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Seismic Vulnerability Assessment of Buildings in Algiers Area

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Abstract**—**Several models of vulnerability assessment have been proposed. The selection of one of these models depends on the objectives of the study. The classical methodologies for seismic vulnerability analysis, as a part of seismic risk analysis, have been formulated with statistical criteria based on a rapid observation. The information relating to the buildings performance is statistically elaborated. In this paper, we use the European Macroseismic Scale EMS-98 to define the relationship between damage and macroseismic intensity to assess the seismic vulnerability. Applying to Algiers area, the first step is to identify building typologies and to assign vulnerability classes. In the second step, damages are investigated according to EMS-98.

Keywords**—**Damage, EMS-98, inventory building, vulnerability classes

I. Introduction

VULNERABILITY, as a part of risk, is defined as the intrinsic predisposition of the exposed element of being susceptible to suffer a loss as a result of the occurrence of an event with a given intensity [1]. In other words, vulnerability represents the possibility of damage or loss of buildings in relation to a seismic event. It may be expressed in probabilistic terms, for prediction purposes, or in statistical terms for purposes of processing the data of post-earthquake survey. The currently available methods for the seismic evaluation of the existing buildings have been formulated with statistical criteria based on a rapid observation and expert opinion. Other methods are based on the analysis of the building by using simple analytical models or detailed procedure analyses [2]. Some authors have derived, from the EMS-98 definitions a methodology to assess the seismic vulnerability [3]. This method has to be employed when the seismic hazard is described in term of macroseismic intensity.

When a great number of buildings are considered in urban area, analytical methods, using simple models, should have the capacity to analyze the whole of buildings in short period of time. However, the detailed procedure analysis, takes more time and serves for the evaluation of individual buildings only and consequently do not remain very practical for earthquake scenarios.

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The main purpose of this paper is the evaluation of physical vulnerability of buildings by using EMS-98 definitions [4]. The vulnerability assessment in Algiers area is carried out according to the following parameters: inventoried buildings are classified into vulnerability classes, and a damage probability matrix is assigned to each class. Vulnerability classes are attributed to the buildings considering their typological, structural, geometric and constructive characteristics.

II. The Macroseismic Method Defined by EMS-98 Scale

A. EMS-98 Scale

In the EMS-98 scale [4] six classes of decreasing vulnerability are proposed (A-F) (see Fig. 1). The first three represent a typical adobe house, brick building and reinforced concrete structures (RC). They should be compatible with building classes A-C in the MSK-64 and MSK-81 scales respectively. Classes D and E represent structures with improved level of earthquake resistant design (ERD): they are reinforced concrete, reinforced or confined masonry and steel structures. Class F represents the vulnerability of a structure with a high level of earthquake resistant design (ERD). In the Vulnerability Table (Fig. 1), for each building type there is a line showing the most likely vulnerability class and also the probable range. The position along this line has to be found considering other factors as: present state, quality of construction, irregularity of building in plan and in elevation and level of earthquake resistant design (ERD).

B. EMS-98 Damage Probability Matrix

The damage probability matrix is a matrix which expresses the statistical distribution of the degrees of damage for a given macroseismic intensity [5]. For each vulnerability class, the damage described by the scale for each degree of intensity may be reported in terms of a damage probability matrix. According to the EMS-98 scale, 5 degrees of damage are considered:

1) Degree 1: Negligible to slight damage (no structural and slight non-structural damage).
2) Degree 2: Moderate damage (slight structural and moderate non-structural damage).
3) Degree 3: Substantial to heavy damage (moderate structural and heavy non-structural damage).

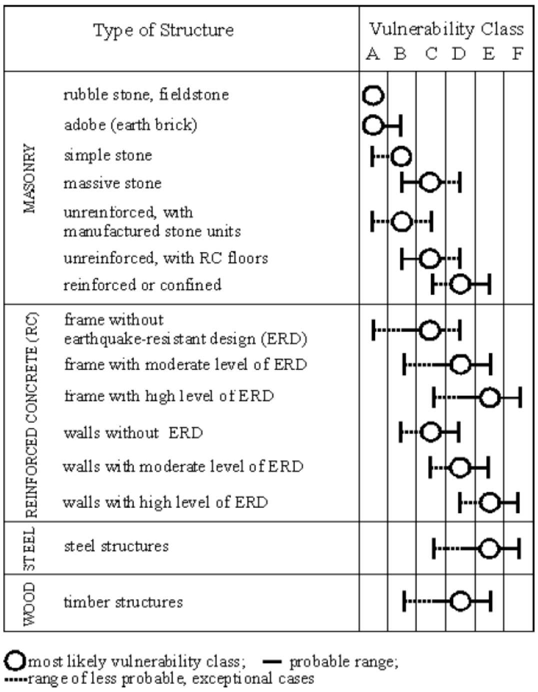

Fig. 1 Buildings typologies and vulnerability classes according to EMS-98 scale

4) Degree 4: Very heavy damage (heavy structural and very heavy non-structural damage)
5) Degree 5: Destruction (very heavy structural damage)

