METHODOLOGY OF THE VULNERABILITY STUDY OF THE STRATEGIC BUILDINGS IN ALGERIA

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ABSTRACT

Algeria is a country with a high seismic activity. During the last decade, many destructive earthquakes occurred, particularly in the northern part, causing enormous losses in human lives, buildings and equipments. In order to reduce this risk in the capital and avoid serious damages to the strategic existing buildings, the government decided to invest into seismic upgrade, strengthening and retrofitting of these buildings. To do so, seismic vulnerability study of this category of buildings has been considered. Structural analysis is performed based on the site investigation (inspection of the building, collecting data, materials characteristics, general conditions of the building, etc), and existing drawings (architectural plans, structural design, etc). The aim of these seismic vulnerability studies is to develop guidelines and a methodology for rehabilitation of existing buildings.
This paper presents the methodology followed in our study and summarizes the vulnerability assessment and strengthening of one of the strategic buildings according to the new Algerian seismic code RPA 99/version 2003. As a direct application of this methodology, both, static equivalent method and non linear dynamic analysis are presented in this paper.

KEYWORDS: Reinforced concrete, frame, vulnerability, structural capacity, non linear dynamic analysis, strengthening.

1. INTRODUCTION

The northern part of Algeria is located in a high seismic activity area, where a major part of the population, buildings and facilities are concentrated. Recently, many strong earthquakes occurred in this region, causing enormous losses in human lives, houses and infrastructure [OUSALEM H. and BECHTOULA H., 2003]. In order to reduce this risk, the Algerian government decided as a first step to protect the strategic existing buildings from the adverse effects of future expected earthquakes. Hence, seismic vulnerability study of this category of buildings has been considered. The vulnerability assessment and strengthening of the paramedical training centre of MUSTAPHA hospital in Algiers, one of the most important strategic existing buildings, is presented in this paper.

2. METHODOLOGY USED TO ANALYZE REINFORCED CONCRETE BUILDING STRUCTURES

The seismic vulnerability methodology for existing buildings used in this context was developed at the National Earthquake Engineering Research Center, CGS, with the cooperation of I.Z.I.I.S. [I.Z.I.I.S/C.G.S, 1993]. The methodology takes into account the following stages:
1 - Data collection.
2 - Definition of the seismic hazard.
3 - Choice of the soil accelerations at the bedrock.

4 - Seismic safety criterion.
5 - Structural building safety and damage analysis.

2.1. Definition of seismic risk and safety criterion

The seismic hazard analysis in Algiers region has been done on the basis of synthesis of the seismic hazard study of Algeria. In this study, the definition of seismic hazard and attenuation laws are used to define the maximum expected bedrock acceleration as a function of a return period of 100 and 500 years are as follows:
A_{max} = 0.25g, for 100 years return period.
A_{max} = 0.40g, for 500 years return period.
The following sets of selected ground motion records are used in our methodology:
- El Centro (California, USA) N-S May, 1940.
- Ulcinj (Albatros, Montenegro) N-S, 1979.
-Cherchel (Algeria) N-S, 1989.

In general, the safety criterion should be determined for two levels of the expected seismic action that are:
First level: corresponding to moderate earthquakes that are expected to happen many times during the life of the building, with a return period of 100 years. The behavior of the structures should remain in the elastic range, without any damage and the building can be used immediately.
Second level: corresponding to major earthquakes that are expected once during the life of the building, with a return period of 500 years. The structure may behave in the non linear range, with a controlled level of damage. No heavy damage or collapse is allowable, and the building must be reused after inspection and slight repairs.
To estimate the safety of the building, static and dynamic analysis for the moderate and major expected ground motions should be carried out and compared to the capacity of the structure.

2.2. Static and dynamic analysis

For the defined vertical and horizontal loads, linear static and dynamic analysis of the building is performed to obtain the periods, the mode shapes, the story stiffness and the relative displacements. Demands in terms of bending moments, M, shear forces, Q, and axial forces, N, are checked for each element constituting the structure. Structural elements of the building are checked according to the new Algerian seismic code RPA 99/version 2003 [RPA99, 2003] requirements. With the expected applied horizontal seismic forces, demands in terms of M, Q and N are computed and compared to the original (initial) design data if they are available.

