RETROFITTING AND STRENGTHENING QUALITY EVALUATION FROM RIGIDITY VARIATIONS OF A DAMAGED BUILDING

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ABSTRACT:

The rigidity of a six-story shear wall building, damaged by the May 21, 2003 Boumerdes (Algeria) earthquake is evaluated before the event, in its damaged state, and after retrofitting, using the estimation of the frequency and damping factor of the structure. The pre-event parameters are estimated through a numerical analysis, based on the structure drawings complemented by a micro-tremor investigation of an identical non-damaged building located on the same site. The damaged and retrofitted parameters have been obtained using only micro-tremor recordings on the studied building. The variation of the frequency and damping factor during the three stages of the building went through allows to evaluate its rigidity changes, and therefore to control the quality of retrofitting and strengthening.

KEYWORDS: retrofitting, strengthening, Boumerdes Earthquake, rigidity evaluation

1. INTRODUCTION

The building damaged by the magnitude 6.8 Boumerdes earthquake (Central North region of Algeria) of May 21st, 2003, is located in the COSIDER neighborhood at Bordj-El-Bahri city, 30 Km East of Algiers city and about 30 Km West of Boumerdes city. It is composed by one underground of 2.5 m height and six stories of 3.0 m height (, photo 01 and figures 02 and 03). The resistant structure is made of 9 transversal RC shear walls of 15 cm thick and one longitudinal RC shear walls 20 cm thick (figure 01). The floors have 15 cm thick RC slab. The building is founded on a 40 cm thick RC mat foundation. The principal and lateral facades are constituted by pre-cast RC elements as shown on photo 01.

