected as follows regardless of the direction of the building. For the second level $E_S = 0.6$.
Z: Zone index.
G: Ground index.
U: Usage index according to the importance of the building.

3.1.3 Main steps for the second level screening procedure

The main steps for the seismic evaluation of existing reinforced concrete buildings using the second level screening procedure are the followings:

1. Determination of vertical structural elements (dimensions, cross sectional dimensions, reinforcement, etc.)

2. Evaluation of the ultimate flexural strength of columns according to vertical axial force *N*:

For $N_{max} \geq N > 0.4bDF_c$, the ultimate bending moment capacity is calculated with Eq. (4)

$$M_U = \left(0.8a_t\sigma_y D + 0.12bD^2F_c\right)\left(\frac{N_{max}-N}{N_{max}-0.4bDF_c}\right) \quad (4)$$

For $0.4bDF_c \geq N > 0$, the ultimate bending moment capacity is evaluated with Eq. (5)

$$M_U = 0.8a_t\sigma_y D + 05ND\left(1-\frac{N}{bDF_c}\right) \quad (5)$$

For $0 > N \geq N_{min}$, the ultimate bending moment capacity is assessed with Eq. (6)

$$\mathrm{M_U} = 0.8\mathrm{a_t}\sigma_\mathrm{y}\mathrm{D} + 0.4\mathrm{ND} \quad (6)$$

where:

$N_{max} = bDF_c + a_g\sigma_y$: axial compressive strength [N]
$N_{min} = -a_g\sigma_y$: axial tensile strength [N]
N: vertical axial force [N]
a_t: total cross sectional area of tensile reinforcing bars [mm²]
a_g: total cross sectional area of reinforcing bars [mm²]
b: column width [mm]
D: column depth [mm]
σ_y: yield strength of reinforcing bars [N/mm²]
F_c: concrete compressive strength [N/mm²]

The ultimate flexural strength of the wall with boundary columns shall be calculated with Eq. (7)

$$M_U^W = a_t\sigma_y l_W + 0.5\sum(a_{Wy}\sigma_{Wy})l_W + 0.5N_W l_W \quad (7)$$

where:

N_W: total axial force in the boundary columns attached to the wall [N]
a_t: cross sectional area of the flexural reinforcement of the boundary column in the tension side of wall [mm²]
a_{Wy}: vertical reinforcing bars in the wall [mm²]
σ_{sy}: yield strength of the flexural reinforcing bars of a boundary column [N/mm²]
σ_{wy}: yield strength of the flexural reinforcing bars in the wall [N/mm²]
l_W: distance between the center of the boundary columns of the wall [mm]

The ultimate shear strength for columns shall be calculated with Eq. (8)

$$Q_{SU} = \left(\frac{0.053p_t^{0.23}(18+F_c)}{\frac{M}{Qd}+0.12} + 0.85\sqrt{p_W\sigma_{Wy}^{S}} + 0.1\sigma_0\right)bj \quad (8)$$

where:

p_t: tensile reinforcement ratio [%]
p_W: tensile reinforcement ratio [%]

Table 1 Classification of vertical structural elements

Vertical elements	Definition
Shear wall	Walls whose shear failure precedes flexural yielding
Flexural wall	Walls whose flexural yielding precedes shear failure
Shear column	Columns whose shear failure precedes flexural yielding
Flexural columns	Columns whose flexural yielding precedes shear failure
Extremely brittle (short) columns	Columns whose $h_0/D \leq 2$ and shear failure precedes flexural yielding

σ_{Wy}^{s}: yield strength of shear reinforcing bars [N/mm²]
σ_0: axial stress in column [N/mm²]
d: effective depth of column, $d = D - 50mm$ can be applied)
M/Q: shear span length. Default value is $h_0/2$
j: distance between centroids of tension and compression forces, default value is $j = 0.8D$

The ultimate shear strength for walls shall be calculated with Eq. (9)

$$Q_{SU} = \left(\frac{0.053p_{te}^{0.23}(18+F_c)}{\frac{M}{Ql}+0.12} + 0.85\sqrt{p_{se}\sigma_{0e}} + 0.1\sigma_{0e}\right)b_e j_e \quad for \quad 1 \leq \frac{M}{Ql} \leq 3 \tag{9}$$

