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Seismic assessment of a R/C strategic existing building

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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. In doing so, seismic vulnerability study of this category of buildings has been considered. Structural analysis is performed on the basis of site investigation (inspection of the building, collecting data, materials, 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 will provide insight to the vulnerability assessment and strengthening of the telecommunication centre, according to the new code RPA 99/version 2003. Both, static equivalent method and non linear dynamic analysis are performed in this study.

Keywords: vulnerability; structural capacity; non linear dynamic analysis; strengthening.

1. Introduction

The northern part of Algeria has a high seismic activity. Almost all the population, the buildings and the facilities are concentrated in this region. Recently, many strong earthquakes occurred in this region, causing enormous losses in human lives, loss of houses and damage to infrastructure. In order to reduce this risk, the government decided firstly to protect the strategic existing buildings, from the adverse effects of future expected earthquakes. In doing so, seismic vulnerability study of this category of buildings has been considered. One of the most important strategic existing buildings is the Telecommunication Centre of Algiers. The vulnerability assessment and strengthening of it will be carried out in this paper.

2. Methodology used for analysis of reinforced concrete building structures

The seismic vulnerability methodology for existing buildings (e.g., I.I.Z.I.S/C.G.S 1993) used in this context takes into account the following stages:

1- Definition of the seismic hazard.

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2- Choice of the soil accelerations at the bedrock.
3- Seismic safety criterion.
4- Structural building safety and damageability analysis.
5- Data collection and existing drawings, etc.

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} = 0.15 g, for 100 years return period.

A_{max} = 0.40 g, for 500 years return period.

The following sets of selected ground motion records are proposed in the methodology:

- El Centro (California, USA) N-S May 8th, 1940.
- Ulcinj (Albatros, Montenegro) N-S 1979.
- Cherchell (Algeria) N-S October 29th, 1989.

The safety design criterion in general should be determined for two levels of expected seismic action as follows:

1st level: Slight (moderate) earthquake ground motion, expected many times during the life of the building, for 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 after without repair.

The maximum allowable deformations (story drift displacements) are:

R/C Frame Structure: $$\Delta = \min\left\{\Delta_{capel};\ \frac{H}{300-400};\ 1\%\ H\right\}$$

R/C Shear Wall + Frames: $$\Delta = \min\left\{\Delta_{capel};\ \frac{H}{350-450};\ 1\%\ H\right\}$$

$$\mu = 1 \text{ to } 1.25$$

H: Story height.

Δ_{capel}: Yield displacement capacity.

μ: Maximum ductility demand.

2nd level: Strong (major) earthquake ground motion, expected once during the life of the building, for a return period of 500 years. The structure should behave in the non linear range, with a controlled level of damage. No heavy damage or collapse is allowable, and the building can be used after inspection and some repairs.

The maximum allowable deformations (story drift displacements) are:

R/C Frame Structure: $$\Delta = \min\left\{\Delta_{capU};\ \frac{H}{125-150};\ 1\%\ H\right\}$$

R/C Shear Wall + Frames: $$\Delta = \min\left\{\Delta_{capU};\ \frac{H}{150-175};\ 1\%\ H\right\}$$

Maximum ductility demand: $\begin{cases} \mu \le \mu_{\mathrm{cap}} \\ \mu \le 2.5 \text{ to } 3.0 \end{cases}$

H: Story height.
Δ_{capU}: Ultimate displacement capacity.
μ_{cap}: Capacity ductility.
μ: Maximum ductility demand.

In doing so, the "capacity approach" is used to estimate the safety and the damageability of the structure. To check the compliance with these criteria, it is necessary to perform the static and dynamic analysis for the moderate and strong expected ground motions.

2.2 Structural analysis

Structural analysis should include the basic structural systems. The primary purpose is to support gravity loads. However, buildings may also be subjected to lateral forces due to wind or earthquakes. It must be able to resist most efficiently the various combinations of gravity and horizontal loading. The non-structural elements should be controlled on the basis of obtaining principal corresponding data (story deformation, flexibility, local instability, etc).

Structural analysis shall include real data on building structures and characteristics of structural materials, as well as existing upgrading or/ and changes in the original systems of the buildings.

2.3 Static and dynamic analysis

For the defined vertical and horizontal loads, linear static and dynamic analysis is performed with SAP2000 (e.g., SAP2000, 1997) for the purpose of obtaining the periods, the mode shapes, the story stiffness and the relative displacements. The static quantities, bending moments, shear and axial forces are checked for existing characteristic frames.

2.4 Seismic analysis according to the new seismic building code "RPA 99/Version 2003"

The building is designed according to the new code RPA 99/version 2003 (e.g., RPA99, 2003) requirements, taking into account determined natural period, building category, total weight, soil conditions, etc. With the applied horizontal forces, we carry out M, Q and N in terms of demand. A comparison with actual data (if they exist) will be made for a qualitative evaluation.

2.5 Deformability and capacity Analysis

The "Capacity design approach" is the actual appropriate method for estimating capacity, deformability and decision making for structures safety. It is also used for vulnerability assessment of existing buildings. It considers the real bearing and deformability characteristics of the structures in the elastic and plastic state. This approach uses the theory of ultimate Limit State of reinforced concrete structures. The input data used for the ultimate state analysis with the program U.A.R.C.S (e.g., Bozinovski and Gavrilovic 1993) for each structural element and at each level are the followings:

- Geometric characteristics of structural elements and position.
- Characteristics of the materials (concrete and reinforcement).
- Vertical loads (due to gravity and seismic loads).

The output data from the ultimate state analysis is carried out firstly for each structural element and at each level in terms of:

- Interaction diagram (*N*, *M*), axial force *N* and bending moment *M*.
- *My* and *Mu*, respectively yielding and ultimate bending moments.
- φy and φu, respectively yielding and ultimate curvatures.
- δy and δu, respectively yielding and ultimate displacements.
- *Qu*, ultimate shear force.
- μ_{cap}, ductility capacity.
- *S*, axial force ratio ($N/(F_{c28}bD)$).

