Dynamic Analysis of a Strengthened Two Story Concrete Building

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SUMMARY
Many buildings have been repaired and/or strengthened following the May 21^{rst} 2003 Boumerdes earthquake (50 Kms East of Algiers) of Magnitude 6.8. These repairing and strengthening operations are based on only visual expertise and the experience of engineers of design, engineering, and technical control offices. Nowadays, there is no experience feedback, as the repaired and/or strengthened buildings did not undergo new earthquakes yet so as to conclude on the effectiveness of the techniques used since El Asnam Earthquake of October 1980.
This study relates to a numerical and experimental analysis of an example of a strengthened two story concrete building on two levels piles. The recordings of the building motions under ambient vibrations before and after strengthening are analyzed to estimate the rigidity in the two states, and to conclude on the efficiency of the used retrofitting techniques.

Keywords :Boumerdes, repairing, strengthening, rigidity

1. INTRODUCTION

The studied building located in Algiers city was built in the Fifties. It is made up of 2 levels supported by a column-beam structure (Fig. 1.1). The first level is situated approximately at six meters from the rigid ground (rock) level where are anchored the foundations. The columns have a section of 25 cm X 25 cm and the beams 25 cm X 30 cm. The hollow concrete blocks floors have 20 cm thickness (Fig. 1.2). This building was strengthened between 2008 and 2009.

Figure 1.1. View of the building, left, view of piles, right

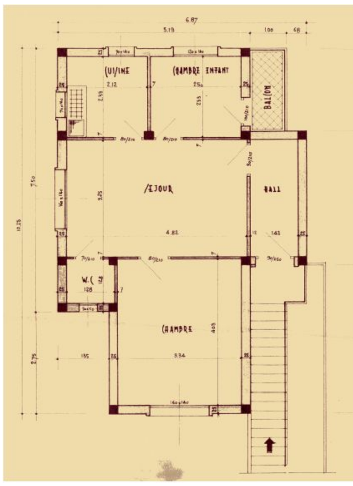


Figure 1.2. Plan view

2. TECHNIQUE OF STRENGTHENING

Jackets with section of 45 X 50 cm were used for all the columns and beams. The jackets at the corners have been reinforced by RC wings of 25 cm length and 15 cm thickness (Fig. 2.2). A new 20 cm thickness slab at the first level was realised in order to create two apartments in the two first levels (Fig. 2.1)

Figure 2.1. View of the strengthened building

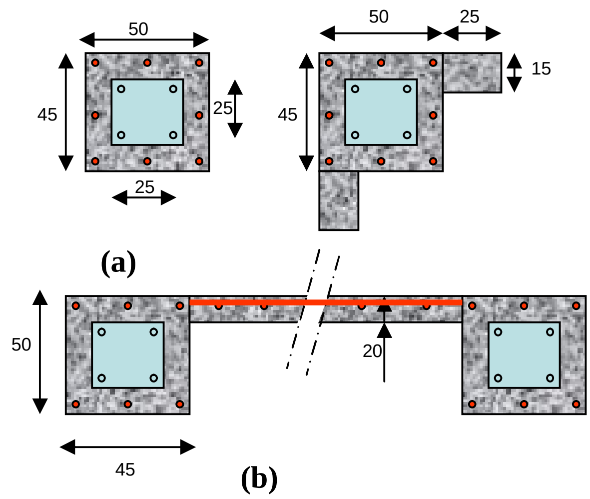


Figure 2.2: details of jacketing: (**a**) column jackets, (**b**) beam jackets and new slab

3. ACQUISITION AND PROCESSING OF DATA

The 4 levels structure of this building (house) is RC frames system. The 3rd and the 4th levels are the inhabitable space and the two first levels (piles) are the empty space supporting the building (Fig. 1.1). The RC frames constitute an irregular plan form (Fig. 1.2).

Ambient vibration recordings were collected at two different times in different ways:
- in initial measurements, part of a global building seismic brittleness survey in the Algiers area, only modal frequencies and damping were evaluated, without taking into account the modal shape. 30-minutes recordings (at 200 sps) have been performed at the ground and the two storeys of the building (Fig. 3.1), using a 5-second Lennartz LE3D seismometer connected to a CityShark I station (Chatelain et al. 2000), equipment considered as pertinent for this type of study (Guillier et al. 2007);
- post-retrofitting measurements included not only fundamental frequencies and damping evaluation, but modal shape too. A CityShark II-6 recording synchronously six 5-second Lennartz LE3D seismometers was used with 30-minute recordings, at 200 sps, with one seismometer per level (Fig. 3.1),

For the two experiments:
- the gain was adjusted to minimize signal clamping for the 3 components (initial and post-seismic measurements) or the 18 components (post-retrofitting measurements)
- the N-S component of the seismometers was oriented along the longitudinal direction and the E-W component in the transversal direction.