Where:
$p_{te} = 100a_t/(b_e l)$: equivalent tensile reinforcement ratio [%]
l: wall length
$b_e = \sum A/l$: equivalent thickness of the wall
$\sum A$: cross sectional area of the wall
$p_{se} = a_h/(b_{se})$: equivalent lateral reinforcement [%]
a_h: cross sectional area of a pair of the lateral reinforcement
s: spacing of the lateral reinforcement
σ_{Wy}: yield strength of the lateral reinforcement bar of the wall
$\sigma_{0e} = N/(b_e l)$: axial stress
j_e: distance between the centroids of tension and compression forces, and may be taken as je = l_W or $0.8l$

The ultimate shear force at ultimate yielding is calculated with Eq. (10)

$$Q_{MU} = \frac{2M_U}{H_0} \tag{10}$$

The classification of vertica structural elements is based on the failure mode, by comparing Q_{SU} to Q_{MU}, according to Table 1.

The basic seismic index of the structure is calculated for each story and each lateral direction based on the ultimate strength, failure mode and ductility of the building.

a) Ductility dominant basic seismic index

The vertical structural elements are classified in three (03) groups or less by their ductility indices F. The basic seismic index for ductile elements is calculated with Eq. (11)

$$E_0 = \frac{n+1}{n+i}\sqrt{(C_1F_1)^2 + (C_2F_2)^2 + (C_3F_3)^2} \tag{11}$$

where:

n: number of levels
i: considered level
C_1: strength index C of the first group
C_2: strength index C of the second group
C_3: strength index C of the third group
F_1: ductility index F of the first group
F_2: ductility index F of the second group
F_3: ductility index F of the third group

b) Strength dominant basic seismic index

The basic seismic index for non ductile elements is calculated with Eq. (12)

$$E_0 = \frac{n+1}{n+i}\left(C_1 + \sum \alpha_j \, C_j\right)F_1 \tag{12}$$

where α_j is the effective strength factor in the j^{th} group at the ultimate deformation.

The seismic index of the structure is evaluated at each story and in each principal horizontal direction of the building, according to Eq. (13)

$$I_s = E_0 S_d T = CFS_d T \tag{13}$$

The next step of the methodology is to evaluate the strength index of the whole structure based on the elements capacities using Eq. (14)

$$\mathrm{C} = \frac{\mathrm{Q_U}}{\sum \mathrm{W}} \tag{14}$$

In Eq. (14), Q_U is the ultimate lateral load -carrying capacity of the vertical members in the story concerned and $\sum W$ is the weight of the building including live load for seismic calculation supported by the story concerned.

The seismic demand index of the structure can be evaluated by Eq. (15) regardless of the story in the building.

$$I_{S0} = E_S ZGU \tag{15}$$

As a final step, the seismic safety of the building shall be judged by comprehensive assessment using Eq. (16)

$$I_s \geq I_{S0} \tag{16}$$

If Eq. (16) is satisfied, the building is classified as "safe". The building possesses the seismic capacity required against the expected earthquake motions. Otherwise, the building is classified to be "unsafe". For buildings classified "safe", additional condition should be satisfied which is given by Eq. (17)

$$C_{TU} S_d \geq max \begin{cases} 0.3ZGU \\ 0.3 \end{cases} \tag{17}$$

where C_{TU} is the cumulative strength index at the ultimate deformation of the structure.

3.2 Illustrative examples

The results of the seismic performance, I_S, assessed with the seismic index methodology of two