A possible distribution to represent buildings damage is the binomial distribution [6]. The probability function is:

$$p_k = \frac{5!}{k!(5-k)!}\,(d)^k\,(1-d)^{5-k} \qquad (1)$$

Where p_K is the probability of having a damage grade D_K (k= 0 - 5) and d is the mean damage.

The binomial distribution has been successfully used for the statistical analysis of data collected after the 1980 Irpinia earthquake (Italy) [6]. So, it may be used in order to build the damage probability matrix. It is possible to determine the values of the mean damage d able to represent the terms: *few*, *many* and *most,* defined in the EMS-98. Some authors [3] consider upper and lower bounds of the mean damage grade in the plausible way and the possible way according to the quantitative definitions of the EMS-98.

III. Case Study

Algiers, capital of Algeria, is located in an area of high seismicity. Historically, north of Algeria knew several earthquakes [7], among which some were catastrophic (1716, 1790, 1825, 1856, 1954, 1980 and 2003). Algiers is located in the western part of Mediterranean. It is the first largest city in Algeria with more than 3 million people. Fig. 2 shows the limits of the study urban area (26 municipalities of 57). This area is characterized by a dense and old building stock, and by a great population growth. The total number of buildings is around 74000 in the study area, with a wide range of structural types. This size allows a visual analysis of the entire building population while maintaining a large variety of buildings.

Fig. 2 Study area

Fig. 3 Town of Algiers – masonry buildings

A. Census Data and Buildings Inventory

When a large population of buildings is considered, each building cannot be analyzed separately. Firstly, each building must be classified into a seismic category. Generally, within a building population there are many different structural types. To simplify, we divide the population into groups of buildings with similar characteristics in terms of seismic performance. These categories are related to the structural types within the building population. The vulnerability of each category is quantified by the distribution of its buildings in different vulnerability classes. These are defined by their vulnerability curves.

The census of population and dwellings conducted by the National Office of Statics in 2008 [8] includes about 260 000 dwellings and 2 million people in the study area. However, the census data are insufficient to identify building typologies and to assign vulnerability classes according to EMS-98 scale. For this reason a collection of additional data is necessary. So, supplementary inventory of buildings through the study area is carried out. Among more than 74000 buildings, 15259 were inventoried. For each building, the following characteristics are considered:

1) Building type (house, building, precarious)
2) Building use (dwelling, educational…)
3) Age of building – code era
4) Number of floors
5) Structure system
6) Plan and vertical irregularity
7) State of preservation

For each of municipality, using statistical processing of data, buildings are classified according to the type as: (1) buildings, (2) individual houses and (3) precarious houses, and according to the period time of construction as: (1) before 1962, (2) between 1962 and 1980, (3) between 1981 and 1998, and (4) after 1999. This distinction on period time of construction is more significant. Constructions designed before 1962, are buildings or individual houses with masonry or reinforced concrete structure without any seismic feature. The buildings designed between 1962 and 1980 are reinforced buildings, without any seismic resistant design. The last category of buildings, designed between 1981 and 1998 and after 1999 are built, respectively, according to the first Algerian seismic code (1981) [9], and the second seismic code (1999) [10], with a level of seismic resistant design.

The classification according to building types gives the following percentages (see Fig. 4): 15.73% are residential building and 66.23% are individual houses. The statistics show that 68% of the buildings in the study area are 1 to 3 floors. The buildings designed before 1962 represent 52% of the total (Fig. 5), they are mainly masonry buildings and low percentage of reinforced concrete buildings without seismic resistant design. 15% of the total of the buildings without seismic design were built between 1962 and 1980. The percentage of buildings having minimum seismic resistant design was built between 1981 and 1998. Among the inventoried buildings in the study area, there are no buildings built after 1999.

B. Building Typologies and Vulnerability Analysis

The analysis of the inventoried buildings provides the following percentages: 60% of masonry buildings are classes A and B, with respectively 25.78% and 34.27%. The classes C, D and E represent 39.95% of the total of buildings, with respectively 16.54%, 16.43% and 6.97% (Fig. 6). The received percentages for D, E and F classes are very conditional, because there are not information for which level of earthquake the buildings had been designed.