2.3. Deformability and capacity Analysis

The capacity approach considers the real bearing and deformability characteristics of the structures in the elastic and plastic state. This approach uses the theory of the Ultimate Limit State of reinforced concrete structures. The capacity of the structure is determined using the Ultimate Analysis of Rectangular reinforced Concrete cross Sections of frames and walls systems, U.A.R.C.S, and Static and Dynamic Ultimate Analysis of Masonry Buildings, S.D.U.A.M.B programs [Bozinovski and Gavrilovic, 1993] for each structural element and at each level of the structure. The envelope curves are then determined for each storey, including all the vertical structural elements at the considered story.

2.4. Dynamic response analysis

Dynamic response analysis of structures represents a numerical computation of structural systems with defined characteristics of masses, stiffness, damping, etc, and defined ranges of elastic (linear) and plastic (non linear) behavior expressed via displacements, forces and accelerations [Chopra, 2001]. To determine the non-linear response of the structure, the Dynamic Response Analysis of Building Structures, D.R.A.B.S [Bozinovski and Gavrilovic, 1993] program is used to assess the demand in terms of force-displacement and ductility at each story of the structure.

2.5. Vulnerability assessment

Based on the analysis performed in accordance with the previously discussed procedure, a final decision and proposal should be submitted to the owner of the building according to the following:

1- If the structure satisfies the stability criteria in accordance with its function, the building can be used in its existing state.

2- If the structure does not satisfy the stability criteria, strengthening or modification of its function should be recommended.

3- If the structure does not satisfy the elementary criteria, a decision has to be made as to its strengthening or demolishing.

Final decision should also take into account the results of the feasibility and the cost analysis of the proposed solution. Figure 1, shows the flow chart of the adopted methodology.

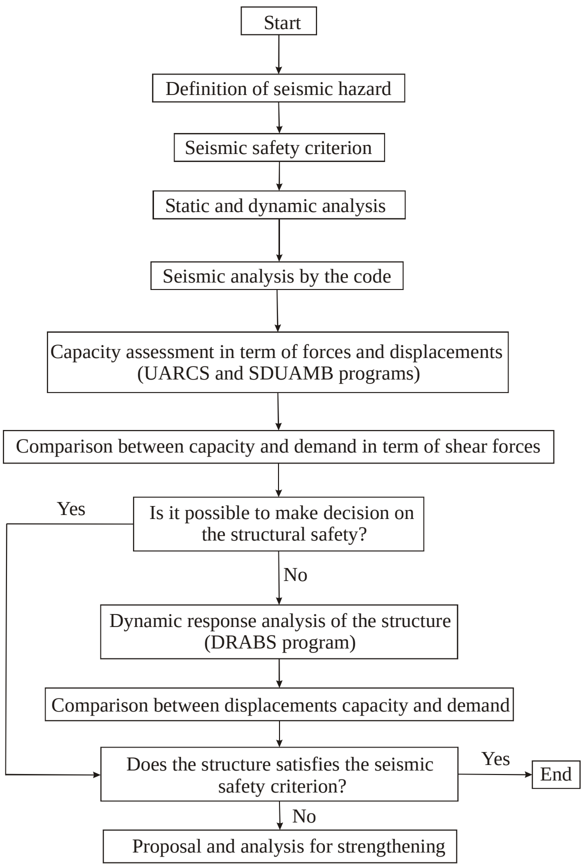

Figure 1: Methodology flow chart

3. CASE STUDY

3.1. Description of the building

The building is for a scientific and technical purpose, and its principal function is the training of doctors and nurses. It was built in 1956, according to the seismic code of that era (AS 55). The building is composed of five stories. The structural system is a moment resisting RC Frames with a partial stone masonry walls at the first level. The building is erected on a medium soil quality with σ_{Soil} = 0.15 MPa. A general view of the paramedical centre building is shown in Figure 2.