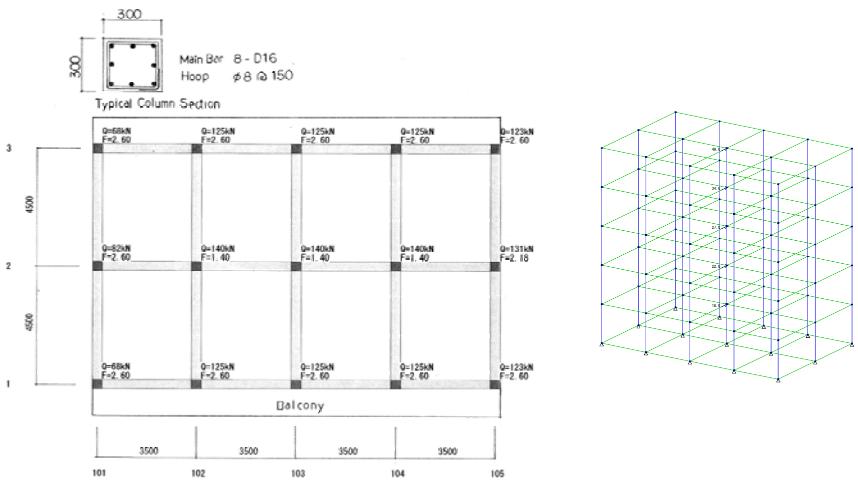


Fig. 7 Drawings and numerical model of building designed with pre-code

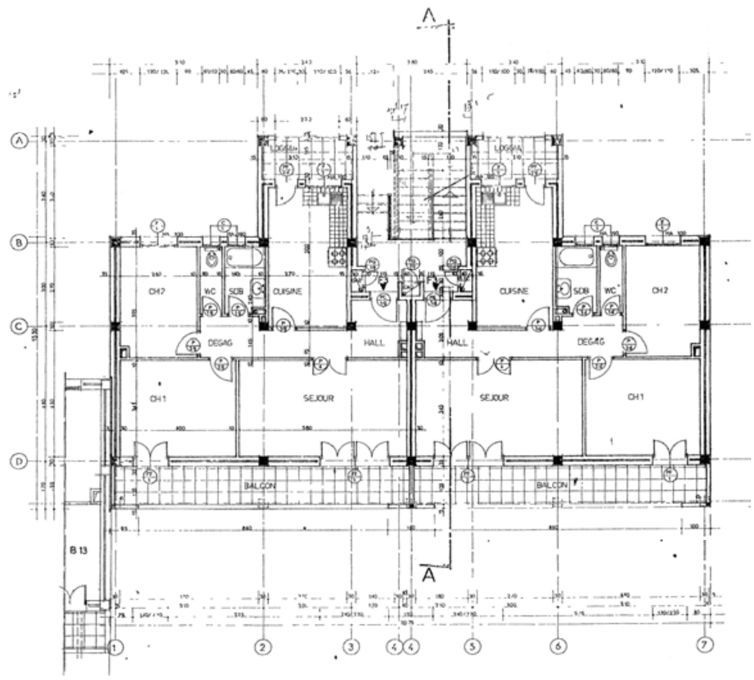


Fig. 8 Drawings of building designed with medium code

Table 2 Seismic index, I_S, of building designed with pre-code

Story	X direction			Y direction		
	I_S	$C_T S_d$	Decision	I_S	$C_T S_d$	Decision
5	0.54	0.24	Unsafe	0.51	0.23	Unsafe
4	0.46	0.22	Unsafe	0.43	0.21	Unsafe
3	0.33	0.19	Unsafe	0.31	0.17	Unsafe
2	0.25	0.15	Unsafe	0.26	0.14	Unsafe
1	0.19	0.13	Unsafe	0.21	0.13	Unsafe

Table 3 Seismic index, I_S, of building designed with medium code

Story	X direction			Y direction		
	I_S	C_TS_d	Decision	I_S	C_TS_d	Decision
5	1.13	0.36	Safe	1.13	0.36	Safe
4	0.62	0.20	Safe	0.62	0.20	Safe
3	0.47	0.16	Unsafe	0.47	0.16	Unsafe
2	0.53	0.18	Unsafe	0.53	0.18	Unsafe
1	0.41	0.18	Unsafe	0.41	0.18	Unsafe

typical residential existing RC buildings are presented hereafter. Demands in terms of bending moments, shear forces and axial forces was performed with SAP2000 (Wilson 2004). The first building with five (05) levels was built in 1953 before any seismic design code (pre-code). The second building with five (05) levels was built in 1985 and designed with medium code RPA 88 (CGS 2003). Fig. 7, and Fig. 8, shows the drawings of the two buildings, where Table 2, and Table 3, illustrate the final results of the analysis for each of the main direction of the two buildings, respectively (Inoue 2008, Zermout *et al*. 2008, Mehani *et al*. 2011).

The above building did not satisfy the criteria of the methodology which are $I_S \geq 0.6$ and $C_TS_d \geq 0.3$ for the second screening level, at each level in both directions. Hence, the building is jugged unsafe.