Secondly, the envelope curve, is then determined for each storey, including all the vertical structural elements in terms of:

- Δy and Δu, respectively story yielding and ultimate displacements.
- *Qy* and *Qu*, respectively storey yielding and ultimate shear force.
- *Ky*, storey yielding stiffness.
- μcap, ductility capacity.
- Shear force at ultimate point Q_u.
- Ductility capacity $\mu = \delta_u / \delta_y$.

This envelope curve can be expressed by the following equations respectively for the yield and the ultimate state

$$Qy = Qy_{\min} + \delta y_{\min}\left[\sum_{i=1}^{i=N-1}\frac{Qy_i}{\delta y_i}\right]$$

$$Qu = Qu_{\min} + \sum_{\delta u\ \min > \delta yi}[Qy_i + K_{2i}(\delta u_{\min} - \delta y_i)] + \sum_{\delta u\ \min \le \delta yi} K_{1i}\delta u_{\min}$$

$$Avec{:}\ K_{2i} = (Qu_i - Qy_i)/(\delta u_i - \delta y_i) \text{ et } K_{1i} = Qy_i/\delta y_i$$

2.6 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 (e.g., Chopra 2001). The structural response to an earthquake effect is given by the following expression

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{I\}\ddot{U}_g$$

There are a large number of different incremental solution methods. In general, they involve a solution of the complete set of equilibrium equations at each time increment. By solving the system of differential equations for a given ground acceleration, displacements, velocities and accelerations can be known at each time interval.

To determine the non-linear response of the structure, the D.R.A.B.S (e.g., Bozinovski and

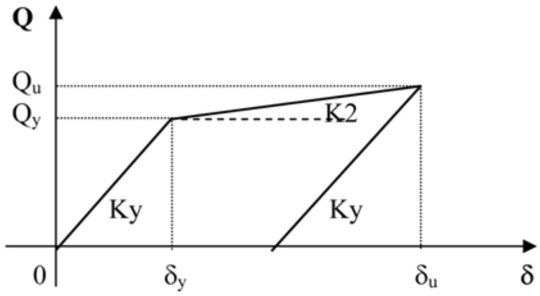

Fig. 1 Bilinear model

Where: $Lp = K2/Ky = \alpha\, Ky/Ky$, with $K2 = (Qu - Qy)/(\delta u - \delta y)$.

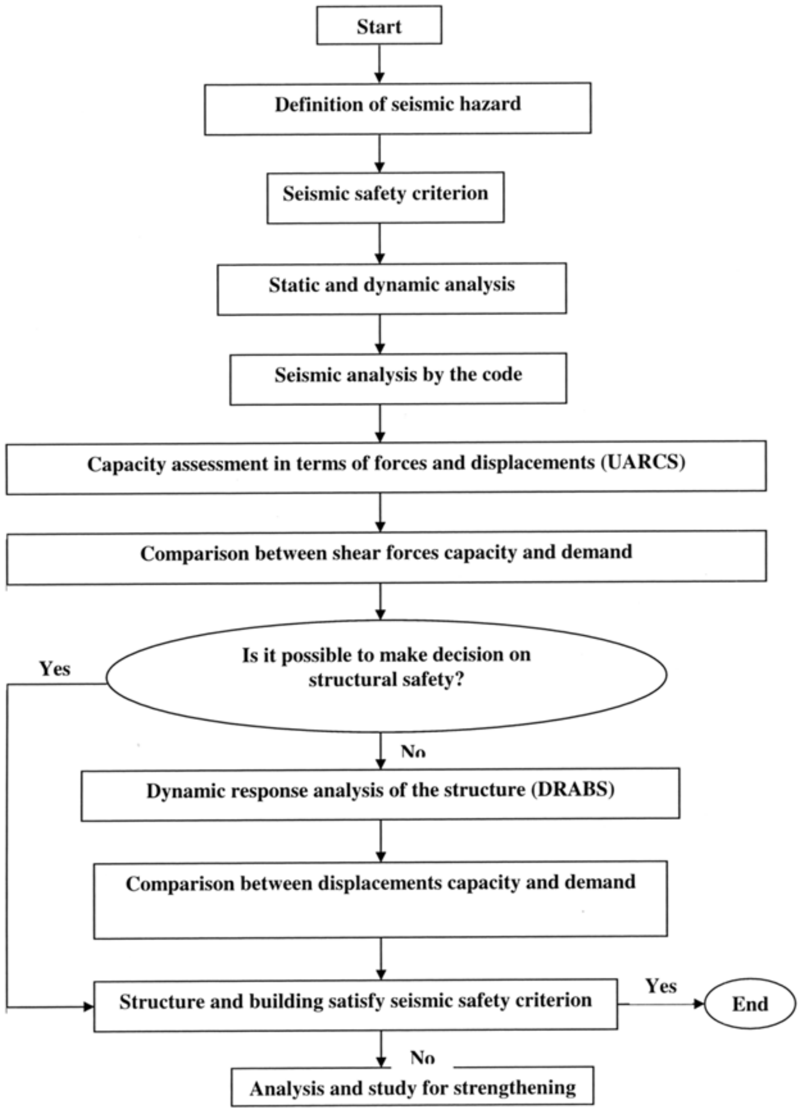

Fig. 2 Methodology flow chart

Gavrilovic 1993) program is used and the bilinear model is adopted The Fig. 1 represents the relationship force-displacement ($Q - \delta$).

2.7 Vulnerability assessment

On the basis of the analysis performed in accordance with the previously discussed procedure, the final decision and proposal should be submitted to the owner of the building.

1- If the structure satisfies the stability criteria in accordance with its function, the building can be used in its existing state.
2- In case of the structure and/or the building 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 be made after economic cost analysis. The Fig. 2, shows the flow chart of the methodology.

3. Application for an existing R/C building

3.1 Description of the building

The building is for a technical purpose, and its principal functions are the telex transmission and the regional numerical maintenance. It was built in 1948, according to the seismic code of that era. The building is composed by seven stories and two basements. The structural system is a reinforced concrete resisting moment frames. The thickness of the hollow concrete floors is (20+4) cm. The building is set on a good soil quality.