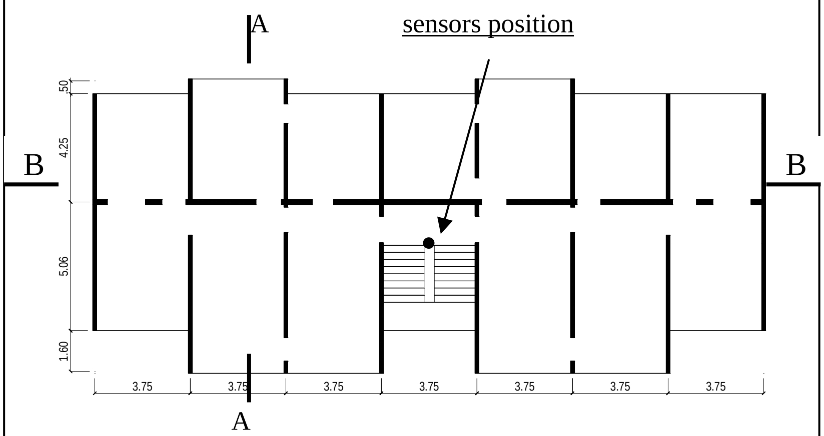


Figure 01: plan view of the building

Photo N° 01: front view of the building

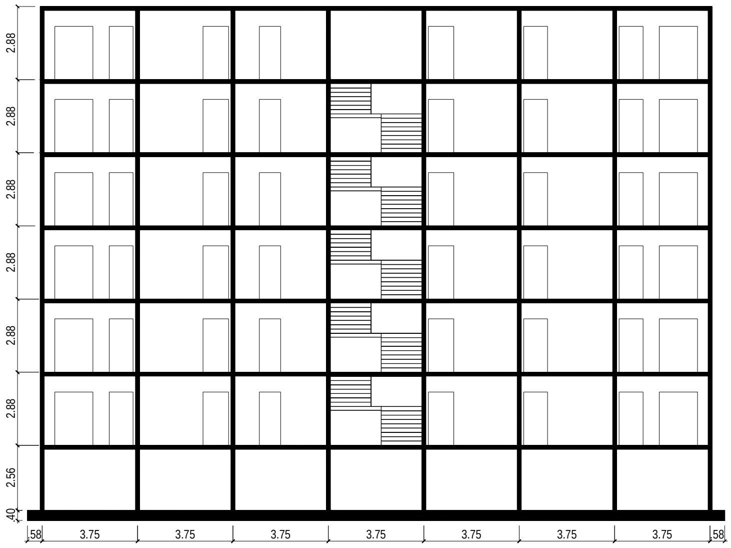


Figure 02: cross section BB

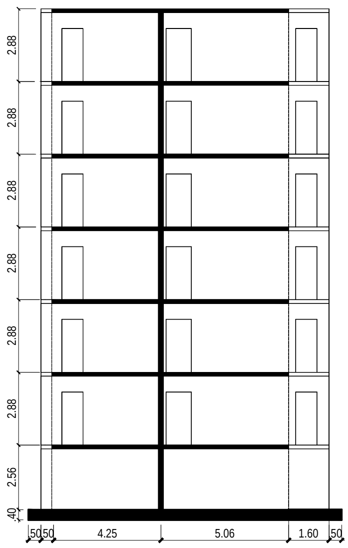


Figure 03: cross section AA

2. STRUCTURAL DAMAGE

The building is oriented, in its longitudinal direction, along the fault direction, i.e. in the same direction as the fault (figure 04). In this longitudinal direction the building rigidity is insufficient because there is only one eccentric shear wall (figure 01). The damages were located therefore on this shear wall at the first and the second levels and resulted in cracks of shearing that reached more than 10cm of opening in some places (photos 02 and 03). The buildings that are perpendicular to the fault directional effect exhibit practically no damage due to the strong rigidity in the transversal direction. The reinforcement of this longitudinal shear wall is made by 2 tablecloths of diameter 12mm steel bars constituting a mesh of 20cm x 20cm. Four steel bars forming a column of 20cm x 20cm cross section (figure 05) are put at each extremity to rigidify the openings. As shown in the figure 05, the more seismic loaded lintels are also reinforced by four steel bars.