The second building designed with medium code according to the Algerian seismic code, RPA88, satisfied the criteria of the methodology, $I_S \geq 0.6$ and $C_TS_d \geq 0.3$, only for the two upper levels. However, the building was classified unsafe and needs strengthening.

3.3 Seismic fragility curves

In order to estimate the seismic risk of a building, seismic fragility curves are widely used (Ji *et al*. 2007, Erberik 2008, Park *et al*. 2009). A vulnerability function describes the relation between seismic intensity during the earthquake event and the damage rate of the structures. They can be represented as damage curves or fragility curves. A fragility curve shows the expected severity of damage associated with each level of hazard. Fragility curves are prepared for each damage state showing the probability of occurrence of that damage state in relation to level hazard (Shinozuka *et al*. 2000b).

In other words, fragility curves define the probability that the expected global damage, d, of a structure exceeds a given damage state, d_{Si}, as a function of a parameter quantifying the severity of the seismic action. Thus for each damage state, the corresponding fragility curve is completely defined by plotting $P[d \geq d_{Si}]$ in the ordinate and the chosen seismic hazard parameter SHP (PGA, S_d or SI, etc.) in the abscissa. For a given damage state, d_{Si}, a fragility curve is well described by the following lognormal probability density function

$$p\left[\frac{d_{Si}}{SHP}\right] = \emptyset\left[\frac{1}{\beta_{dSi}} ln\left(\frac{SHP}{SHP_{dSi}}\right)\right] \tag{18}$$

where SHP is the seismic hazard parameter, representing the median value of (PGA, S_d or SI, etc.) at which the building reaches a certain threshold of the damage state, d_{Si}, β_{dSi} the standard deviation of the natural logarithm of the seismic hazard parameter of the damage state d_{Si} and $\emptyset$ the standard normal cumulative distribution function (Ramamoorthy *et al*. 2006). In probability theory, a log-normal distribution is a continuous probability distribution of a random variable whose logarithm is normally distributed. A random variable which is log-normally distributed takes only positive real values which is the case of our interest.

3.4 Methodology for damage curve of RC buildings

Damage curves for existing RC buildings were estimated based on the results of the post earthquake survey inventory (analyzed in detail by experts of CGS), the post earthquake survey of intensity and the European Macro seismic scale, EMS98 (formerly MSK). Damage to buildings was estimated based on the number of existing RC buildings, vulnerability of each structural typology in accordance with the age of the construction (damage rates based on EMS98 definitions) and the intensity of ground (observed and recorded). The EMS98 was based on the modification of the MSK scale buildings vulnerability classes (Rosseto 2003). The correlation between the different intensities and the peak ground acceleration is shown in Table 4.

The European Macro seismic scale EMS98 with the corresponding grades is shown in Fig. 9.

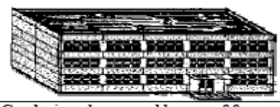
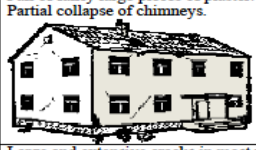
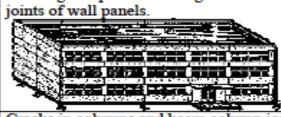
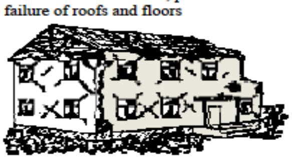
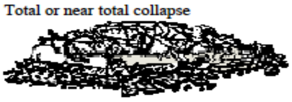
Classification of Damage		
	Masonry	**RC Building**
Grade 1: Negligible to slight damage (no structural damage, slight non-structural damage)	Hair-line cracks in very few walls. Fall of small pieces of plaster only. Fall of loose stones from upper parts of buildings in very few cases. 	Fine cracks in plaster over frame members or in walls at the base. Fine cracks in partitions and infills 
Grade 2: Moderate damage (slight structural damage, moderate non-structural damage)	Cracks in many walls. Fall of fairly large pieces of plaster. Partial collapse of chimneys. 	Cracks in columns and beams of frames and in structural walls. Cracks in partition and infill walls; fall of brittle cladding and plaster. Falling mortar from the joints of wall panels. 
Grade 3: Substantial to heavy damage (moderate structural damage, heavy non-structural damage)	Large and extensive cracks in most walls. Roof tiles detach. Chimneys fracture at the roof line; failure of individual non-structural elements (partitions, gable walls). 	Cracks in columns and beam column joints of frames at the base and at joints of coupled walls. Spalling of concrete cover, buckling of reinforced rods. Large cracks in partition and infill walls, failure of individual infill panels. 
Grade 4: Very heavy damage (heavy structural damage, very heavy non-structural damage)	Serious failure of walls; partial structural failure of roofs and floors 	Large cracks in structural elements with compression failure of concrete and fracture of rebars; bond failure of beam reinforced bars; tilting of columns. Collapse of a few columns or of a single upper floor. 
Grade 5: Destruction (very heavy structural damage)	Total or near total collapse 	Collapse of ground floor or parts (e. g. wings) of buildings. 