(σ_{Soil} = 200 KN/m^2).

A general view of the existing building is shown in Fig. 3.

Fig. 3 General view of the telecommunication centre

3.2 Mechanical characteristics of the materials

Concrete:
- Characteristic compressive cylinder strength at 28 days: f_{c28} = 20 Mpa.
- Design tensile strength: σ_t = 1.8 Mpa.
- Strain at yield: ε_e = 0.002.
- Ultimate strain: ε_u = 0.0035.

Steel:
- Characteristic tensile yield strength of reinforcement: f_e = 400 Mpa.
- Characteristic tensile strength of shear reinforcement: f_t = 235 Mpa.
- Yield strain of reinforcement: ε_y = 0.002.
- Yield strain of shear reinforcement: ε_e = 0.0018.
- Ultimate strain: ε_u = 0.010.

3.3 Mathematical model

The mathematical model of the structure is defined as a system with masses concentrated at the level floor structures, connected by springs and dampers. The system is fixed at the base. The floors are supposed rigid in their plan. The Fig. 4 shows the mathematical model of the structure.

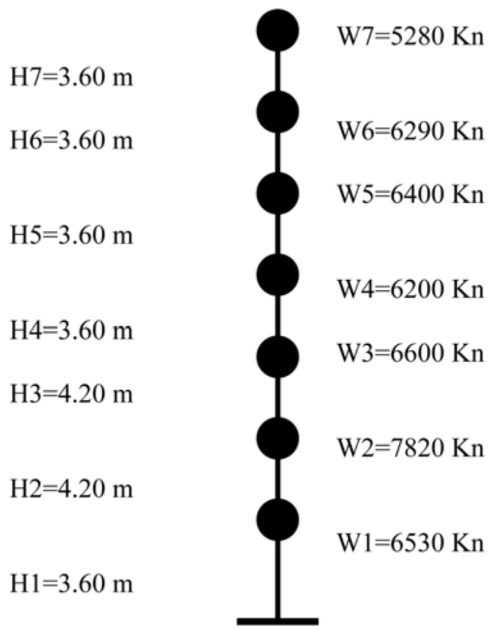

Fig. 4 Mathematical model of the structure

3.4 Structural analysis

In the analysis, the structure was modeled as a 3D space frame, using SAP 2000 (e.g., SAP2000, 1997) program. The Figs. 5 and 6 show respectively a plan and three dimensional views of the initial structure.

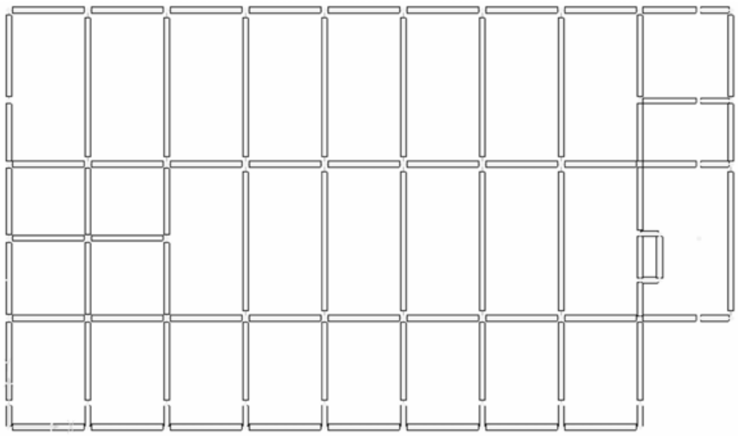

Fig. 5 Plan view of the initial structure

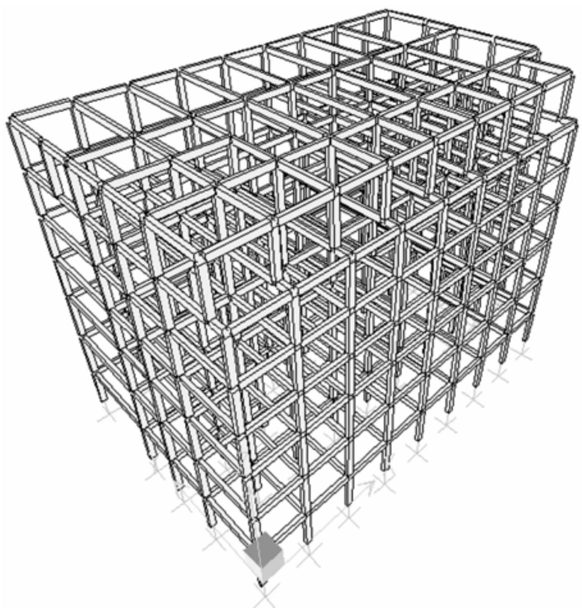

Fig. 6 Three-dimensional view of the initial structure

3.5 Seismic assessment by the code RPA 99/version 2003

The total design base shear force is estimated using the static equivalent force procedure (e.g., C.G.S, 2003 and Dimova 2005), and determined from formula

$$V = \frac{ADQ}{R}W$$

Where:
V : Total design base shear force.
A : Design base acceleration coefficient.

D : $f(T)$, Mean dynamic amplification factor, function of the fundamental natural period.
Q : Quality factor.
R : Behavior factor of the structure (R/C frames).
T : Fundamental natural period of the structure.
W : Total seismic weight.

The total force is distributed over the height of the structure in conformance with the following formula

$$F_K = \frac{(V - F_t)W_K h_K}{\sum_{i=1}^{N} W_i h_i}$$

Where:
F_k : Seismic horizontal force at the K^{ith} level.
F_t : Shall be assumed to be concentrated at the top of the structure in addition to Fn, and equal to 0.07 TV, except that F_t need not exceed 0.25 V and may be considered as zero when T does not exceed 0.7 sec.
W_k : Seismic weight at level k.
h_k : Height of level k from the base.

The distribution of the lateral seismic loads is shown in Table 1.