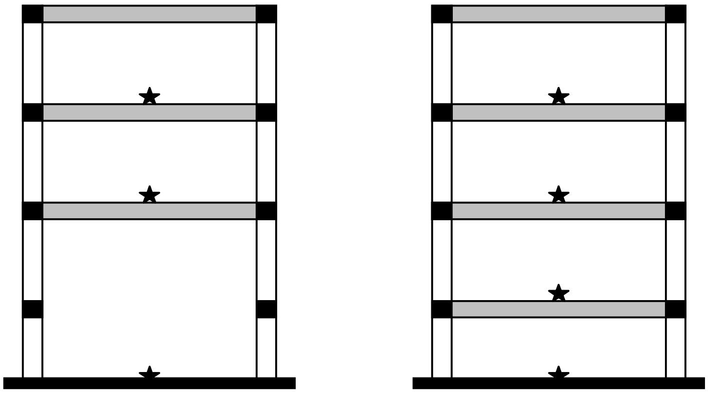


Figure 3.1. *Instrumentation schemes, left before strengthening, right after strengthening,*
★ *Sensors position*

4. EVALUATION OF THE FREQUENCY AND DAMPING

The analysis of the recordings before reinforcement showed a behaviour of a very flexible structure (frequency close to a value of 1 Hz), and very low damping (0.6%) (Fig. 4.1)

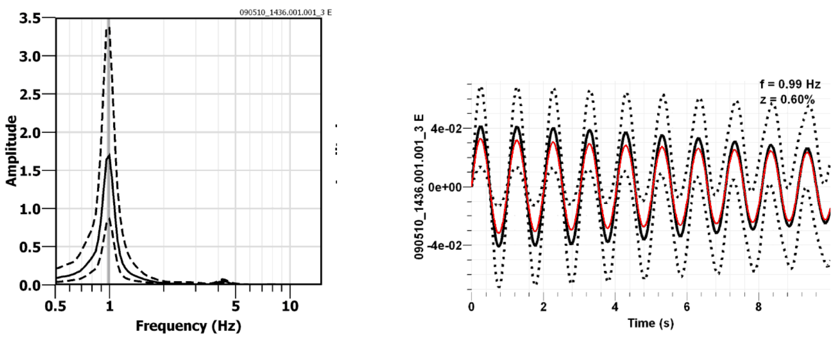


Figure 4.1. *Frequency and damping of the house before strengthening*

The reinforcement made increased the frequency and the damping in a significant way, thus making the structure very rigid. The frequency increased of more than 4 times and the damping of more than 3 times (Fig. 4.2).

The new reinforced structure can therefore resist to severe earthquake if we consider only its rigidity. But this rigidity alone may not be sufficient for the structure to have good performance as was the case for the initial structure that has resisted all the earthquakes that occurred in Algiers region.

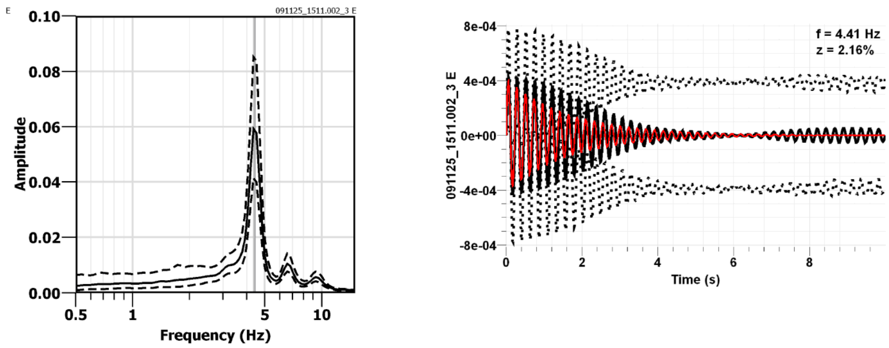


Figure 4.2. Frequency and damping of the house after strengthening

5. SOIL CONDITIONS

The building foundations are square foot foundations on a rock soil (tuff). The H/V spectrum (Fig. 5.1) is flat and the amplitude values oscillate around value 1, this shows that the soil is rigid. However we can see on this curve a bulge between 5 and 7 Hz, this can be a frequency range to amplify the structure motion.