Fig. 9 Classification of damage to masonry and RC buildings by EMS 98

Table 4 Relation between different intensities scale and maximum acceleration

JMA	I	II	III	IV	V	VI	VII				
MM	I	II	III	IV	V	VI	VII	VIII	IX	X XI XII	
MSK	V	VI	VII	VIII	IX	X	XI XII				
Acc	1	2	5	10	20	50	100	200	500	1000	cm/s_2

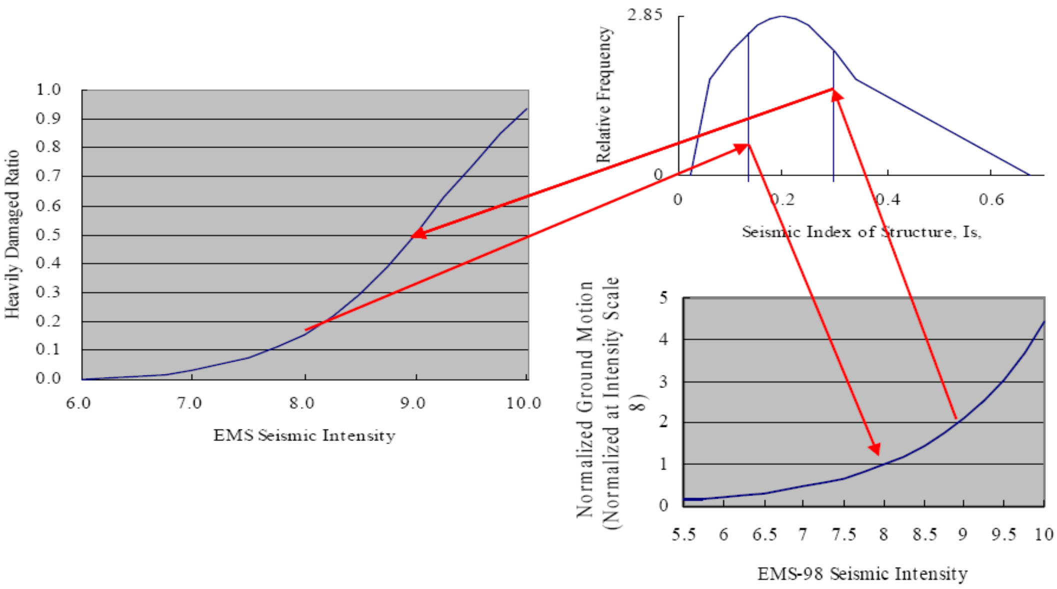


Fig. 10 Main process to determine damage curves for existing RC buildings

Table 5 Mean and standard deviation of the seismic index I_S

Seismic index I_S	Mean	Standard deviation
Pre-code	0.09	0.08
Low code	0.13	0.09
Medium code	0.17	0.11
High code	0.21	0.12

It has been proposed to introduce the idea of a distribution of seismic index of structure I_S, for each structural type and combine that with the surveyed damage ratio in order to develop a damage curve. This is a new methodology for determining a building damage function. The supposed distribution of seismic index, I_S, for investigated structures was considered as lognormal distribution. Fig. 10, shows the procedure and the relationship between the post earthquake surveyed intensity, the damage ratio from field, the seismic index I_S, and the probabilities of damage buildings in accordance with EMS98. This Figure illustrates a damage curve for a pre-code (non-engineered) existing RC frame structure, as an example.

