VULNERABILITY ANALYSIS OF A DAMAGED BUILDING

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ABSTRACT :

The current article presents a vulnerability study of a model of the "cité des1200 logements" situated in Boumerdès city where significant disorders had been noted after the Zemmouri earthquake occurred on May, 21st 2003. This city was built in 1975-1980 without any aseismic norms. The structural system is constituted of self-stabilising reinforced concrete frames. The method used to evaluate the seismic resistance of this building is that one developed in the Institute of Earthquake Engineering and Engineering Seismology in " St Cyril and Methodius University ", Skopje, Macedonia. Two ground motion records of ZEMMOURI earthquake are proposed in this paper : the main shock of May, 21st 2003 recorded by the Dar-El-Beida station and the aftershock of May 27th 2003 recorded at Boumerdès Station. The results of the analysis are interpreted in the structure behaviour point of view and its capacity to resist to different aggression levels of the earthquake and to the real one.

KEYWORDS: Vulnerability, Capacity analysis, Deformability capacity, Non-linear dynamic response.

1. INTRODUCTION

On May, 21st 2003, Algeria was shaken by an earthquake of magnitude 6.8 on the Richter scale; the epicentre was located in the area of Zemmouri, wilaya of Boumerdès, in the east of Algiers.

The initiated study in this article rests on the approach in term of resistance capacity and deformability of the structure. This study allows the analysis of the seismic stability of the existing buildings and their reinforcement if necessary. It gathers several phases of analysis, continuation to which decisions must be made for the building safety.

The analysis requires, as a preliminary, the knowledge and the collection of several datas related to the building and its site, such as the desired safety criteria, architecture planes and reinforced concrete planes, the type, the function and the nature of constitutive materials of the structure.

The building concerned in the present study is a standard block of the city of the 1200 residences "Cité des 1200 logements" established in BOUMERDÈS and damaged during the ZEMMOURI earthquake of May, 21st 2003, the aim is to confirm through out this study the damages noted in-situ after the earthquake.

2. METHODOLOGY OF VULNERABILITY STUDY OF REINFORCED CONCRETE BUILDINGS

The method for evaluation of the seismic resistance of reinforced concrete building, adopted in Algeria, is inspired from the one developed at the Institute of Earthquake Engineering and Engineering Seismology in

Skopje (Macedonia). It has been adopted in cooperation between the National Center of Applied Research in Earthquake Engineering, CGS (Algeria) and the Institute of Earthquake Engineering and Engineering Seismology in Skopje, IZIIS (Macedonia). This method consists in the following steps (Necevska, 92, 98, 2000):

1. Input parameters definition of the structural system of the building and determination of the quantity and quality of the built in material for existing buildings.
2. Determination of the Q-Δ diagram for each element separately and the storey Q-Δ diagram.
3. Definition of the seismic parameters and the design criteria. The seismic actions to consider are represented by accelerations data record.
4. Nonlinear dynamic analysis of the structural system. It consists to determine the maximum displacements at the storey level for different acceleration datas and hysteretic model of nonlinear behaviour of the system adopted in 2.
5. Evaluation of the seismic resistance for the existing structure, a comparison of the required displacement with the displacement capacities of the structural members and the required ductility with ductility capacity of the structural members is carried out.

Two ground motion records of ZEMMOURI earthquake of May, 21st 2003 are proposed in this paper :

- Acceleration record of Dar-El-Beida station located at 25 km from Boumerdès (main shock of May 21st, M=6.8)
- Acceleration record of Boumerdès station located at 500 m from "Cité des 1200 logements" (aftershock of May 27th, M=5.8)

In addition to the aggression levels defined by the methodology and the seismic hazard of Algiers (0.15g, 0.25g), we propose to examine the effect of the real level of the recorded acceleration during the earthquake. For the precedent seismic intensity levels, safety criteria were fixed in order to ensure the stability of the structure.

Based on the carried out analysis, a final decision will be made for the safety of the structure via the following vulnerability assessment :

1- If the structure satisfies the criteria of stability in accordance with its function, the building can be used in its current state.
2- If the structure doesn't satisfy the stability criteria, strengthening or modification of its function could be recommended.
3- If the structure doesn't satisfy the elementary criteria,. a decision has to be made for its reinforcement or demolition after an economic cost analysis.

3. STRUCTURAL ANALYSIS

The structural analysis must include in addition to the basic structural system, the system of foundation by taking into account the ground conditions. The analysis of the structure will be carried out with the real or estimated data of the concerned buildings. These data relate to the characteristics of materials of the structural system.