Table 1 Distribution of the transversal (YY) and the longitudinal (XX) seismic forces

Level	Wi (Kn)	Hi (m)	F_i^y (Kn)	V_i^y (Kn)	F_i^x (Kn)	V_i^x (Kn)
7	5280	3.60	2494.94	2494.94	2376.13	2376.13
6	6290	3.60	2566.89	5061.83	2444.66	4820.79
5	6400	3.60	2199.39	7261.22	2094.66	6915.45
4	6200	3.60	1731.16	8992.38	1648.73	8564.18
3	6600	4.20	1417.58	10409.96	1350.07	9914.42
2	7820	4.20	1091.75	11501.17	1039.76	10954.01
1	6530	3.60	420.76	11922.47	400.72	11354.73

$$V_i^y = F_t + \sum_{k=i}^{7} F_k^y \qquad V_i^x = F_t + \sum_{k=i}^{7} F_k^x$$

Vyi : Transversal shear force at level i.
Fyk : Transversal horizontal force at level i.
Vxi : Longitudinal shear force at level i.
Fyk : Longitudinal horizontal force at level i.
XX : Longitudinal direction.
YY : Transversal direction.

3.6 Deformability and strength capacity

To determine the bearing capacity of the structure in terms of strength and deformability, the

U.A.R.C.S (e.g., Bozinovski and Gavrilovic 1993) program is used.

The input data needed are:

- Vertical loads (due to gravity and seismic loads).
- Storey height.
- Geometric characteristics of cross sections.
- Uniformly distributed and stirrup steel.
- Material characteristics.

The structure is considered as stable when the safety factor is greater than 1.15 at each level.

$$Fs = \frac{Q_K^U}{V_K} \geq 1.15$$

Where:

$Q_{u,K}$: Shear force capacity at level k.

V_K : Shear force demand at level k.

The Table 2, resumes the results of shear capacity, shear demand and safety factors, for both transversal (YY) and longitudinal (XX) directions.

Table 2 Shear capacity, shear demand and safety factors of the structure in the transversal (YY) and the longitudinal (XX) directions

Level	Q_u^y (Kn)	V_i^y (Kn)	F_s^y	Q_u^x (Kn)	V_i^x (Kn)	F_s^x
7	986.62	2494.94	0.39	1014.29	2376.13	0.42
6	2074.20	5061.83	0.40	1871.60	4820.79	0.38
5	2440.57	7261.22	0.33	2172.14	6915.45	0.31
4	3452.11	8992.38	0.38	3127.87	8564.18	0.36
3	3408.73	10409.96	0.32	3136.80	9914.25	0.31
2	4606.64	11501.71	0.40	4363.25	10954.01	0.39
1	5409.30	11921.47	0.45	5487.46	11354.73	0.48

Similarly, and as comparison, seismic forces were determined according to the Euro code 8. The Table 3 shows the seismic forces, the shear forces and the safety factors for both the transversal (YY) and the longitudinal (XX) directions.

Table 3 Shear capacity, shear demand and safety factors of the structure in the transversal (YY) and the longitudinal (XX) directions

Level	Q_u^y (Kn)	V_i^y (Kn)	F_s^y	Q_u^x (Kn)	V_i^x (Kn)	F_s^x
7	986.62	2983.66	0.33	1014.29	2983.66	0.33
6	2074.20	6053.36	0.34	1871.60	6053.36	0.30
5	2440.57	8683.59	0.28	2172.14	8683.59	0.25
4	3452.11	10753.86	0.32	3127.87	10753.86	0.29
3	3408.37	12449.07	0.27	3136.80	12449.07	0.25
2	4606.64	13754.68	0.33	4363.25	13754.68	0.31
1	5409.30	14257.86	0.37	5487.46	14257.86	0.38

The Figs. 7 and 8 show the demand and the capacity of the structure in terms of shear forces for both transversal (YY) and longitudinal (XX) directions, according to the Algerian seismic code RPA99/version 2003.

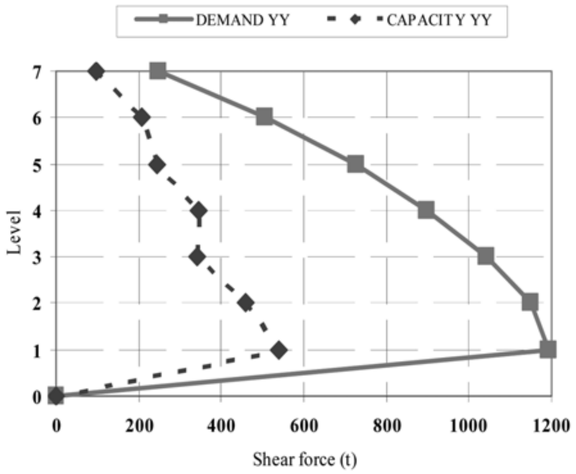

Fig. 7 Capacity and demand in transversal direction

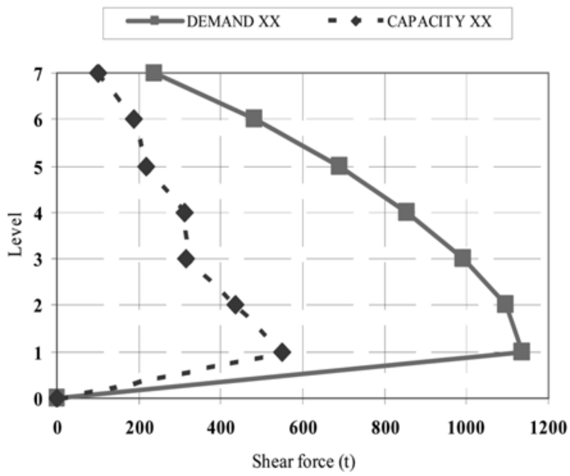

Fig. 8 Capacity and demand in longitudinal direction

According to these results, the structure is unstable and can't sustain a major earthquake.

3.7 Non linear dynamic response analysis

The dynamic response analysis of the structure is carried out by using the D.R.A.B.S (e.g., Bozinovski and Gavrilovic 1993) program and the selected ground motion records.

