# Seismic Vulnerability Evaluation of Existing Reinforced Concrete Building Retrofitted with RC Wing Walls

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#### SUMMARY:

Northern part of Algeria has frequently suffered from major damaging earthquakes during the last century, causing enormous losses in human lives, buildings and equipments. Still, there are thousands of buildings in earthquake-prone regions in Algeria that need seismic evaluation and retrofitting. This paper describes a study for the seismic vulnerability assessment and retrofit plan of an existing strategic reinforced concrete office building by the Japanese method and the IIZIS/CGS method before and after retrofitting with reinforced concrete wing walls. The building, located in Algiers (Algeria), was built in the earlier 80s and it was designed according to older standards and does not match the requirement of the current seismic regulation. IIZIS/CGS method requires static equivalent method and non linear time history analysis for serviceability and ultimate limit states. While, Japanese method allows seismic judgment by comparing seismic demand index, ISO, and seismic index of the building, IS, evaluated based on strength and ductility of the building. However, the Japanese method was adjusted based on the expected seismic intensity of the region.

Keywords: seismic vulnerability evaluation, retrofit, reinforced concrete

# **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. The strong earthquake of El-Asnam October 10, 1980 with a magnitude of 7.3, was the starting point of seismic building regulations in Algeria. The first Algerian Seismic Regulation appeared in 1981 (RPA81) then followed by RPA83, RPA88 and RPA99. After the 21st May 2003, Boumerdes earthquake, with a magnitude 6.8, a new version was established where a revision of some chapters was made based on the observed damage and study of the recent earthquake, this version was named RPA99/Version 2003 (MHU, 2003). Beside that, 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 main target of this paper is to evaluate the seismic vulnerability of an existing reinforced concrete building (moment resisting frame structure) designed by an old version of Algerian seismic regulations using two methodologies: IIZIS/CGS methodology and Japanese methodology. 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.*, 2000 (a) ; Shinozuka *et al.*, 2000 (b) ; Nour El-Din, 2007 ; Zermout *et al.*, 2008). The two main keys elements of the seismic index method are the "Demand" and the "Capacity". Demand represents the intensity of the ground motion to which the buildings are subjected to, such as shear force and ductility, 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 and Padilla, 2009).

# 2. JAPANESE METHODOLOGY FOR SEISMIC VULNERABILITY OF EXISTING RC BUILDINGS

There are three levels of seismic screening procedures in the Japanese Standard (JBDPA, 2001). The first level seismic screening is simple and the result is conservative. The second level screening is performed based on column collapse mode. The third level screening is performed including beam collapse mode, but calculation volume increases. Column collapse mode will be dominant for buildings in Algeria as observed in many previous earthquakes (Bertero et al., 1981, Oussalem and Bechtoula, 2003; Oussalem and Bechtoula, 2005). As a result, the second level seismic screening procedure was applied in this study.

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. The seismic safety of the building shall be judged based on standard for judgment on seismic safety wherein seismic performance demands are prescribed.

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):

$$I_s = E_0 S_d T = CFS_d T \tag{1}$$

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 categories:

- 1. Shear wall: shear failure precedes flexural yielding.
- 2. Flexural wall: flexural yielding precedes shear failure.
- 3. Shear column: shear failure precedes flexural yielding.
- 4. Flexural column: flexural yielding precedes shear failure.
- 5. Extremely short columns:  $h_0/D$ , with  $h_0$  and D are the clear height and the cross section dimension of the considered element, respectively.

The classification of vertical structural elements is based on the failure mode, by comparing the ultimate shear capacity,  $Q_{SU}$ , to the ultimate flexural capacity,  $Q_{MU}$ , according to Table 1.

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	Columns whose $h_0/D \le 2$ and shear failure precedes flexural			
(short) columns		yielding			

Table 1. Classification of vertical structural elements

Seismic safety of structure shall be judged by comparing  $I_s$  to  $I_{s0}$  using Eq. (2):

$$I_{S} \ge I_{S0} = E_{S}ZGU \tag{2}$$

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 screening method  $E_s = 0.6$ ;

*Z* : Zone index;

*G* : Ground index;

U: Usage index according to the importance of the building.

Expected seismic intensity in Algiers by Scenario Earthquakes is in the range of 8 to 9 of EMS-98 (JICA-CGS, 2006). Based on this estimated seismic intensity and the relation of seismic intensity among EMS-98, MSK-64 and JMA, the value of 0.5 was used for the judgement.

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. As a final step, the seismic safety of the building shall be judged by comprehensive assessment using Eq. (3):

 $I_{s} \ge I_{s0} \tag{3}$ 

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 assessed to be "unsafe". For buildings classified "safe", additional condition should be satisfied which is given by Eq. (4):

$$C_{TU}S_d \ge \max\begin{cases} 0.3ZGU\\ 0.3 \end{cases}$$
(4)

Where,

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

#### 3. IZIIS/CGS METHODOLOGY FOR SEISMIC VULNERABILITY EVALUATION

The IZIIS/CGS methodology for seismic vulnerability evaluation of existing reinforced concrete buildings (IZIIS/CGS, 1993) 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.