The static and dynamic analysis will be carried out on the basic structural systems in order to determine the flexure moments M, shear efforts Q and the normal efforts N under the effect of the self-weight loads and the exploitation over-loads as well as the dynamic characteristics.

The input data for the mathematical model are the characteristics points of the primary curve that are obtained by means of the UARCS (*Ultimate Analysis of Rectangular Reinforced Concrete Cross-country race-Section of frame wall system*) program (Bozinovski, 1993) that carry out the yield displacement Δ_y, shear force at yielding Q_y, ultimate displacement Δ_u and ultimate shear force Q_u

To determine the dynamic response in the nonlinear domain, we adopted the bilinear model depending on whether the inclination of the line after the yielding point is positive, negative or zero, this model can be positive bilinear, negative bilinear and elasto-plastic. This model is used and yields relatively good results for the behaviour of steel frame structures. The negative bilinear model is used for modelling of elements considering high values of axial forces. The seismic forces according to the Algerian aseismic code (RPA, 1999) will be given according to the category of the building of the fundamental mode period and of the global weight :

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

A : zone acceleration factor
D : dynamic amplification factor
Q : quality factor
R : behaviour factor
W : global weight of the structure

This force will allow us to obtain the demand in terms of moments, shear forces and normal forces. A correlation will be made between the capacity and the request.

4. DEFORMABILITY AND STRENGTH CAPACITY ANALYSIS

The method known as ″the capacity approach″ remains most suitable for the buildings vulnerability estimation. This method takes into account the real characteristics of bearing capacity and deformation in elastic and plastic states of the structure, according to its behaviour, using the limit states. The limit states analysis makes possible to determine the strength capacity and the deformability of the structure. The data necessary to the analysis are :

- Geometrical characteristics of the bearing element.
- Vertical load due to the self-weight loads and the exploitation overloads.
- Material characteristics of the bearing elements.
- Longitudinal and transversal steel reinforcement

The study of the bearing capacity of the structure, in term of resistance and deformbility, is determined by program UARCS. The results are obtained as well for one element as for the whole storey in a given direction.

5. DYNAMIC RESPONSE ANALYSIS

The DRABS (*Dynamic Response Analysis of Building Structures*) program (Bozinovski, 1993) and the selected ground motion records were used to compute the dynamic response analysis of the structure. Evaluation of the seismic strength of a considered building is made by comparison between the non-linear response "requirements" of the building to the earthquake effects for the moderate, major and real ground motion records and the ultimate "capacity" of the building.

6. APPLICATION OF THE METHODOLOGY FOR AN EXISTING REINFORCED CONCRETE BUILDING

The methodology of structures vulnerability study will be illustrated on a reinforced concrete building presented on figure 1. The building concerned in this study is situated in Boumerdès city, about 50 km east of Algiers, the residential building is located at "Cité des 1200 logements" built in the seventies, and it is composed of five levels, four (04) floors and RDC.

The structural system is composed of self-stabilizing reinforced concrete frames of total height of 15.00 m, dimensions in plane and distances between axes of the building are 17.95 m x 9.50 m. Surface of each level is 170.525 m², from where a total surface of the building floors of 852.625 m².

The dimensions of the bearing elements are 20x40 cm for the columns of axes 1 and 3, 20x50 cm for the central columns (axe 2) and 20x40 cm for the beams. The external masonry is carried out with two ranges of brick panels in the plane of the frames.

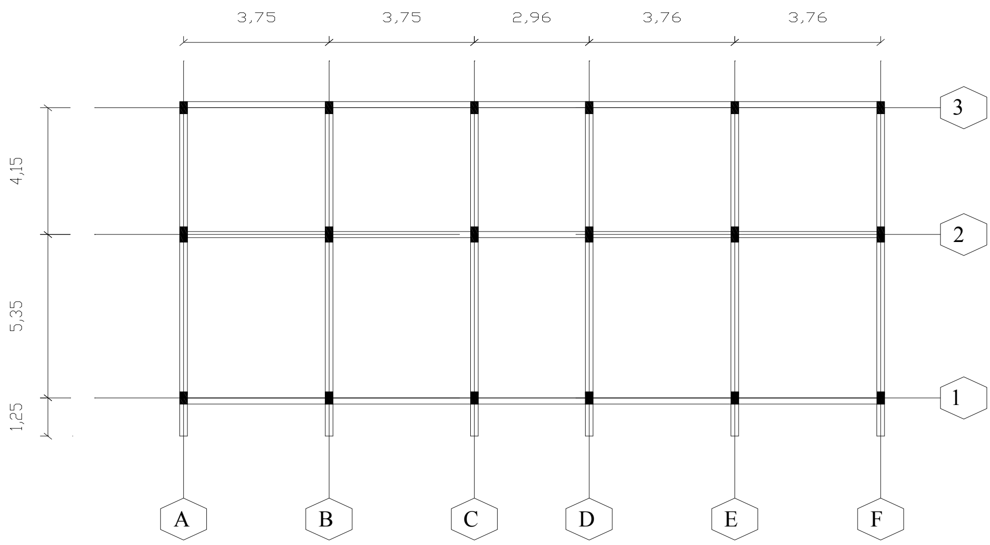

Figure 1 Plane view of typical building of "Cité des 1200 logements"