3.2. Structural analysis

A lumped mass model was selected to represent our structural system with a rigid diaphragm and fixed base. Material characteristics were selected based on the field investigation and the laboratory tests. The structural elements of the building were modeled in a 3D space, using the non linear SAP 2000 [Wilson, E., and Habibullah, A., 2006] program. Figure 3 shows the analytical model of the existing structure.

Figure 2: View of the paramedical centre building

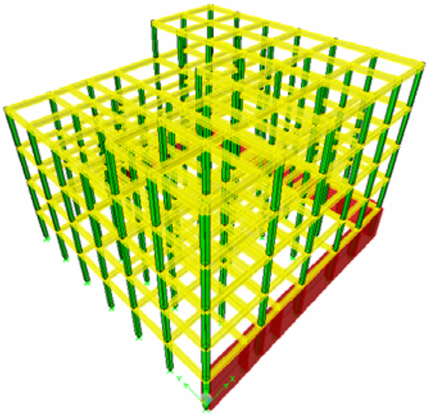

Figure 3: Three-dimensional model of the initial structure

The total design seismic base shear force is estimated using the static equivalent force method [C.G.S, 2003 and Dimova, 2005], and evaluated as:

$$V = \frac{A\,D\,Q}{R} W \tag{3.1}$$

Where: V is the total design base shear force, A is the design base acceleration coefficient, D is the dynamic amplification factor, function of the fundamental natural period, Q is the quality factor, R is the behavior factor of the structure (Masonry plus RC frames), T is the fundamental natural period of the structure and W is the total seismic weight.

3.3. Deformability and strength capacity

As already mentioned in section 2, capacity of the structure in terms of strength and deformability, was evaluated using U.A.R.C.S [Bozinovski and Gavrilovic, 1993].
The structure is considered stable when the safety factor is greater than 1.15 at each level where:

$$F_S = \frac{Q_K^U}{V_K} \geq 1.15 \tag{3.2}$$

Where: Q_k^U is the shear force capacity at level k, V_K is the shear force demand at level k.

Figures 4 and Figure 5 show a comparison between the demand and the capacity of the structure in terms of shear forces for both transversal and longitudinal directions, according to the Algerian seismic code RPA99/version 2003. It is clearly shown that the capacity does not satisfy the demand at any of the stories.

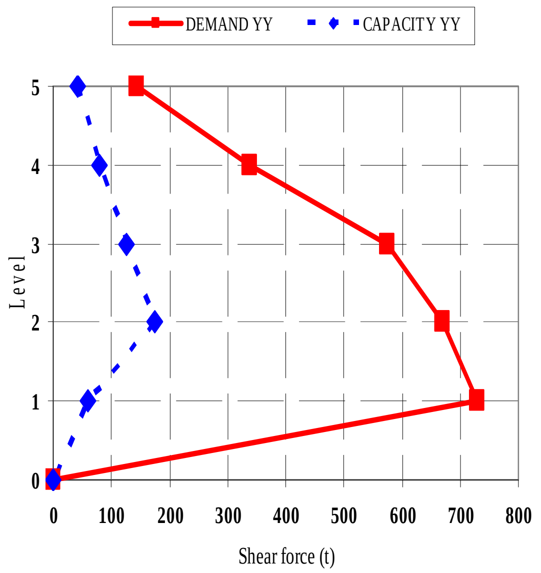

Figure 4: Capacity and code demand in the transversal direction.

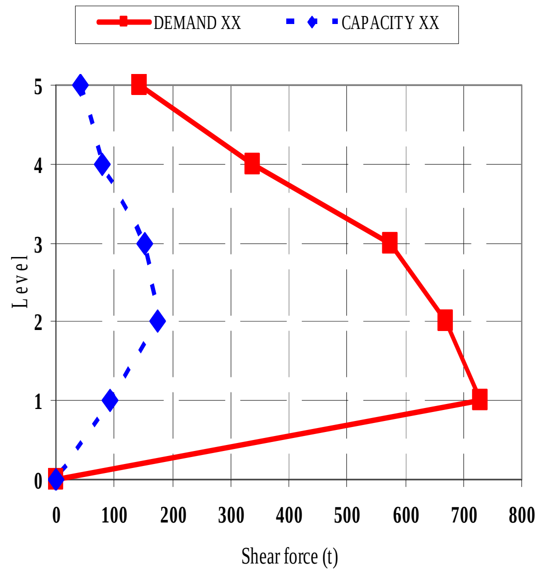

Figure 5: Capacity and code demand in the longitudinal direction.

