Citation: AIT ALI SLIMANE, N., T. Saito (2022), Comparison of retrofitting methods on an existing residential RC building in Algeria, heavily damaged by the 2003 Boumerdes earthquake, Synopsis of IISEE-GRIPS Master's Thesis.

COMPARISON OF RETROFITTING METHODS ON AN EXISTING RESIDENTIAL RC BUILDING IN ALGERIA, HEAVILY DAMAGED BY THE 2003 BOUMERDES EARTHQUAKE

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ABSTRACT

The 2003 Boumerdes earthquake caused a large amount of damage, particularly in the city of Boumerdes. After the disaster, a revision of Algerian code and the retrofitting of the 1,200 dwellings of Ibn Khaldoun city were made. The study of the city was made by a group of engineers from the National Body for Technical Control of Construction of the East (CTC-EST), and tests were carried out just after the disaster by a group of researchers from the National Center for Applied Research in Paraseismic Engineering (CGS) and the Internal Geophysics and Tectonophysics Laboratory (IRD), then other tests were carried out after the rehabilitation as part of a magister thesis in 2010. The retrofitting method at that time was based on an experimental approach without following a specific code. Japan, being especially advanced in seismic evaluation and rehabilitation of different structures, the Japan Building Disaster Prevention Association (JBDPA) method was used during this study to evaluate and retrofit a building of Boumerdes and compare 4 models of retrofitting under 3 different earthquakes. The comparison was based on the seismic index "Is", the story drift and shear at each floor, to find the most safely and economically effective result. During the study, the Japanese code and factor had to be adapted to Algerian seismic activity and ground proprieties. The use of STERA-3D and the time history analysis method was also necessary for the calculations. The final result showed the model of the after earthquake retrofit having higher safety, but the JBDPA method proposed retrofitting model with lower capacity, which satisfy the minimum safety conditions and were more economical than the retrofit proposed at that time. Therefore, it would be beneficial for Algeria to be inspired by the JBDPA method for the future changes in the Algerian seismic code and add to it an evaluation and rehabilitation procedure adaptable to the different seismic zones of Algeria.

Keywords: Reinforced concrete (RC) building, seismic evaluation, retrofitting, time history analysis.

1. INTRODUCTION

On May 21, 2003, Boumerdes in the northern part of Algeria were struck by a disaster that damaged a large part of the residential RC buildings in the city. This disaster led to the revision of the Algerian seismic code in its current version RPA99/V2003 and the retrofitting of housing in the city of Ibn Khaldoun. After the disaster, a study of 15 heavily damaged 5-floor residential RC buildings in Boumerdes city was made by a group of engineers from the CTC-EST to evaluate the seismic performance of the buildings and propose the appropriate rehabilitation measures. A first series of tests

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was carried out just after the earthquake in 2003 by a group of researchers from the CGS and IRD then a second after the rehabilitation as part of a magister thesis in 2010. The evaluation of the seismic performance was possible using the Algerian code, RPA99, but concerning the retrofitting method itself, it was based on an experimental approach using RC column jacketing and RC shear walls added to the building without following a specific code, due to the absence of a rehabilitation code implemented at the time. The objectives of this research is to compare different methods of retrofitting for RC buildings applicable in Algeria (column jacketing and shear walls) with the retrofitting done after the 2003 earthquake, using the JBDPA method for the evaluation, rehabilitation and retrofitting, and test the application of the JBDPA method and the different factors in the Algerian zone.

2. TARGET BUILDING

The 1200 housing units of the Ibn-Khaldoune city were made of RC residential buildings with 5-floors and a basement, with a floor height of 3 m, forming 1 to 4 blocks separated by expansion joints of 2 cm, the plan dimensions of the building were 10.9*21.7 m² or 10.9*18 m², for this study the dimensions of 10.9*21.7 m² were taken. The plan of the building is shown in Figure 1. The building is composed of 6 spans in the longitudinal direction and 2 in the transverse direction, the roof total area (A_{Roof}) is 236.53 m² with a weight (Q_{roof}) of 10 kN /m², the standard floor area without balcony (A_{Floor}) is 179.03 m² with a weight (Q_{floor}) of 13 kN /m², and the balcony area ($A_{Balcony}$) is 57.51 m² with a weight ($Q_{Balcony}$) of 6.5 kN/m². The load for the roof (P_{roof}) was calculated 2365.30 kN and the load for a standard floor (P_{floor}) was calculated 2701.11 kN.