An expertise of the building was made in order to raise the damages and cracking after the earthquake. This expertise of the buildings enabled us to note that the damages are concentrated in the inferior floors. In the majority of the buildings, the masonry of the first level (RDC) broke out and plastic hinges are developed at the columns joints. There is then formation of a flexible floor leading in several cases to floor mechanisms.

The characteristics of used materials are for reinforced concrete: compressive strength f_{c28}=20 MPa, tensile strength σ_t=1.8 MPa, yield strain ε_e=2 $\%^0$, ultimate strain ε_u=3.5 $\%^0$ and for steel reinforcements: strength f_e=400 MPa, yield strain ε_e=2 $\%^0$, ultimate strain ε_u=10 $\%^0$.

After the analysis of the collected data relating to the building and the expertise of the damages, a static calculation makes possible to determine the vertical forces due to the self-weight loads and the exploitation overloads in the bearing elements of the structure.The structure was modelled using SAP2000 software (Sap2000). The choice of the adopted model depends on the geometrical configuration of the structure and the disposition of its structural elements. The seismic force obtained using Eqn 3.1 for RPA 99 code parameters values (RPA, 1999) of : $A = 0.15$, $D = 2.2$, $Q = 1.2$, $R = 3.5$ and $W = 8178\ t$ is : V_{code} = 925.3 t

7. DEFORMABILITY AND STRENGTH CAPACITY

The following table gives comparisons between seismic shear forces according the code and as obtained by UARCS program, as well as parts of shear forces belonging to frames in both longitudinal and transversal directions.

The seismic shear force defined by the code Q_c is 4 times larger at all the storeys of the building compared to the seismic forces obtained by UARCS program Q_u in longitudinal direction. Reverse case is observed for the transversal direction, the seismic force based on UARCS program is 8 times higher.

Table 7.1 Comparisons between seismic shear forces according the code
and as obtained by UARCS program

Storey	Q_c (KN)	*Longitudinal direction*			*Transversal direction*		
		Q_y (KN)	Q_u (KN)	$F_s = \frac{Qu}{Qc}$	Q_y(KN)	Q_u (KN)	$F_s = \frac{Qu}{Qc}$
1	9252.6	3254	3344	0.360	30961	32254	3.49
2	7407.4	1035	1079	0.146	57133	63374	8.55
3	5562.2	951	1004	0.180	41577	45255	8.14
4	3711.7	884	922	0.250	32177	37230	9.49
5	1871.8	773	893	0.480	13448	16788	8.96

The safety factor F_s being higher than 1.15, the structure is stable and resists to seismic stresses in term of shear force in the transversal direction. For the longitudinal direction the structure is not stable (F_s< 1.15), it presents a weak strength capacity.

8. NONLINEAR DYNAMIC RESPONSE ANALYSIS

The represented curves in figures 2 to 5 illustrate the comparison of the deformability capacity and required displacement for each level for the three aggression levels of the two selected ground motion records for ZEMMOURI earthquake in longitudinal and transversal direction.

On the basis of the different obtained results, the deficiency of the structure was its excessive flexibility in the longitudinal direction for the real aggression level of the Boumerdès station record. Reverse case is obtained for the transversal direction for the three levels of aggression for the selected records.

The calculation of the allowed inter-floors displacements show that a majority the computed displacements particularly those of the inferior storeys exceed the allowed values in the longitudinal direction for the two selected accelerograms, for the transversal direction these allowed values are respected.

From the results, we note that the displacements in the N-S direction present larger values than in the E-W one. The damages noted in situ confirm the results carried out in this study, among 45 controlled buildings, 16 are oriented N-S and 29 are oriented E-W, we note 10 collapsed buildings in the N-S direction i.e. 63 %, the 6 others buildings undergo hard damages, when 6 collapsed building were noted in the E-W one i.e. 21 %.