The deformability capacity and displacement demands are compared at each level, for the moderate and strong earthquakes. The Table 4 resumes the results of the capacity and the demand of drift displacements for Amax = 0.15 g, in the transversal (YY) direction.

Table 4 Capacity and demand of drift displacements (cm) in the transversal (YY) direction

Level	Δ_{capel}	H/(300/400)	1% H	Ulcinj	El Centro	Cherchell
7	1.18	1.02	3.60	0.98	0.74	0.59
6	1.55	1.02	3.60	1.42	1.08	0.90
5	1.58	1.02	3.60	2.16	1.41	1.13
4	1.26	1.02	3.60	1.12	0.86	0.69
3	1.30	1.20	4.20	1.43	1.14	0.85
2	1.20	1.20	4.20	1.19	1.03	0.65
1	1.48	1.02	3.60	2.66	2.23	1.38

The Table 5 resumes the results of the capacity and the demand of drift displacements for Amax = 0.15 g, in the longitudinal (XX) direction.

Table 5 Capacity and demand of drift displacements (cm) in the longitudinal (XX) direction

Level	Δ_{capel}	*H*/(300/400)	1% *H*	Ulcinj	El Centro	Cherchell
7	0.90	1.02	3.60	0.97	0.74	0.40
6	1.76	1.02	3.60	1.62	1.33	0.80
5	1.99	1.02	3.60	2.23	1.73	1.12
4	1.36	1.02	3.60	1.22	0.95	0.65
3	1.45	1.20	4.20	1.57	1.26	0.80
2	1.29	1.20	4.20	1.33	1.13	0.66
1	1.43	1.02	3.60	2.53	1.93	1.20

The Table 6 resumes the results of the capacity and the demand of drift displacements for *A*max=0.40 g, in the transversal (YY) direction.

Table 6 Capacity and demand of drift displacements (cm) in the transversal (YY) direction

Level	Δ_{capU}	*H*/(125/150)	1% *H*	Ulcinj	El Centro	Cherchell
7	6.75	2.61	3.60	5.56	5.01	3.87
6	3.62	2.61	3.60	2.93	3.27	2.17
5	2.60	2.61	3.60	3.71	4.23	4.02
4	2.13	2.61	3.60	3.17	3.93	3.26
3	2.44	3.05	4.20	4.22	4.97	3.34
2	2.28	3.05	4.20	3.17	3.35	2.32
1	1.68	2.61	3.60	4.67	5.27	3.21

The Table 7 resumes the results of the capacity and the demand of drift displacements for *A*max = 0.40 g, in the longitudinal (XX) direction.

Table 7 Capacity and demand of drift displacements (cm) in the longitudinal (XX) direction

Level	Δ_{capU}	*H*/(125/150)	1% *H*	Ulcinj	El Centro	Cherchell
7	6.99	2.61	3.60	4.45	5.21	4.30
6	3.78	2.61	3.60	2.77	3.63	3.11
5	2.68	2.61	3.60	2.89	3.21	3.27
4	2.25	2.61	3.60	4.21	2.47	3.69
3	2.90	3.05	4.20	4.91	3.63	3.77
2	2.62	3.05	4.20	4.81	3.32	2.73
1	1.86	2.61	3.60	3.12	3.82	2.15

The Table 8 resumes the results of the capacity and the demand in terms of ductility for *A*max = 0.40 g, in the transversal (YY) direction.

Table 8 Capacity and demand in terms of ductility for *A*max = 0.40 g, in the transversal (YY) direction

Level	μ_{cap}	μ_{limit}	Ulcinj	El Centro	Cherchell
7	5.68	3	4.68	4.22	3.26
6	2.32	3	1.88	2.09	1.39
5	1.64	3	2.34	2.66	2.53
4	1.69	3	2.51	3.11	2.58
3	1.86	3	3.23	3.80	2.55
2	1.88	3	2.62	2.77	1.92
1	1.13	3	3.14	3.54	2.61

The Table 9 resumes the results of the capacity and the demand in terms of ductility for *A*max = 0.40 g, in the longitudinal (XX) direction.

Table 9 Capacity and demand in terms of ductility for *A*max = 0.40 g, in the longitudinal (XX) direction

Level	μ_{cap}	μ_{limit}	Ulcinj	El Centro	Cherchell
7	7.68	3	4.89	5.73	4.73
6	2.14	3	1.56	2.05	1.76
5	1.34	3	1.44	1.60	1.63
4	1.65	3	3.09	1.81	2.70
3	2.00	3	3.38	2.50	2.60
2	2.03	3	3.72	2.57	2.11
1	1.29	3	2.17	2.66	1.49

The Figs. 9 and 10 show respectively, the capacity and the demand of drift displacements for *A*max = 0.15 g, in the transversal (YY) and the longitudinal (XX) directions of the initial structure.
The Figs. 11 and 12 show respectively, the capacity and the demand of drift displacements for *A*max = 0.40 g, in the transversal (YY) and the longitudinal (XX) directions of the initial structure.
The Figs. 13 and 14 show respectively, the capacity and the demand in terms of ductility for *A*max = 0.40 g, in the transversal (YY) and the longitudinal (XX) directions of the initial structure.