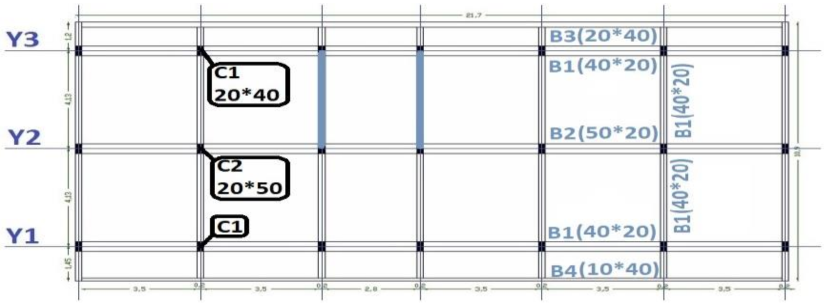

Figure 1. Standard plan of the building.

The RC columns were oriented transversely, for the edge columns (C_1) and for the central columns (C_2). The transverse RC beams are (B_1), the longitudinal RC beams are for the edge beams (B_1), the central RC beams (B_2), and (B_3), (B_4), for the RC balcony's beams. The main bars were 8D16 and the hoops were 2ф8 with 150mm spacing. The concrete minimum design compressive strength (F_c) was taken at 25 N/mm², and the yield strength of reinforcing bars (σ_y) and the yield strength of shear reinforcement bars (σ_{yw}) were both taken at 413 N/mm².

The neglected basement was formed by a peripheral RC wall. The stairs were oriented in the transverse direction, supported by transversal RC walls with a thickness of 150 mm. The exterior fillings were masonry walls, made up of hollow bricks of 10*20*30 cm^3 in the plane of the porticoes.

3. SEISMIC EVALUATION AND RETROFITTING

3.1. Seismic performance by JBDPA 2nd level screening procedure

By the JBDPA method, the calculation of the seismic index and the seismic demand index of the target building was done using Eq. (1) and Eq. (2), and the evaluation of its safety by Eq. (3) and Eq. (4).

$$I_s = E_0 * S_D * T, \tag{1}$$

$$I_{so} = E_s * Z * G * U, \tag{2}$$

$$I_s \geq I_{so}, \tag{3}$$

$$C_{TU} * S_D \geq D_S * Z * G * U, \tag{4}$$

Where, *Is* is seismic index of the structure, E_0 is basic seismic index of structure, S_D is irregularity index, *T* is time index, I_{SO} is seismic demand index of structure, E_S is basic seismic demand index of structure, *Z* is seismic hazard zoning factor, *G* is ground index, *U* is usage index, C_{TU} is cumulative strength index at the ultimate deformation of structure, and D_S is structural characteristic factor.

With Algeria having a different seismic intensity, the seismic hazard zoning factor was recalculated using the target response spectrum and the natural period of the building to get *Z*=0.12 and *Z*=0.82. The structural characteristic factor "*Ds*" were also modified to *Ds*=0.2. The result for *Z*=0.12 and *Ds*=0.2 gave safe judgment, the rest of the calculations were conduct for *Z*=0.82 and *Ds*=0.2.

Table 1 shows the first and second conditions to evaluate the building safety, using Japanese factor adapted with the Japanese target response spectrum at safety limits. It is found that all stories of the target building need retrofitting.

Table 1. Seismic performance evaluation of the target building.

Story	ϕ	F	Ctu*SD	Ds*Z*G*U	Evaluation
5	0,6	2,59	0,19	0,2*0,82*1*1	Safe
4	0,67	2,59	0,12	0,16	Not safe
3	0,75	2,59	0,10	0,16	Not safe
2	0,86	2,59	0,10	0,16	Not safe
1	1,00	2,59	0,10	0,16	Not safe
Story	E01	E02	IS	ISO	Evaluation
5	0,49	0,49	0,488	0,489	Need Retrofitting
4	0,31	0,31	0,311	0,489	Need Retrofitting
3	0,26	0,26	0,264	0,489	Need Retrofitting
2	0,25	0,25	0,248	0,489	Need Retrofitting
1	0,25	0,25	0,247	0,489	Need Retrofitting

3.2. Retrofitting of the target building

By the JBDPA method, the required additional strength at each story was calculated using the following Eq. (5) and the evaluation using Eq. (3) and Eq. (4).

$$\Delta Q_{ui} = \Delta I_{si} * \sum w_i = (I_{so} - I_s) * \sum w_i \tag{5}$$

The retrofitting was made in 3 different cases, by jacketing of all the columns, RC Infill walls, and using both methods. The 3 retrofits are shown in Figure 2-4.