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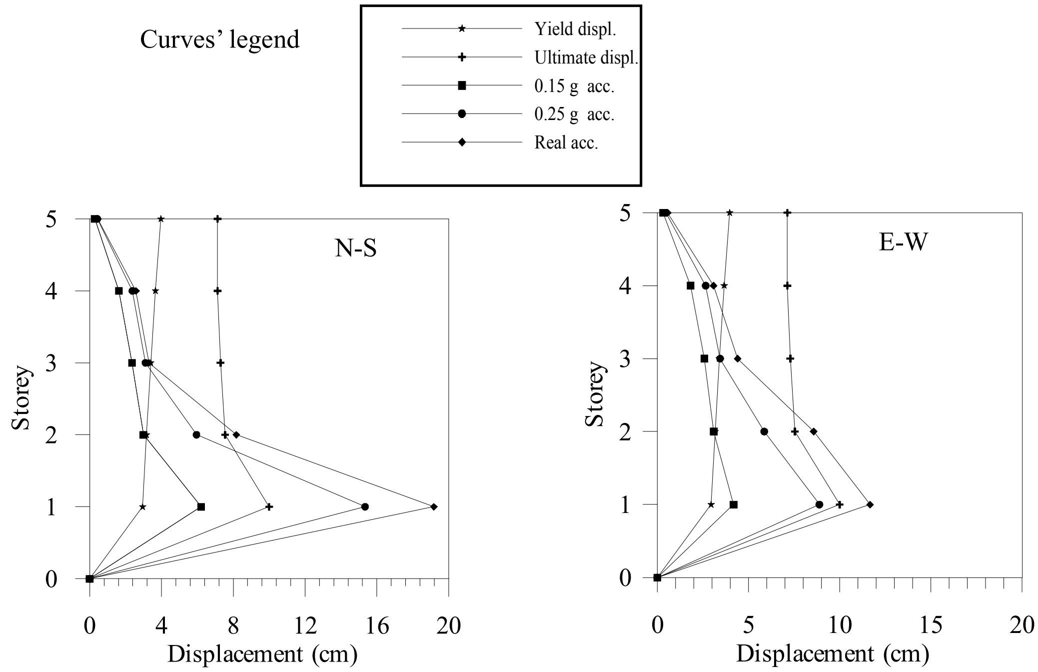

Figure 2 Displacement capacity and requirement – Longitudinal direction
Zemmouri Earthquake (Boumerdes Station)

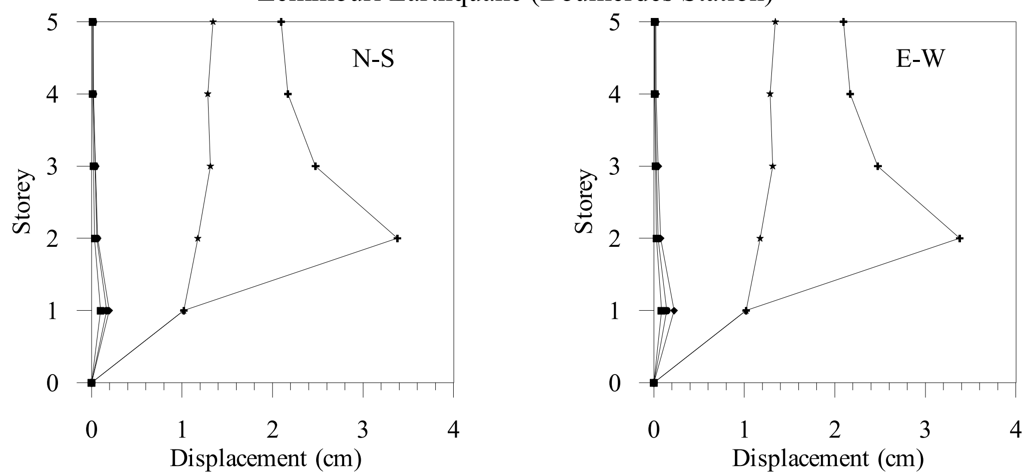

Figure 3 Displacement capacity and requirement – Transversal direction
Zemmouri Earthquake (Boumerdes Station)