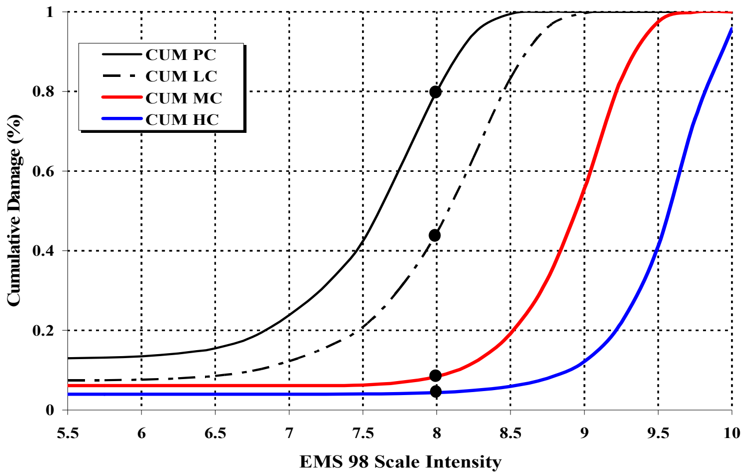


Fig. 11 Fragility curves according to seismic design code

Table 6 Cumulative damage for an intensity of 8

Design code	Pre-code	Low code	Medium code	High code
Cumulative Damage (%)	79.95	44.38	8.43	4.35

The results of the seismic index, I_S, in terms of mean and the standard deviation of the one thousand investigated existing RC structures of the four groups are shown in Table 5.

3.5 Fragility curves of investigated RC buildings

Specific seismic fragility curves have been developed for existing RC buildings of Algiers city, according to the seismic code design of the structures, taking into account the age of the construction (Ghosh 2010, Rosseto 2004). Fig. 11 shows these seismic fragility curves for the pre-code, the low code, the medium code and the high seismic design code. It is apparent that the non-engineered existing RC buildings (pre-code) show high expected seismic damage and are the most vulnerable in case of future earthquakes.

Another important observation consists in the fact that for the same intensity the gap in term of cumulative damage ratio is low between high and medium code, whereas, it is important between high, low and pre-code, as illustrated in Fig. 11. As an example, Table 6, summarizes the cumulative damage ratios for the four design code groups for an intensity of eight (I=8).

It is clearly seen in the figure that, in general, the older buildings are more vulnerable than the newer buildings. Aging of buildings may be mostly responsible for this observation, especially for non-engineered existing RC buildings. However, the several revisions of the Algerian seismic code in 1983, 1988, 1999 and 2003 might affect the reduction of building damage.

4. Conclusions

The seismic fragility curves were expressed by the damage probabilities of structures according to the design codes, taking into account the age of the buildings. In order to characterize the damage state of existing RC buildings, the Japanese seismic index methodology was applied as the damage characterization measure. The adopted method was applied to Algiers, which is a typical Mediterranean city, located in a moderate to high seismic hazard area. Thirty four communes (districts), the most populated of Algiers were considered in this study. The assessment of the seismic index concerned one thousand existing RC buildings and three structural types: resisting moment frame systems, dual systems and shear wall systems. The selected buildings were classified into four groups depending on the age and the design codes as following: pre-code code: concerns buildings erected before 1955, low code: concerns buildings erected between 1956 and 1980, medium code: concerns buildings erected between 1981 and 1999 and high code: concerns buildings erected after 1999. One of the main conclusions showed that, for the same intensity the gap in term of cumulative damage ratio is low between high and medium code, whereas, it is important between high, low and pre-code. This is due to the improvement of the Algerian seismic code and the details of the structural elements at the plastic hinge region and the beam-column connections.

The present seismic fragility curves must be used with careful by the users since in our case these curves were derived for existing RC building erected in Algiers city. The methodology is still applicable for other regions by considering the specificities of the seismic hazard and buildings characteristics of the studied area. The obtained seismic fragility curves constitute excellent information sources and tools for risk managements, emergency planning and also useful for civil protection, prevention and preparedness for the city of Algiers. The accuracy of the proposed fragility curves can further be improved by introducing building damage data of neighboring cities and the result of analytical studies.

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