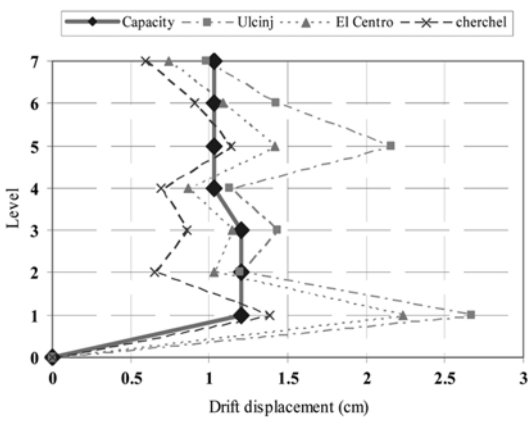

Fig. 9 Transversal direction *A*max = 0.15 g

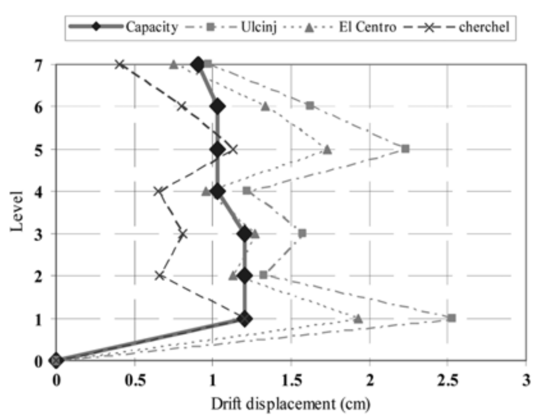

Fig. 10 Longitudinal direction *A*max = 0.15 g

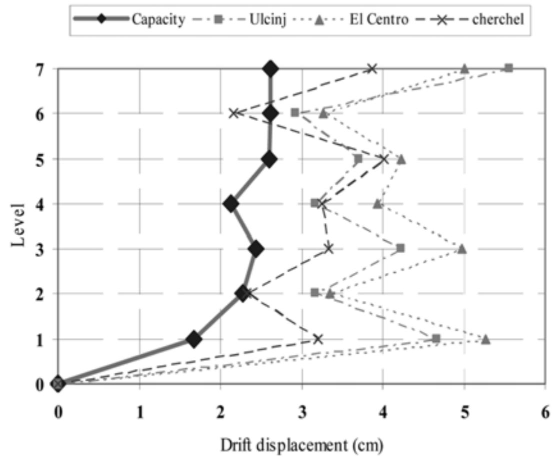

Fig. 11 Transversal direction Amax = 0.40 g

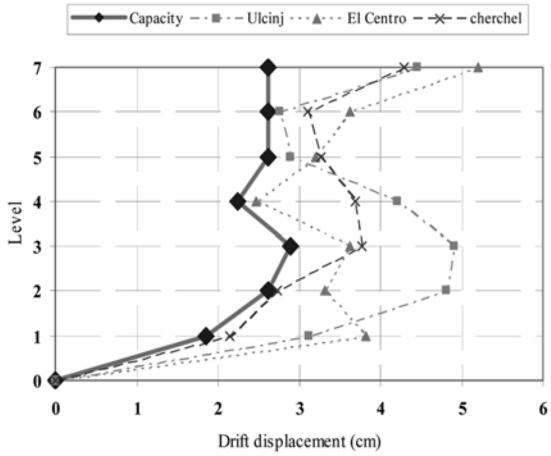

Fig. 12 Longitudinal direction Amax = 0.40 g

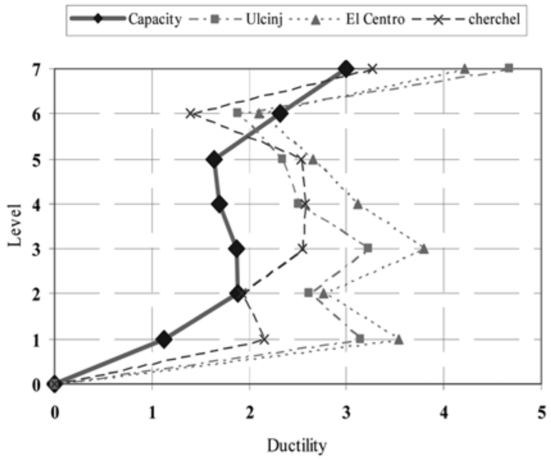

Fig. 13 Transversal direction Amax = 0.40 g

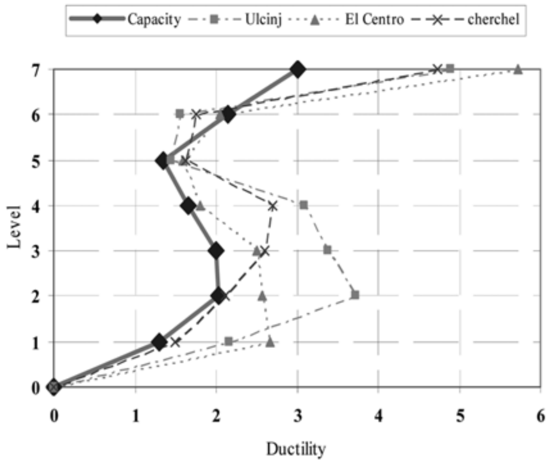

Fig. 14 Longitudinal direction Amax = 0.40 g

Commentary

On the basis of the different obtained results, the deficiency of the structure is its excessive flexibility. Drift displacements under lateral forces exceeded considerably the allowed capacity values. All calculations 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. This needed about ten different simulations

3.8 Suggestion of strengthening

Four new shear walls with 20 cm thickness were added in both directions along the height of the structure (e.g., Rocha 2004). Two, in the transversal (YY) direction and two in the longitudinal direction, at the end frames in order to get a dual system (behavior factor = 5). The Fig. 15, shows the suggested strengthening of the structure.

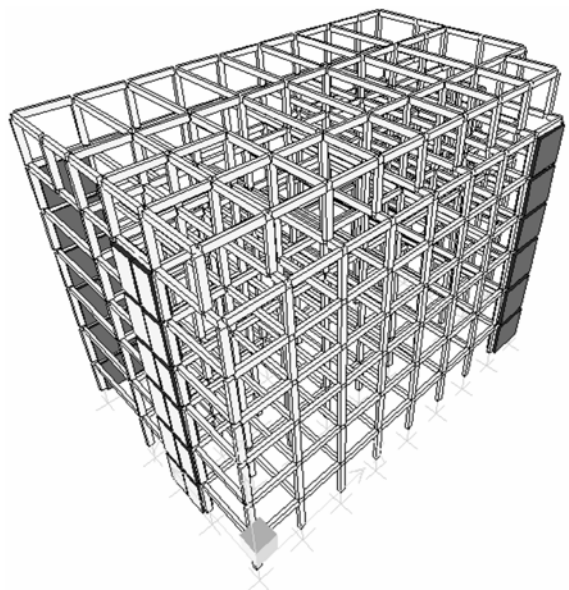

Fig. 15 Three-dimensional view of the strengthened structure

The same analysis steps are repeated in order to check the behavior of the strengthened structure. The main results of the strengthened structure are shown in Tables 10 to 15, for respectively the transversal (YY) and the longitudinal (XX) directions, with Amax = 0.40 g.