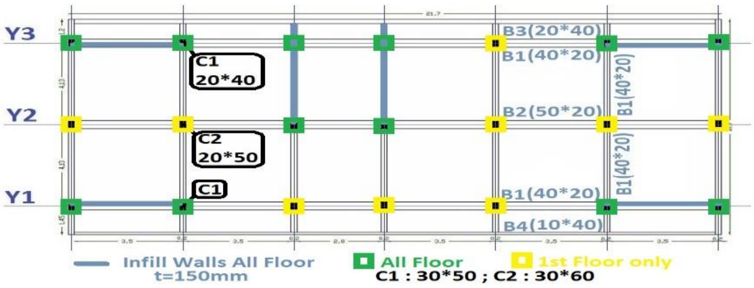

Figure 2. Retrofit plan for both column jacketing and infill walls.

Table 2. Column dimensions for RC jacketing retrofitting.

Story Level	Frame Y	b (mm)	D (mm)	b2 (mm)	D2 (mm)
5	Y3	400	200	450,0	250,0
	Y2	500	200	550,0	250,0
	Y1	400	200	450,0	250,0
4	Y3	400	200	481,0	250,0
	Y2	500	200	601,0	250,0
	Y1	400	200	481,0	250,0
3	Y3	400	200	546,0	273,0
	Y2	500	200	683,0	273,0
	Y1	400	200	546,0	273,0
2	Y3	400	200	600,0	300,0
	Y2	500	200	749,0	300,0
	Y1	400	200	600,0	300,0
1	Y3	400	200	642,0	321,0
	Y2	500	200	802,0	321,0
	Y1	400	200	642,0	321,0

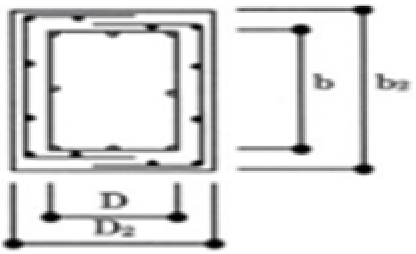

Figure 3. Column RC jacketing retrofitting.

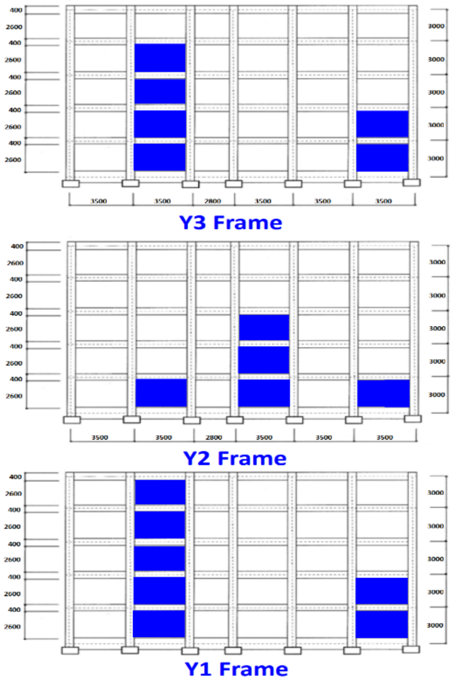

Figure 4. Retrofit plan for RC infill walls.

The result of evaluation for the building without retrofitting, with column jacketing and with infill walls are shown in Figure 5. It is confirmed that the building with retrofitting is safe for all stories. The building with both column jacketing and infill walls was not included in the comparison because of a lack of information regarding the method to calculate the *Is* index for this case.