3.4. Non linear dynamic response analysis

The dynamic response analysis of the structure was carried out using the D.R.A.B.S [Bozinovski and Gavrilovic, 1993] program and the selected ground motion records given in Table 1.

Table 1: Characteristics of the selected earthquakes

Earthquake	Country	Direction	Year	Duration (s)	Amax (m/s²)
Ulcinj Albatros	Serbia	N-S	1979	40	1.68
El Centro	U.S.A	N-S	1940	40	3.42
Cherchel	Algeria	N-S	1989	24	2.26

Ductility demand was evaluated for the major earthquake at each story and compared to the ductility capacity, μ_{cap}, and the ductility limit, μ_{limit}. Comparison is given in Table 2 for the transversal directions as an example.

Table 2: Comparison capacity-demand in terms of ductility in the transversal direction

Level	μ_{cap}	μ_{limit}	Ulcinj	El Centro	Cherchel
5	3.55	3	2.53	2.87	2.37
4	1.75	3	2.78	2.20	1.58
3	1.52	3	3.09	2.61	1.95
2	1.47	3	2.41	1.72	1.58
1	1.19	3	24.30	24.52	10.64

Figure 6 and Figure 7 show a comparison between the capacity and demand in terms of displacements for the moderate and the major earthquakes, respectively.

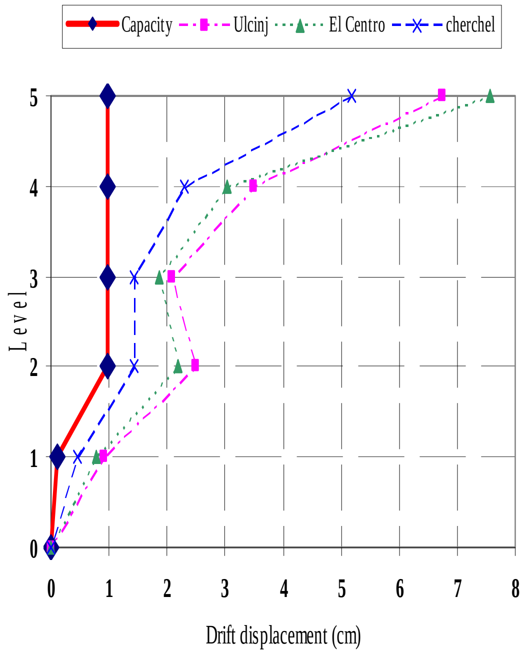

Figure 6: Displacement Capacity-Demand, longitudinal direction Amax=0.25 g.

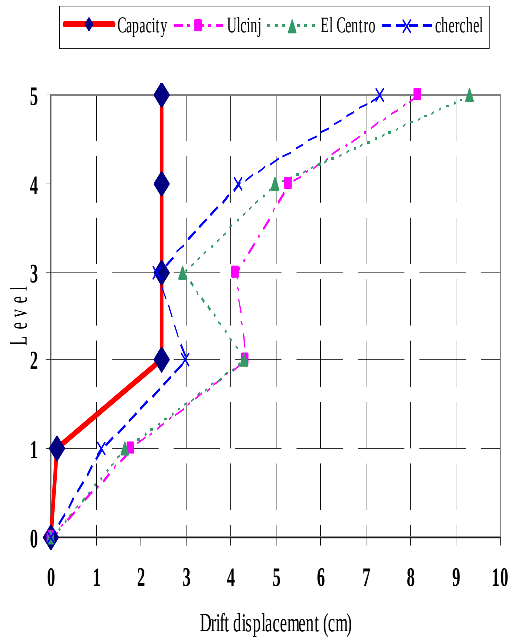

Figure 7: Displacement Capacity-Demand, longitudinal direction Amax=0.40 g.