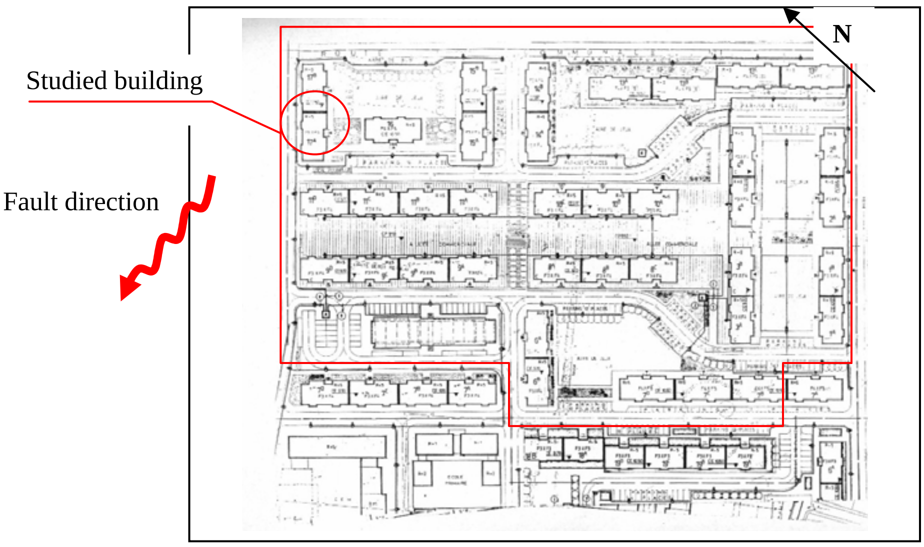


Figure 04: General plan of the COSIDER neighborhood

Photo 02: crack on longitudinal shear wall

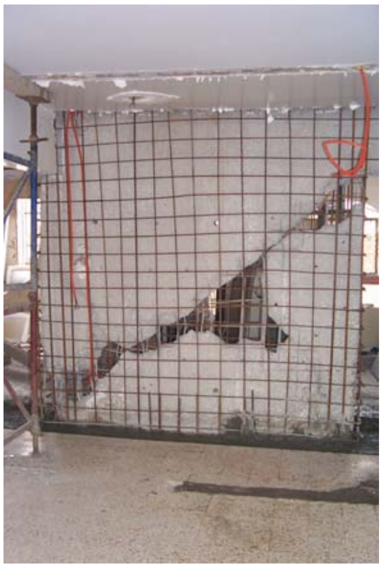


Photo 03: Steel reinforcement of longitudinal shear wall jacket

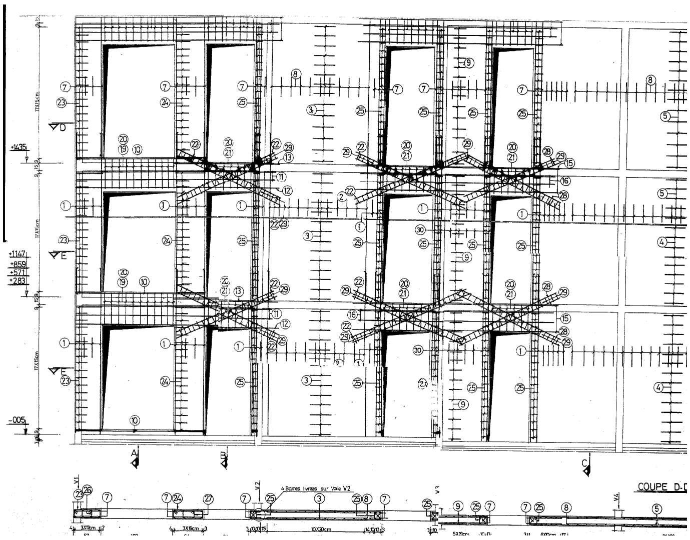


Figure 05: steel reinforcement of longitudinal shear wall

3. DYNAMIC ANALYSIS

A dynamic analysis has been done using a finite elements method to estimate the frequencies and the damping of the building before earthquake**.**
The hypotheses considered are the following:
Density of concrete: 25 KN/m3
Elasticity modulus of concrete: 2.3 10^7 KPa

Masses: - roof: 7.3 KN/m2
- Current story: 6.75 KN/m2

Rigidity of soil: 50 000 KN/m3

Damping: 10%

The results of this analysis are discussed below.

4. TECHNIQUE OF RETROFITTING AND STRENGTHENING

The jacketing technique was use to repair and to strengthen the damaged shear wall. This repair and to strengthen operation has concerned only the underground level and the ground level when the cracks have appeared. The jacket has 15 cm thick in the both sides of the wall with a steel reinforcement constituted by a 14 mm diameter bars forming a mesh of 20x20 cm (photo 03 and figure 06).