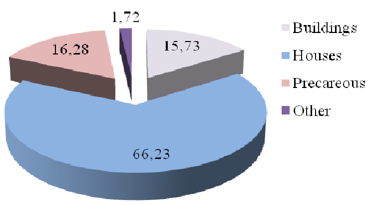

Fig. 4 Building distributions according to their types

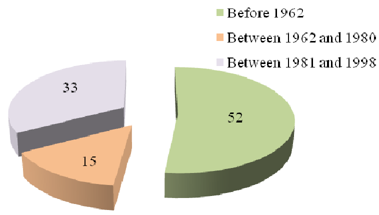

Fig. 5 Building distributions according to the construction period

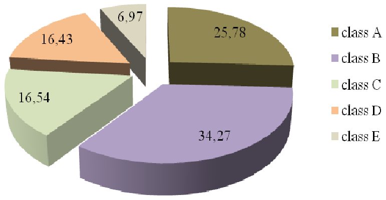

Fig. 6 Vulnerability classes of inventoried buildings

According to the characteristics of the inventoried buildings, they are classified into 12 typological categories as:

1) M0: precarious houses
2) M1: unreinforced masonry, built before 1981, with 3floors or less
3) M2: unreinforced masonry, built before 1981, with more than 3 floors
4) RC1: reinforced concrete buildings, built before 1981, with 3 floors or less
5) RC2: reinforced concrete buildings, built before 1981, with more than 3floors
6) RC3: reinforced concrete buildings, built after 1981, with 3 floors or less
7) RC4: reinforced concrete buildings, built after 1981, with more than 3floors
8) S: steel structures
9) EDU : educational buildings
10) MED: hospitals
11) COM: commercial buildings
12) IND: industrial buildings

The most probable vulnerability class for M0 typology is class A. M1 and M2 typologies are masonry structures, their most probable vulnerability class is class B. RC1 and RC2 typologies correspond to reinforced concrete buildings built before 1981 without seismic resistant design. The most probable vulnerability class for these typologies is class C. RC3 and RC4 typologies are reinforced concrete buildings built between 1981 and 1998, so they belong to the buildings class with moderate to good level for earthquake resistant design. Their most probable vulnerability class is the class D. S typology represents steel structures which remain rare. The most probable vulnerability class for this type is the class E.

The results show that M1 typology represents the higher percentage with 37.73% (Fig. 7). It is the predominate typology of the building stock in the study area. The percentage of the typology M2 is 10.57%, from where masonry buildings (dwelling) represent 48%. The vulnerability classes in each typology are illustrated on Fig. 8.

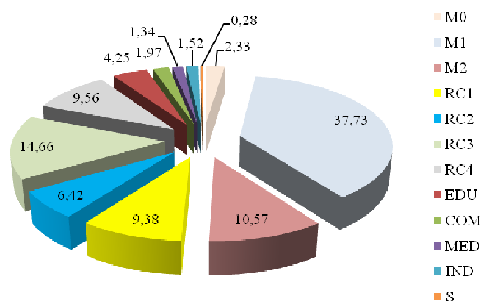

Fig. 7 Percentage of building typologies

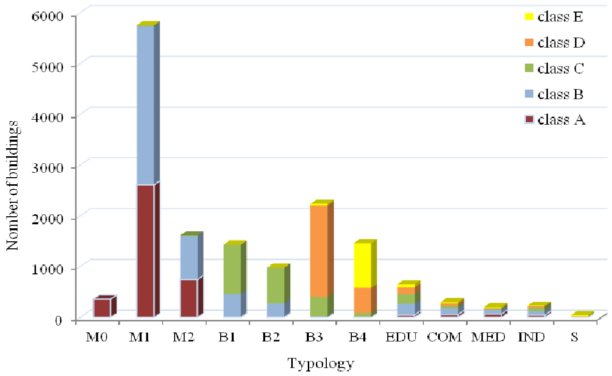

Fig. 8 Distribution of vulnerability classes into each typology

The inventory by sampling was done on the basis of visual aspect along arbitrary routes within each district. They are 15259 surveyed buildings, nearly 20% of the whole of the stock. The information collected for each building aimed to identify its typology within the 12 typologies suggested and, to identify the factors which influence the attribution of the vulnerability class (general state, number of floors, irregularity in plan or elevation...). We could extrapolate the vulnerability classes to all the buildings in each district by considering routes more representative of the whole of the town (Fig. 9).