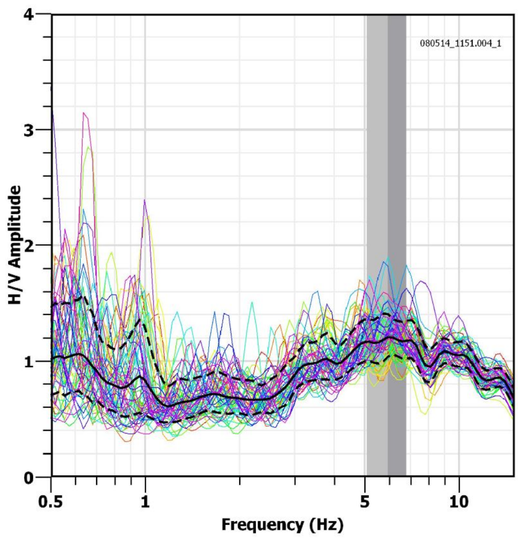
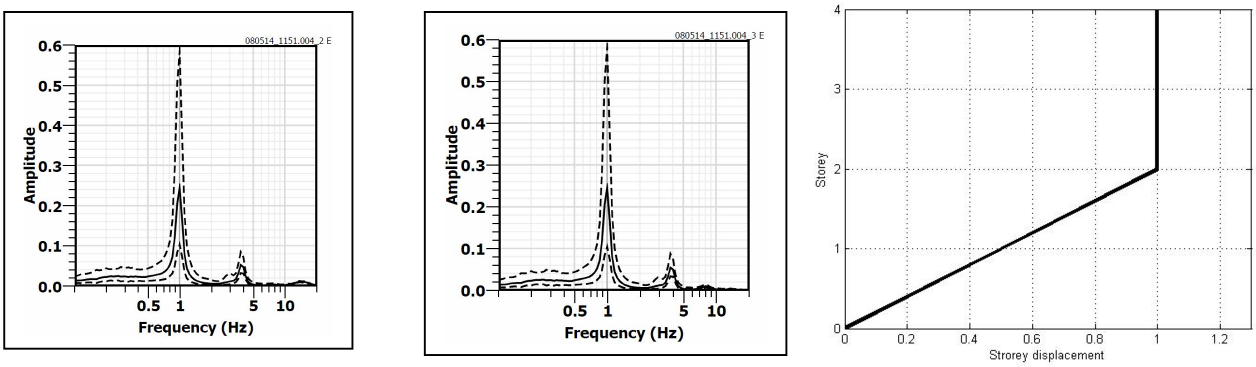


Figure 5.1: H/V spectrum of soil

6. MODAL SHAPES

Before streingthening

The building has a behaviour like the one of an inverse pendulum, that means a behaviour of a rigid mass on a flexible support (Fig. 6.1**c**). This building of which the fundamental frequency is 1.0 Hz has resisted to all the seismic events that occurred in Algiers region since 1980. This is due to fact that it is a soft structure based on a rock soil having a frequency ranged between 5 and 7 Hz.



a b c

Figure 6.1: building modal shape before strengthening: (**a**) and (**b**) displacement amplitude of inhabitable storeys, (**c**) modal shape

After strengthening

The strengthening technique that has been adopted has certainly rigidified the building structure and has limited the storeys displacements. However, as the strengthening has been carried out, i.e due to a limited budget, the columns strengthening has stopped under the first inhabitable storey (Fig. 2.1), behaviour problems, which did not exist before, have been created. First, the new fundamental frequency of the strengthened structure is ranged between 5 and 6 Hz, this can generate resonance phenomena with soil vibrations. Second, the strengthening has rigidified only the two first levels of the piles (Fig. 6.2) while the inhabitable storeys continue to move as the initial structure. In addition, this strengthening has created short columns between the first inhabitable slab and the end of jackets (Fig. 2.1).