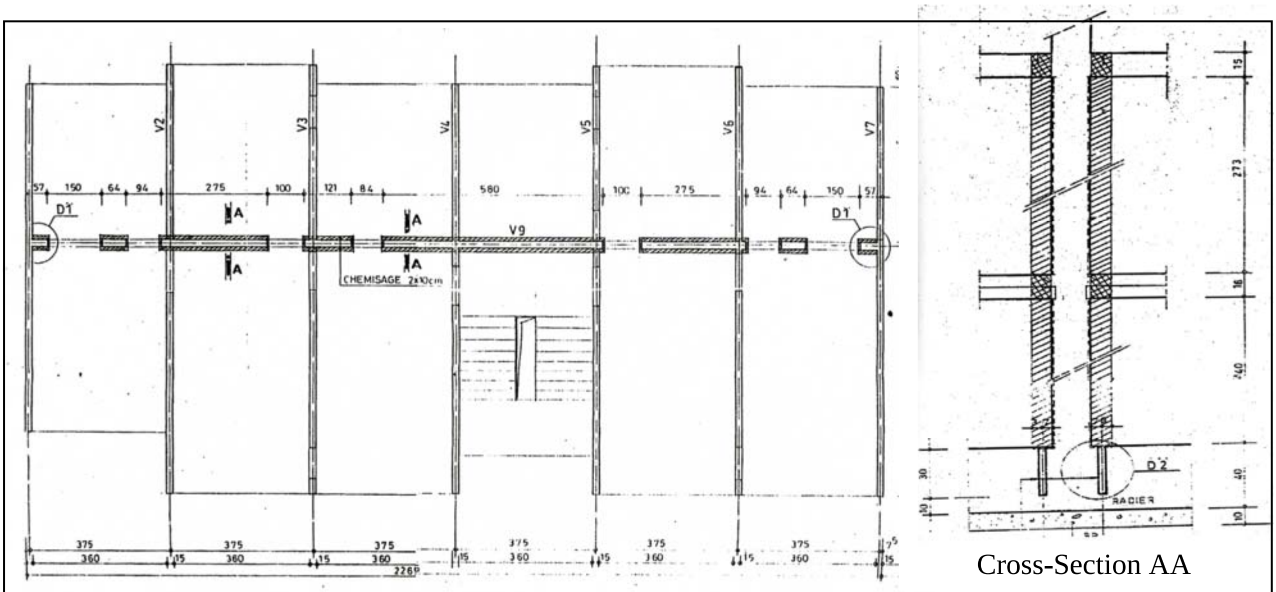


Figure 06: longitudinal shear wall jacket

5. DATA ACQUISITION AND PROCESSING

Ambient vibration recordings were carried out using six 5-second 3C Lennartz seismometers, i.e. one at each floor of the building, installed in the stairwell, simultaneously recorded with a CitySark II-6 station (Chatelain et al. 2000).

The records were 30 minutes long with a sampling frequency of 200 sps. The gain was adjusted to obtain the best ration noise/signal record for the 18 components.

6. ESTIMATION OF FREQUENCY AND DAMPING

6.1. Frequency

The dynamic analysis using finite elements method showed that the first mode is in the transversal direction, the second mode is in the longitudinal, direction and the third one is a torsional mode (figures 07, 08 and 09). The values of the frequencies are as follow:

Transversal direction (first mode): 3.71 Hz before earthquake and 3.76 Hz after retrofitting

Longitudinal direction (second mode): 4.26 Hz before earthquake and 4.30 Hz after retrofitting

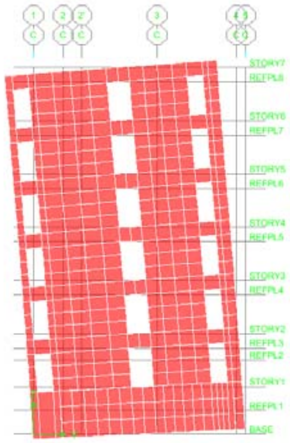


Figure 07: Mode 1 (transversal)

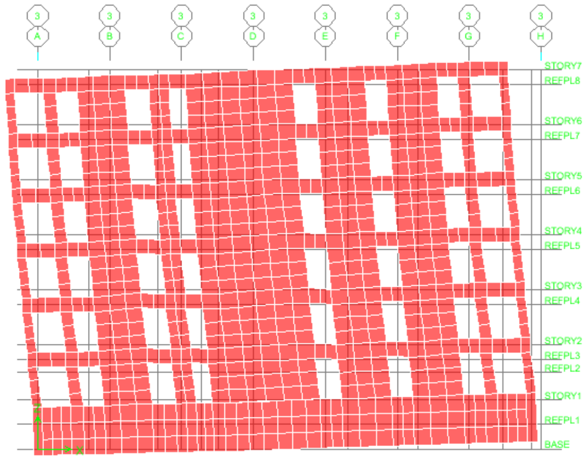


Figure 08: Mode 2 (longitudinal)