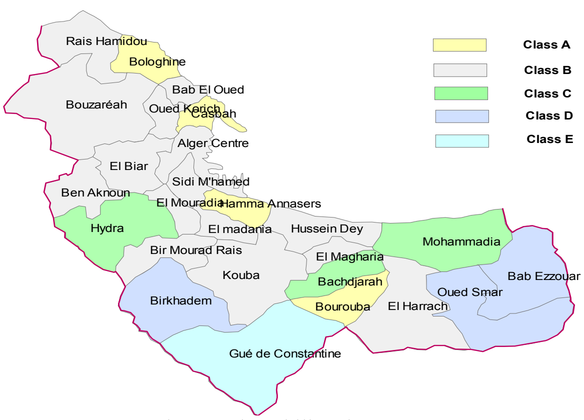

Fig. 9 Vulnerability classes map

The most percentages of vulnerability classes A and B are recorded in M1 typology, so this typology remains most vulnerable. The analysis shows that the vulnerability class B is the more representative of masonry buildings in Algiers town. It represents typically the simple stone masonry and the unreinforced masonry. In additional, the particular condition of many masonry buildings in Algiers, which lack proper maintenance, and are possibly damaged also before the earthquake strikes. The most probable vulnerability class for RC buildings is the class C, which includes mainly dwellings, not built according to seismic codes, often with modest reinforcement. In these buildings the masonry infills are stiff and brittle, so they cooperate with the RC structure in sustaining the seismic loads for low or even medium intensity levels. At higher intensities the RC elements and infill masonry walls crack.

C. Estimate of Damage

The distribution of damage is very different from district to another. The damages are presented in a discrete form through the five levels. They are obtained using the damage probability matrix. For each vulnerability class the percentage values for each damage grade referred to the different degrees of macroseismic intensity are described. For the whole of inventoried buildings the distribution of damage degrees (D_1 to D_5) for various intensities is given in Fig. 10 and 11.

In many cases, for political and economical reasons, the use of the mean damage ratio MDR is more significant. The mean damage ratio is defined as the ratio between the repair cost and the reconstruction cost [11], is of practical importance when the results of engineering analysis have to be extended or applied to insurance purpose (loss estimation).

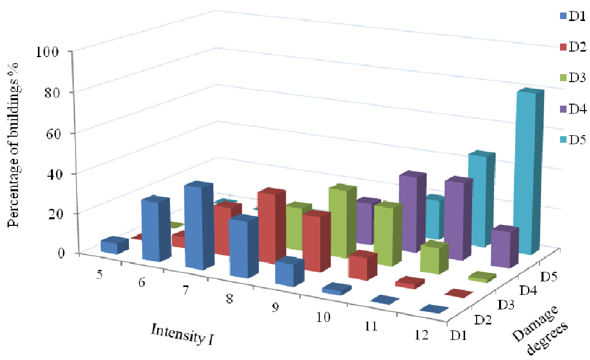

Fig. 10 Distributions of damage degrees for different intensities

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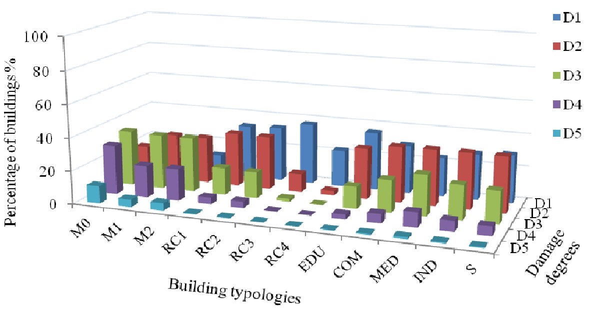

Fig. 11 Distribution of damage degrees into each typology for I_{EMS}=8

IV. Conclusion

The procedures for the evaluation of vulnerability classes and damage distribution are presented using a macroseismic method. A seismic inventory was established for the building population of the city of Algiers. The building population was segmented into seismic typologies. Because it was based on a limited number of simple parameters, this segmentation could be done on the basis of rapid visual survey. The seismic inventory provides an assessment of the global vulnerability of the built environment of the city of Algiers. It allows an estimate of the number of buildings suffering a given level of damage for a given seismic intensity. Damages are investigated according to EMS-98 definitions. Results lead to the conclusion that Algiers buildings stock has an average vulnerability class B, and, in case of stronger earthquakes (I_{EMS}=8 and more) the damage will be concentrated in the north-west of Algiers (old city centre), resulting from the increased vulnerability of the building stock. In contrast, the south of the area will be less affected. The extent of damage will be more pronounced caused by the large number of masonry buildings for which a vulnerability classes A and B have to be assigned.

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