From the above obtained results it can be observed that, drift displacements under lateral forces exceeded considerably the allowed capacity values. All computations led to the conclusion that the structure needs strengthening in order to increase the strength and to limit the drift displacements under a major earthquake. Many simulations have been tried in order to get the most economic and convenient solution which is presented hereafter.

3.5. Suggestion of strengthening

In order to get a dual system [C.G.S., 1994] with a behavior factor of five, R=5, four new RC shear walls , two in the transversal direction and two in the longitudinal direction, with 20 cm thickness were added along the total height of the structure. Figure 8, shows the model of the strengthened structure with the new RC walls. We suggested also, disconnecting the masonry wall from the RC Frames by creating a gap of 5 cm width. The strengthened structure was reanalyzed using the same procedure. Some results of the strengthened structure are summarized in Table 3 and Table 4. Figures 9 trough Figure 11 show the new capacity and the demand in terms of shear forces and displacements for the strengthened structure.
From these tables and figures it can be concluded that the demands (in terms of strength, displacement and ductility) are largely satisfied at all levels of the structures.

Table 3: Shear capacity, shear demand and safety factors in the transversal (Y) and the longitudinal (X) directions for the strengthened structure.

Level	$Q_k^{U(Y)}$ (kN)	$V_K^{(Y)}$ (kN)	$F_S^{(Y)}$	$Q_k^{U(X)}$ (kN)	$V_K^{(X)}$ (kN)	$F_S^{(X)}$
5	14471.61	5233.58	2.76	14895.87	4984.36	2.98
4	20835.34	6513.63	3.19	10902.20	6203.45	1.75
3	22298.13	7562.69	2.94	13800.63	7202.55	1.91
2	23129.93	8367.07	2.76	15456.10	7968.63	1.93
1	21388.91	8678.61	2.46	15033.66	8265.33	1.81

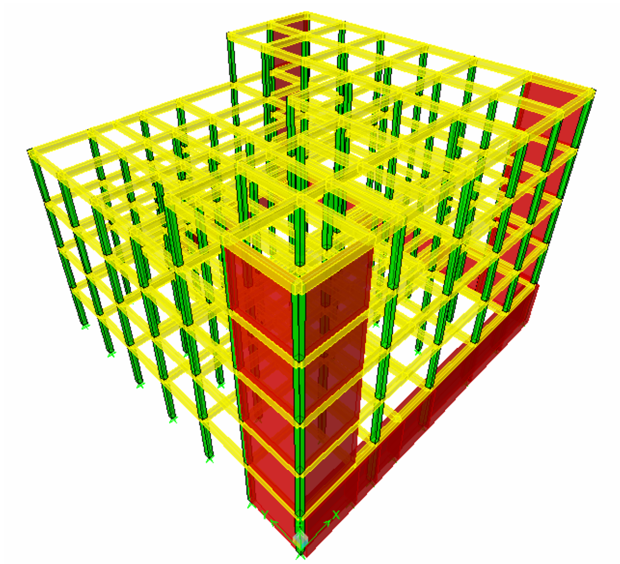

Figure 8: Three-dimensional model of the strengthened structure

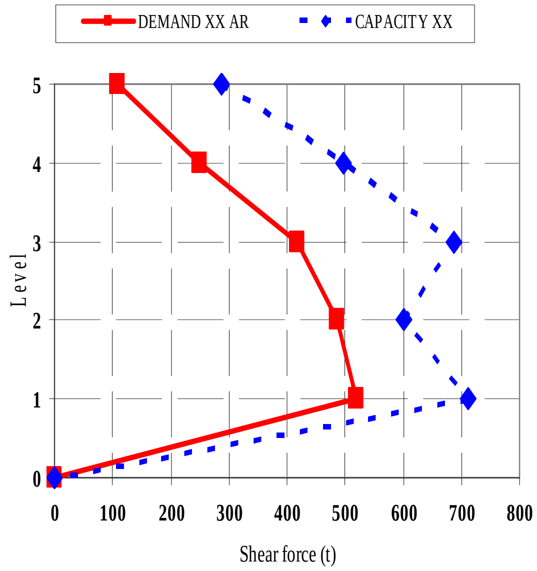

Figure 9: Capacity and code demand in the longitudinal direction -strengthened structure-

Table 4: Capacity and demand in terms of ductility for Amax=0.40 g, in the transversal direction for the strengthened structure.