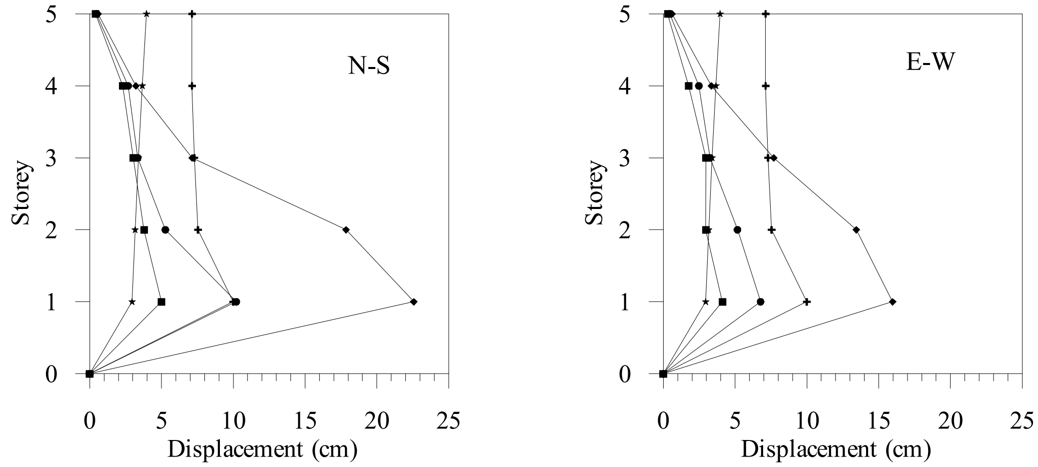

Figure 4 Displacement capacity and requirement – Longitudinal direction
Zemmouri Earthquake (Dar-El-Beida Station)

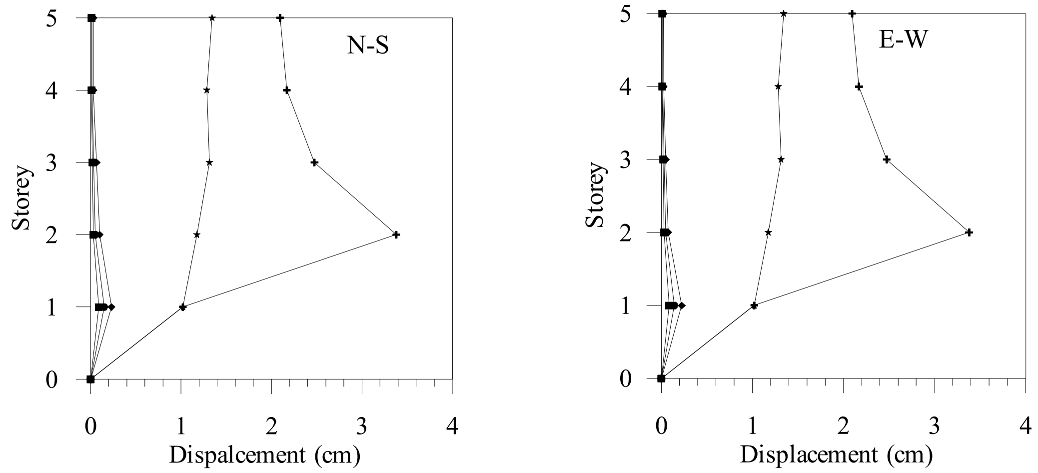

Figure 5 Displacement capacity and requirement – Transversal direction
Zemmouri Earthquake (Dar-El-Beida Station)

9 CONCLUSION

The definition of a method for design and evaluation of the seismic resistance of R/C building structures is a wide and complex problem. One hand, it is necessary to carry out the most possible realistic definition of the structural system capacity, in terms of strength and deformability capacity of the system, and on the other hand, after having selected the expected earthquake effect on a given site, in terms of intensity, frequency content and time duration, to predict as realistically as possible the nonlinear behaviour of the structure, and on the basis of these results to define the earthquake, i.e., the seismic force or the acceleration that would cause damage to structural elements and the integral structural system.

The application of the methodology described in this paper to the evaluation of the strength capacity and deformability capacity of the ″Cité des 1200 logements″ situated in Boumerdès allowed us to carry out a preliminary correlation between the results of the analysis and the damage observed after the Zemmouri earthquake. As seen through the obtained results the building oriented in the N-S direction don't satisfy the safety criteria in terms of strength and deformability capacity which are insufficient for the aggression levels of 0.25g and the real one in the transversal direction. The building oriented E-W present the same insuffiency for the real aggression level.

The different results of the analysis carried out the deficiency of the structure due to a weak deformability and strength capacity in the longitudinal direction where drifts under lateral forces exceeded considerably the capacity values at some levels for both selected ground motion accelerograms. All calculations led to the conclusion that the structure needed strengthening in this direction, at least, before the occurrence of the considered earthquake.

The current study shows that it is imperative to check the seismic vulnerability degree of structures realised without any aseismic norms, in sight of a possible reinforcement or a demolition, according to an evaluation methodology of the building stability during earthquakes.

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