Table 10 Distribution of the transversal (YY) and the longitudinal (XX) seismic forces

Level	Wi (Kn)	Hi (m)	F_i^y (Kn)	V_i^y (Kn)	F_i^x (Kn)	V_i^x (Kn)
7	5280	3.60	1757.35	1757.35	1673.67	1673.67
6	6444.26	3.60	1852.37	3609.72	1764.16	3437.83
5	6708.52	3.60	1623.86	5233.58	1546.53	4984.36
4	6508.52	3.60	1280.05	6513.63	1219.09	6203.45
3	6934.23	4.20	1049.06	7562.69	999.10	7202.55
2	8179.94	4.20	804.38	8367.07	766.08	7968.63
1	6864.23	3.60	311.54	8678.61	296.70	8265.33

Table 11 Shear capacity, shear demand and safety factors of the structure in the transversal (YY) and the longitudinal (XX) directions

Level	Q_u^y (Kn)	V_i^y (Kn)	F_s^y	Q_u^x (Kn)	V_i^x (Kn)	F_s^x
7	2070.30	1757.35	1.17	1984.29	1673.67	1.18
6	11880.11	3609.72	3.29	9694.60	3437.83	2.81
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

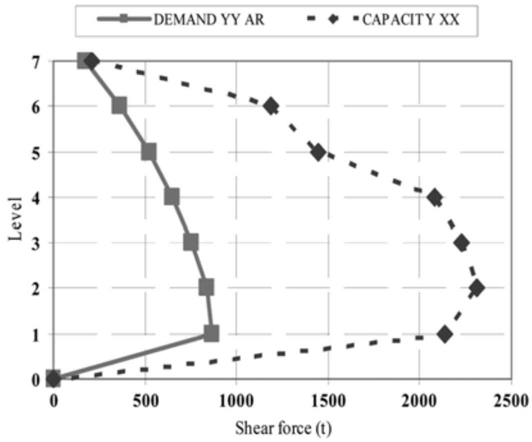

Fig. 16 Capacity and demand in transversal direction

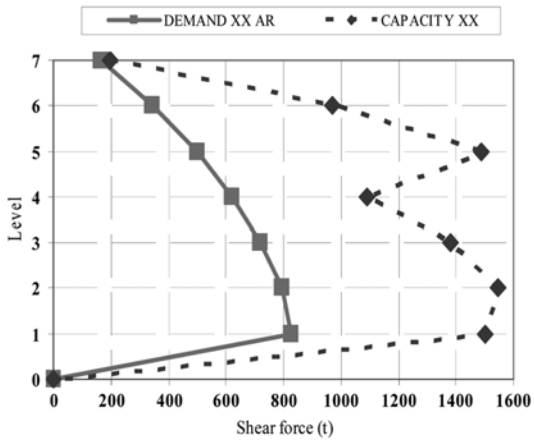

Fig. 17 Capacity and demand in longitudinal direction

Table 12 Capacity and demand of drift displacements (cm) for Amax = 0.40 g in the transversal (YY) direction

Level	Δu cap	H/(150/175)	1% H	Ulcinj	El Centro	Cherchell
7	6.75	2.21	3.60	2.14	2.06	2.01
6	7.21	2.21	3.60	1.24	1.99	1.97
5	6.77	2.21	3.60	2.11	1.98	1.56
4	4.91	2.21	3.60	2.12	1.56	1.45
3	5.27	2.58	4.20	2.14	1.74	1.43
2	4.83	2.58	4.20	2.33	1.55	1.56
1	3.37	2.21	3.60	1.98	1.83	1.62

Table 13 Capacity and demand of drift displacements (cm) for Amax = 0.40 g in the longitudinal (XX) direction

Level	Δu cap	H/(150/175)	1% H	Ulcinj	El Centro	Cherchell
7	6.99	2.21	3.60	2.15	2.12	2.07
6	6.12	2.21	3.60	2.17	2.21	1.87
5	5.83	2.21	3.60	2.19	2.11	1.72
4	4.73	2.21	3.60	1.86	1.83	1.65
3	5.22	2.58	4.20	1.78	1.73	1.55
2	4.93	2.58	4.20	1.99	1.64	1.41
1	3.83	2.21	3.60	2.01	2.11	1.56

Table 14 Capacity and demand in terms of ductility for Amax = 0.40 g, in the transversal (YY) direction

Level	μ cap	μ limit	Ulcinj	El Centro	Cherchell
7	3.02	3	1.73	1.66	1.62
6	1.93	3	1.20	1.92	1.90
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

Table 15 Capacity and demand in terms of ductility for *A*max = 0.40 g, in the longitudinal (XX) direction

Level	μ cap	μ limit	Ulcinj	El Centro	Cherchell
7	6.26	3	1.92	1.90	1.85
6	5.81	3	2.06	2.09	1.77
5	4.37	3	1.64	1.58	1.28
4	3.60	3	1.41	1.39	1.25
3	3.45	3	1.17	1.14	1.02
2	3.65	3	1.47	1.21	1.04
1	2.56	3	1.34	1.41	1.04