The seismic hazard analysis in Algiers region has been done on the basis of synthesis of the seismic hazard study of Algeria (Devechère *et al.*, 2005; Laouami *et al.*, 2006). 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 500 years is set as  $A_{max} = 0.40g$  (Mehani *et al.*, 2011). A set of 9 selected ground motion records scaled to 0.40g are used in this study.

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 requirements (MHU, 2003). With the expected applied horizontal seismic forces, demands in terms of flexural moments, shear forces and axial loads are computed and compared to the initial design data if they are available.

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 reinforced concrete cross sections for each vertical 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.

Dynamic response analysis of structures represents a numerical computation of structural systems with defined characteristics of masses, stiffness, damping, and defined ranges of linear and nonlinear 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 is used to assess the demand in terms of force-displacement and ductility at each story of the structure.

# 4. CASE STUDY

# 4.1. Description of the building

The aimed building in an office building constructed in the beginning of 90<sup>th</sup> of the last century and seismicly designed according to an older version of the Algerian seismic regulations RPA88 (MHU, 1988). The building is composed of five stories. The structural system is a moment resisting RC frames with masonry infill walls. The existing dimensions and reinforcement are summarized in Table 2. The building is erected on a medium soil quality with  $\sigma_{Soil} = 0.15$  MPa. A plan view and elevation view of the building is shown in Figure 1 and Figure 2, respectively. The building is classified as strategic building that should remain functional without or with light damages in case of strong earthquake corresponding to A<sub>max</sub> = 0.40g.

Tuble 2. cross section unichoron una remitre ement						
Element	Dimension (mm)	Main bar	Stirrup			
Column (Border)	300×300	4-D16+4-D14	4-D8@100			
Column (Central)	300×400	4-D16+4-D14	4-D8@100			
Beam (Y direction)	300×500	6-D14/3D14	4-D8@100			
Beam (X direction)	300×350	3-D14/3D14	4-D8@100			

Table 2. Cross section dimension and reinforcement



Figure 2. Elevation view of the building

# 4.2. Seismic vulnerability evaluation according to Japanese methodology

Results of seismic vulnerability evaluation according to Japanese methodology before strengthening are summarized on Table 3.

Level	Longitudina	al direction	Transversal direction	
	Iso	Is	Iso	Is
5	0.604	0.603	0.604	0.676
4	0.604	0.360	0.604	0.405
3	0.604	0.266	0.604	0.300
2	0.604	0.218	0.604	0.264
1	0.604	0.185	0.604	0.209

Table 3. Seismic Index of Structure before strengthening

#### 4.3. Seismic vulnerability evaluation according to IZHS/CGS methodology

A lumped mass model was selected to represent the structural system with a rigid diaphragm and fixed base. Material characteristics of concrete were selected based on the field investigation and the laboratory tests. The characteristics of the materials used in this study are summarized as follows:

- Concrete:  $f_{C28} = 25$  MPa (compressive strength),  $f_{t28} = 2.1$  MPa (tensile strength).
- Steel: High adherence rebars FeE40 fe: 400 MPa (General using)

Figure 3 and Figure 4 show a comparison between the capacity and demand in terms of displacements for the moderate and the major earthquakes, respectively. 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.



Figure 3. Displacement demand vs. displacement capacity



Figure 4. Ductility demand vs. ductility capacity

### **5. STRENGTHENING PLAN**

In order to get a dual system (CGS, 1994), a strengthening plan is proposed by columns RC jacketing of 50x50 (cm<sup>2</sup>) and by adding a set of wing walls with 150 cm length and 20 cm thickness in both transversal direction and longitudinal direction in the total height of the building. Figure 5 shows the model of the strengthened structure with the new RC wing 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. Results of the strengthened structure showed the effectiveness of this strengthening method by both evaluation methods. Results of seismic vulnerability evaluation according to Japanese methodology after strengthening are summarized on Table 4.



Figure 5. Plan view of the building after strengthening

Level	Longitudina	al direction	Transversal direction	
	Iso	Is	Iso	Is
5	0.604	1.322	0.604	1.398
4	0.604	0.766	0.604	0.783
3	0.604	0.939	0.604	0.644
2	0.604	0.610	0.604	0.612
1	0.604	0.626	0.604	0.627

 Table 4. Seismic Index of Structure after strengthening

# 6. CONCLUSIONS

Seismic evaluation and retrofit plan was introduced for an existing strategic RC building of Algiers. Providing RC wing walls and column jacketing were proposed for the retrofit. It is important to evaluate quantitatively the strength and the ductility of a building for the seismic evaluation. It is necessary to consider the retrofit by means of strength upgrading or ductility upgrading based on characteristics of a building. Cost estimate that is not shown in this paper will also be required to judge retrofit, or demolish and new construction.

Basic Seismic Demand Index was suggested based on the expected seismic intensity in Algiers and to coordinate with the present seismic design code RPA99 ver.2003.

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. Columns RC jacketing and RC wing 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 both the methodologies.

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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