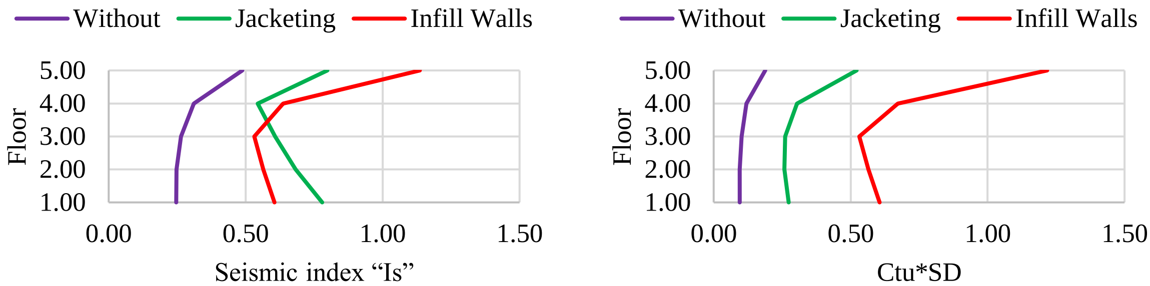

Figure 5. Comparison of the seismic index "Is" and the second safety condition "Ctu*SD" .

4. TIME HISTOTRY ANALYSIS

4.1. Analysis method and results

Before comparing the 4 models, a first test on STERA-3D was made comparing the results of the building with and without considering the masonry walls using the 2003 Boumerdes Eq. The result (Figure 6) showed considerable change by considering the secondary masonry walls, so the rest of the calculation were made considering the secondary masonry wall.

Using the 3 earthquakes (2003 Boumerdes Eq, 1995 Kobe Eq, 1940 El centro Eq), time history analysis was applied on the 4 models to get the story drift *sdx* and shear *sfx* on each floor. The results are shown in Figures 6-8.

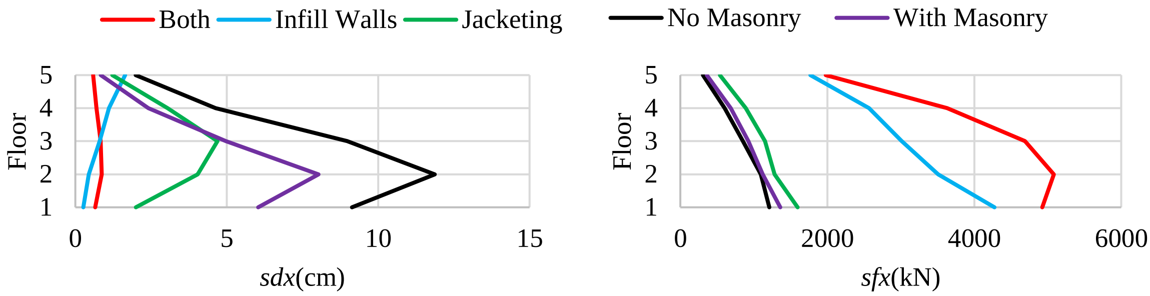

Figure 6. Story drift “*sdx*” and shear “*sfx*” for the record of 2003 Boumerdes Eq.

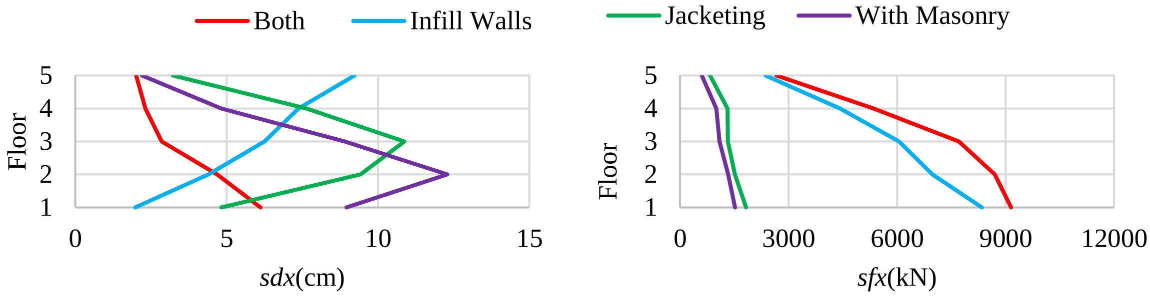

Figure 7. Story drift “*sdx*” and shear “*sfx*” for the record of 1995 Kobe Eq.