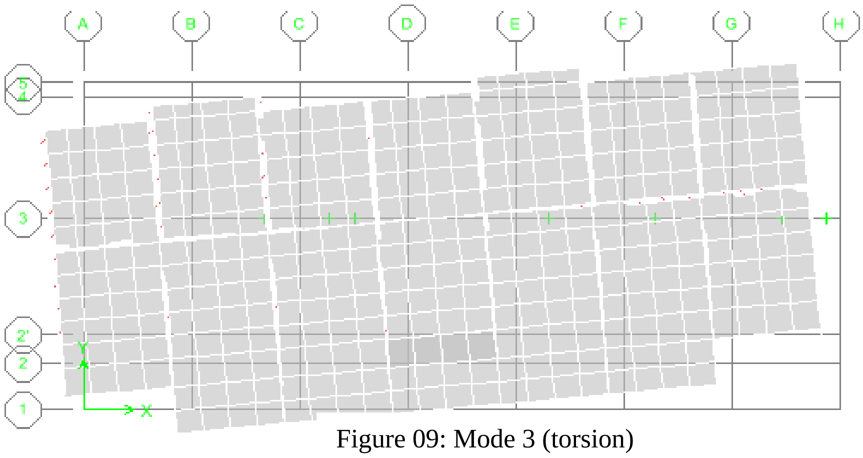


Figure 09: Mode 3 (torsion)

The ambient vibration data analysis, based on an antitrigger procedure, has given the following frequencies as shown in figure 10.
Before earthquake: transversal direction 3.61 Hz, longitudinal direction 4.20 Hz
Damaged state: transversal direction 3.22 Hz, longitudinal direction 2.07 Hz
After repairing: transversal direction 3.80 Hz, longitudinal direction 5.10 Hz
We can note here that the earthquake did not really affect the building in the transversal direction. The retrofitting has increased very slightly the rigidity in this direction represented by the retrofitting of the wings of the transversal shear walls.
In the longitudinal direction, the building had lost a significant part of its rigidity, about 50%, after earthquake occurrence. This is probably due to the coincidence between the building direction and the fault directional effect, i.e. the highest acceleration.
The repairing and retrofitting, as explained above, have strongly rigidified (5.1 Hz) the longitudinal direction but more than the initial state (4.20 Hz). Based on these results we can admit that the repairing and retrofitting operation has been a success and the choice technique is good. However, looking on the modal shapes (figure 11 a and b) we can note that, if on the first level the building is more rigid than on the other levels (that is normal because of the retrofitting), on the third level exists a "fracture" which is probably due to no detected micro-cracks.

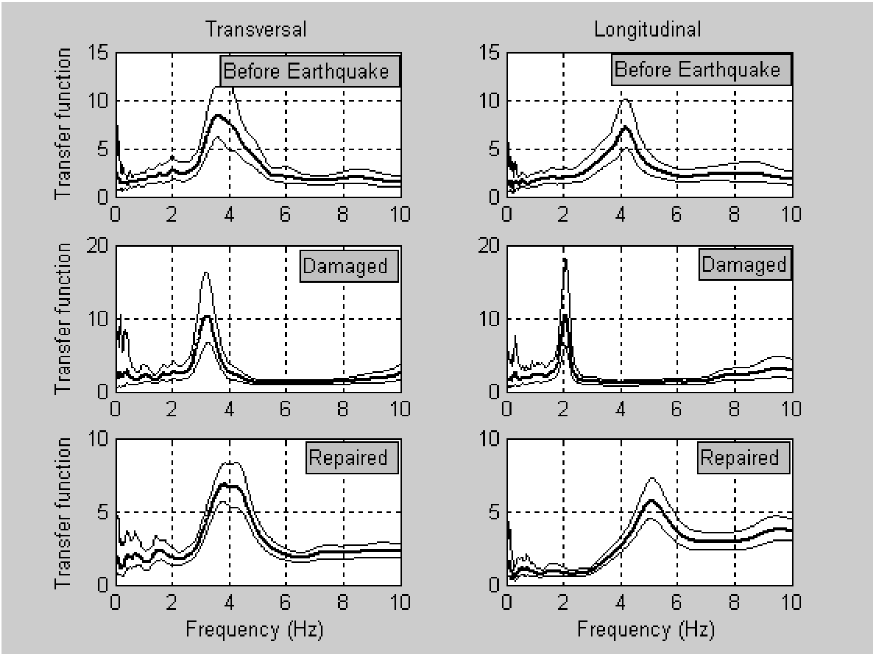
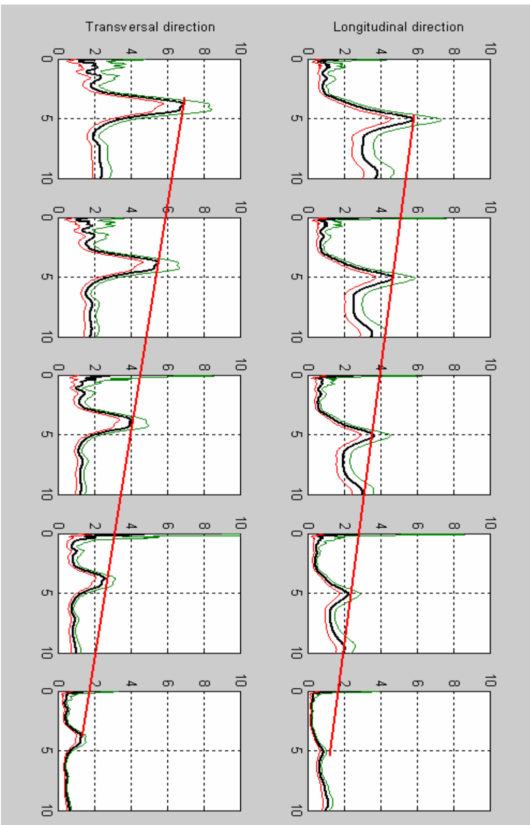