Level	μ_{cap}	μ_{limit}	Ulcinj	El Centro	Cherchel
5	2.02	3	1.36	1.28	1.00
4	1.58	3	1.61	1.19	1.10
3	1.75	3	1.55	1.26	1.04
2	2.18	3	1.87	1.24	1.25
1	2.26	3	1.41	1.30	1.15

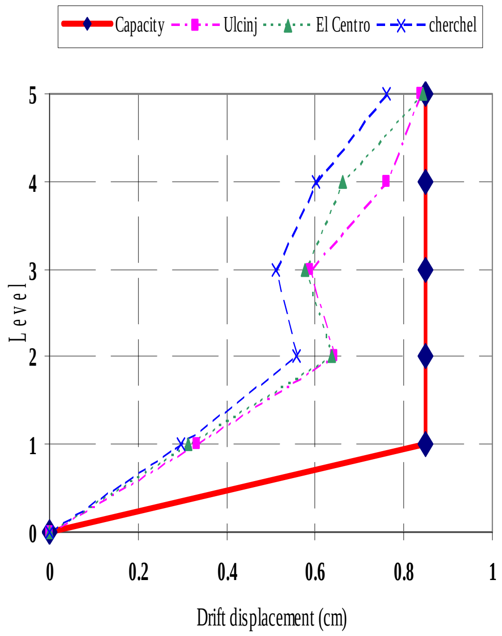

Figure 10: Displacement Capacity-Demand for the strengthened structure, longitudinal direction Amax=0.25 g.

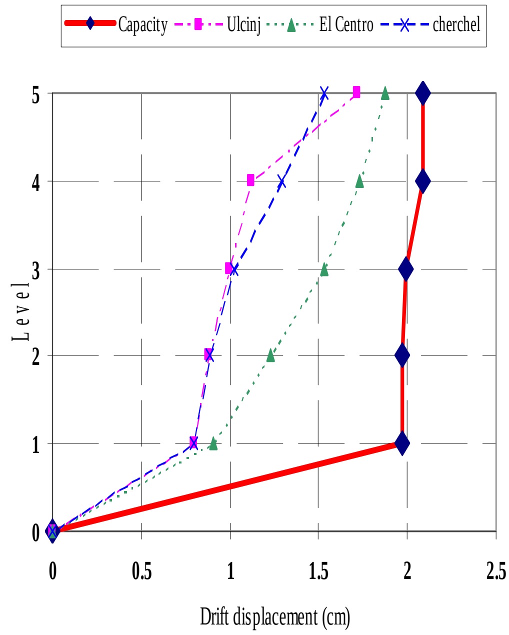

Figure 11: Displacement Capacity-Demand for the strengthened structure, longitudinal direction Amax=0.40 g.

4. CONCLUSIONS

Methodology of the vulnerability study of the strategic buildings in Algeria was introduced. A case study of one of these strategic buildings located at Algiers city was presented. The original structural system showed an important deficiency in capacity criteria in terms of forces, displacements and ductility at each level of the structure. One of the most difficult problems of strengthening of an existing building is how to find the most adequate solution that satisfies both economical and technical aspects. In our case, many solutions were carried out to get the best and feasible solution. Four additional RC walls placed at the external frames were inserted to the existing system. This retrofitting method showed a great amelioration in the capacity of the building, and satisfied the criteria of the methodology.

It is important to mention that the vulnerability and functionality of a strategic building must include the whole neighboring buildings even if they are not strategic, since they may block the access and the functionality of this building.

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