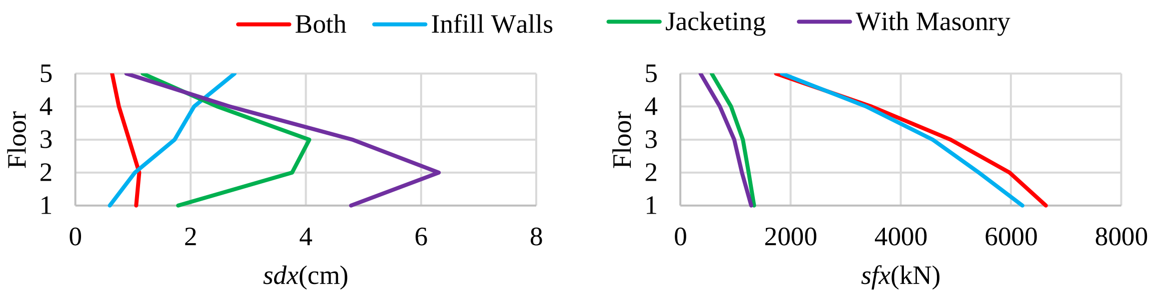

Figure 8. Story drift “*sdx*” and shear “*sfx*” for the record of 1940 El Centro Eq.

The comparison of story drift and shear on each floor using time history analysis on Figures 6-8 showed better results with the model of both methods, followed by infill walls and column jacketing.

4.2. Additional reinforced concrete volume after retrofitting

The volume of additional reinforced concrete added for each retrofitting method was calculated to have an idea about the difference in price for each model. The results are shown in Figure 9.

The comparison of additional reinforced concrete for the 3 retrofitting methods on Figure 3 showed lower additional RC for column jacketing retrofit, than, infill walls retrofit, with the higher value for the model with the both methods. Higher volume of reinforced concrete implies higher cost for the building retrofit, while those additional cost are not always needed to satisfy the building safety.

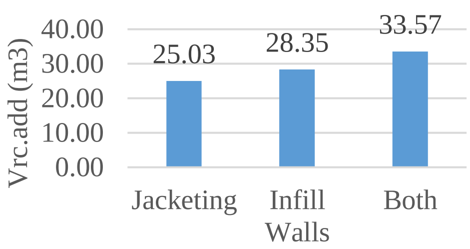

Figure 9. Volume in m^3 of additional reinforced concrete, added for each retrofitting method.

5. CONCLUSIONS

To adapt and apply the Japanese method for evaluation and retrofitting on Algerian geological and seismic conditions, some factors, particularly the seismic hazard zoning factor “*Z*” and the structural characteristic factor “D_S” in Japanese code were modified according to Algerian conditions.

The JBDPA pointed that it is important to include masonry walls in the rest of calculations even for secondary masonry walls.

By comparing 4 models (without retrofitting, with RC column jacketing retrofitting, with RC infill walls retrofitting, and with both column jacketing and infill walls that was applied on the target building after the 2003 Boumerdes Eq) based on the story drift and the shear, using STERA-3D and the time history analysis method showed the efficiency of RC infill walls compared to RC column jacketing. The model applied after the 2003 Boumerdes earthquake was as much efficient if not more efficient than the retrofitting with RC infill walls in some case.

The comparison of additional volume of reinforced concrete for the 3 retrofitting methods showed that even if the retrofitting applied by Algerian engineers in the 4th model gave better result, it could have cost less while still satisfying the safety conditions by just using a different method of retrofitting. The same applies to the retrofitting with infill walls that will give better results than column jacketing retrofit but cost more regarding only the volume of reinforced concrete needed for its execution.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my sincere gratitude to Dr. T. Saito (Professor, Department of Architecture and Civil Engineering, Toyohashi University of Technology, Japan) for supervising me and giving me his time, advice, suggestions, and welcoming me at Toyohashi University during my individual study and also my advisor Dr. M. Ito and all the other staff members at IISEE/BRI for their support and encouragement during this training program. Thanks, are also due to Dr. A. BOURZAM (Researcher, Department of Structures and Materials, University of Science and Technology Houari Boumediene, Algeria) for recommending and permitting me to join this program. Further, I am extremely thankful to Dr. T. AZUHATA (BRI) for his advice and comments regarding the topic of my individual studies. I would like to also express my gratitude to JICA for giving me chance to follow this course by financial supporting.

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