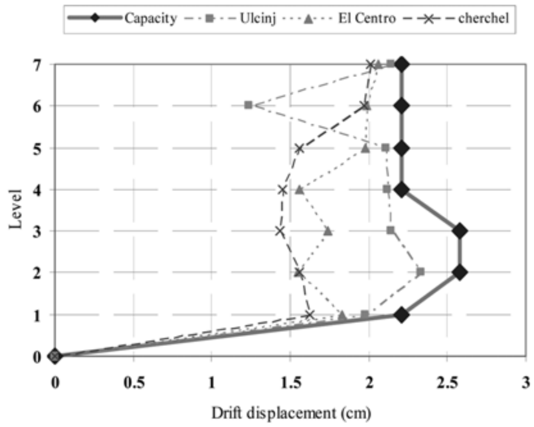

Fig. 18 Transversal direction *A*max = 0.40 g

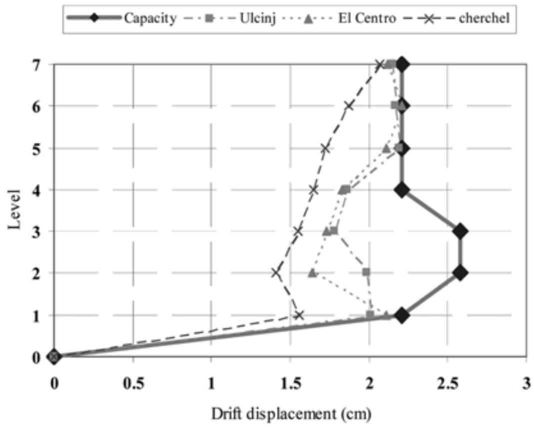

Fig. 19 Longitudinal direction *A*max = 0.40 g

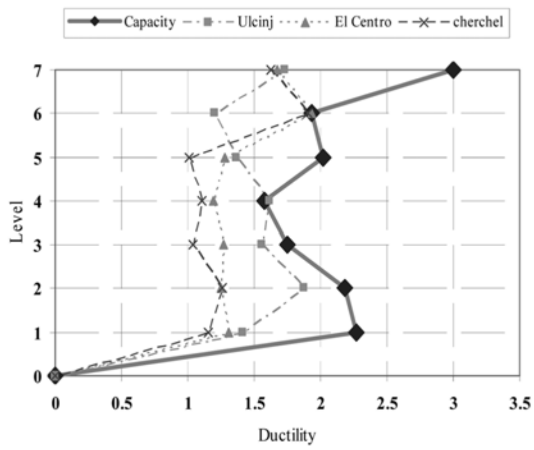

Fig. 20 Transversal direction *A*max = 0.40 g

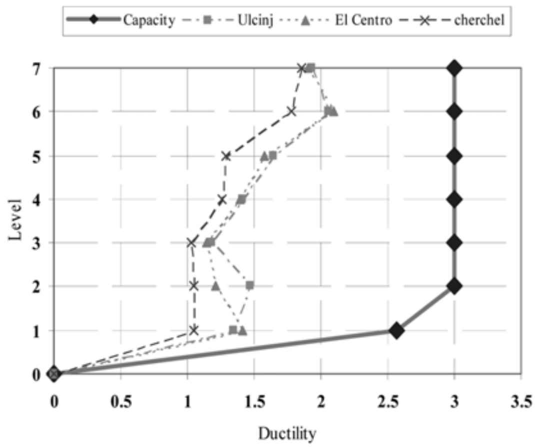

Fig. 21 Longitudinal direction *A*max = 0.40 g

The Figs. 16 to 21 show for the strengthened structure, the capacity and the demand in terms of shear forces, the capacity and the demand of drift displacements for *A*max = 0.40 g, the capacity and the demand in terms of ductility, respectively in the transversal (YY) and the longitudinal (XX) directions.

3.9 General conclusion

One of the basic problems of strengthening of existing buildings is how to select the most adequate solution from both economic and stability aspects. In our case, many simulations have been done to get the best solution. The close proximity with the neighborhood building was a major problem, but the hammering effect has been controlled. It is necessary to mention that the vulnerability study must include the whole neighbor buildings even if there are not strategic.

References

Biondini, F. and Toniolo, G. (2003), "Seismic behavior of concrete frames: Experimental and analytical verification of Euro code 8 design rules", *Int. proc. FIB 2003 Symposium. 2003.*

Bozinovski, Z. and Gavrilovic, P. (1993), "Computer program for dynamic response analysis of building structures, D.R.A.B.S", *I.Z.I.I.S, University of Skopje,* Republic of Macedonia.

Bozinovski, Z. and Gavrilovic, P. (1993), "Computer program for ultimate analysis of rectangular reinforced concrete cross sections of frames and walls systems, U.A.R.C.S", *I.Z.I.I.S, University of Skopje,* Republic of Macedonia.

C.G.S. (1994), "Methods' Catalogue for repair and strengthening of buildings", *Nat. Earthq. Eng. Centre,* Algiers, Algeria.

C.G.S. (2003), "Seismic code for building design and construction, R.P.A 99/Version 2003", *Nat. Earthq. Eng. Centre,* Algiers, Algeria.

CEB (1996), "RC frames under earthquake loading", *Comité Euro-International du Béton",* Bulletin N° 231.

Chopra, A. (2001), *Dynamics of Structures. Theory and Applications to Earthquake Engineering.* Prentice-Hall, Englewood Cliffs, NJ.

Dimova, S.L. and Negro, P. (2005), "Seismic assessment of an industrial frame structure designed according to Eurocodes. Part 2: Capacity and vulnerability", *Eng. Struct.,* **27** (2005), 724-735.

I.I.Z.I.S/C.G.S. (1993), "Methodology and vulnerability study of strategic buildings in the city of Algiers", *Na. Earthq. Eng. Centre,* Algiers, Algeria.

Pinho, R. (2000), "Selective retrofitting of RC structures in seismic areas. London", *PhD Thesis, Imperial College of Science and Technology, 2000.*

Regulations for Seismic Design A World List – 1996. *"International Association for Earthquake Engineering IAEE".*

Rocha, P., Delgado, P., Costa, A. and Delgado, R. (2004), "Seismic retrofit of RC frames", *Comput. Struct.,* **82**, 1523-1534.

Varum, R. (2003), "Seismic assessment, strengthening and repair of existing buildings", *Universidade de Aveiro, PhD Thesis, 2003.*

Wilson, E. and Habibullah, A. (1997), *Three Dimensional Static and Dynamic Analysis of Structures, SAP 2000.* Computers and Structures, Inc. Berkeley, California.