Figure 10: frequency in longitudinal and transversal directions
of non-damaged, damaged and repaired building



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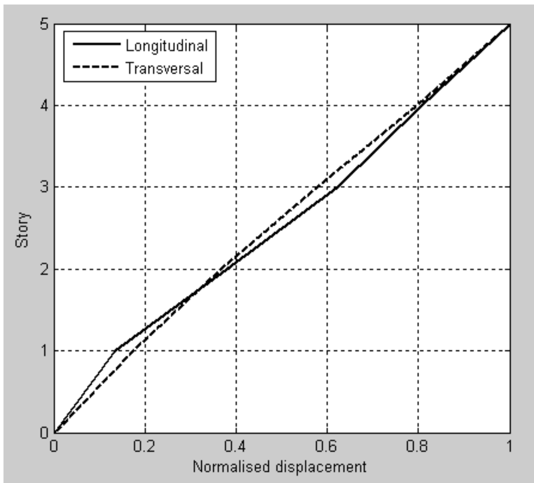

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Figure 11: modal shape of first mode

6.2. Damping

The damping value considered in the dynamic analysis is 10% for shear wall resisting system according to Algerian the seismic code.

For the analysis using ambient vibrations, damping was estimated using random decrement method. The different values of this damping are shown in table 1:

Table 1: Damping values

	Transversal direction	Longitudinal direction
Before earthquake	3;67%	3.03%
Damaged state	2.14%	1.77%
After retrofitting	3.67%	5.80%

7. CONCLUSION

Frequencies and damping evaluations are very good techniques to detect the change in rigidity of a structure. A decrease of rigidity proves the existence of damages in the structure. In the case of the present studied building, the frequency in the longitudinal sense that fell of practically of half shows that the damages are important as we can note them on the photos. The measure of the frequency of a building periodically will permit to follow its health in the time.
The techniques of repair and retrofitting that have been adopted are efficient since the building recovered its initial state, which means its initial capacity of resistance.
The calculated frequencies with numeric modeling and the dynamic analysis are in the same order that those valued estimated from ambient vibrations. The damping input value (10% generally adopted for the structures in walls carriers made of reinforced concrete) in the numeric analysis is very far from those evaluated from the ambient vibrations. This is probably due to the bad quality of the materials and also to the soil-structure interaction. It is necessary to recognize also that the damping parameter is not easy to estimate that the frequency. Once again we note that the numeric modeling is far to reflect the real behavior of a structure.
It would be useful to carry out more investigations on the neighborhood buildings and soils, to better understand what happened and to explain why the damages are so different from one building to other ones sometime very close.

9. REFERENCES

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