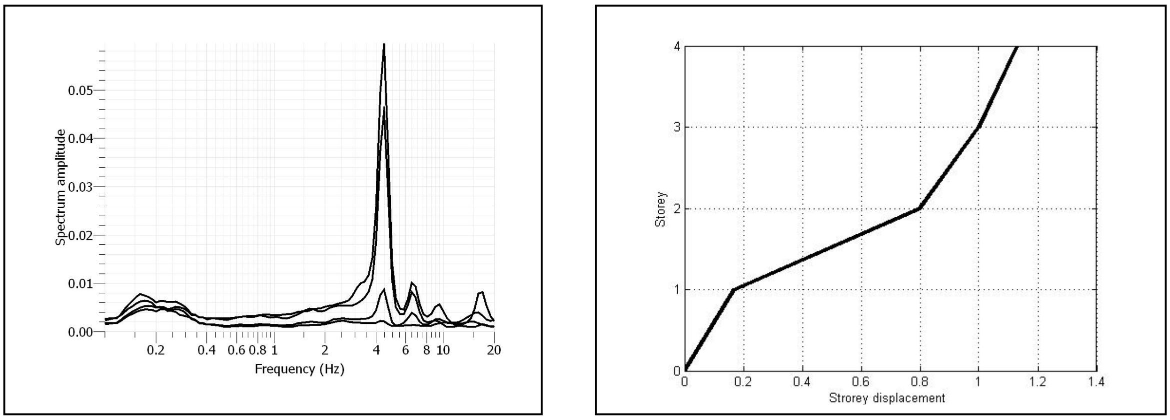


Figure 6.2: spectrum amplitude (a), modal shape (b) of the strengthened structure

The problem can be more complicated in terms of building behaviour if the strengthening will carried out for the total structure, i.e jacketing of columns until the roof.

7. NUMERICAL ANALYSIS

The building was numerically analysed in the two states of the structure, before and after strengthening, using SAP2000 software. Before the strengthening, the first and third modes are torsional modes having a frequencies of 0.97 Hz with 40% of modal participating mass ratio and 1.10 Hz with 32% of modal

participating mass ratio, respectively (Fig. 7.1). The strengthening has rigidified the structure, rising the first frequency to 1.86 Hz value, but did not create favourable conditions of building behaviour. In this case also the first and the third mode are torsional modes having, respectively, frequencies of 1.86 Hz with a 31% modal participating mass ratio and 2.10 Hz with a 22% modal participating mass ratio (Fig. 7.2). We not thus that the torsion has not disappeared and remains preponderant.
The frequencies found by numerical analysis are lower than the ones evaluated by experimental method. This difference is due to the masonry that has not taken into account in the modeling.

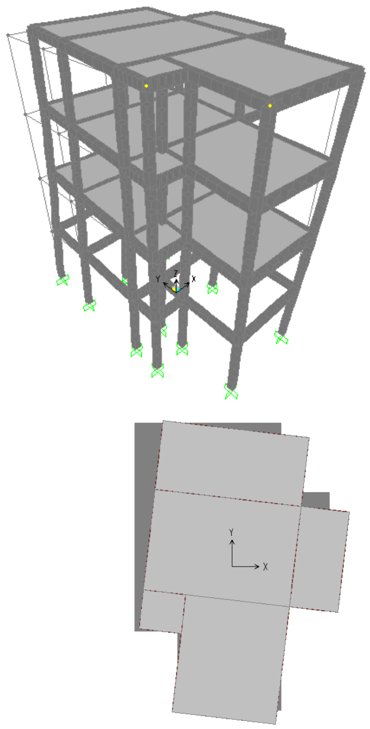


Figure 7.1: 1^{rst} vibration mode (torsion) of the initial structure

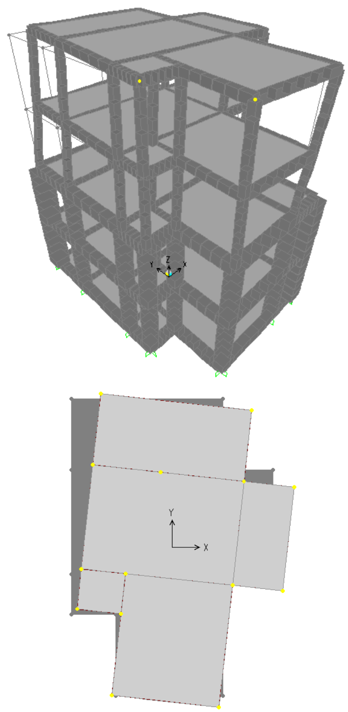


Figure 7.2: 1^{st} vibration mode (torsion) of the strengthened structure

7. CONCLUSION

The evaluation of the frequencies and damping is a very good technique to detect changing in the rigidity of a structure. A variation of rigidity proves the existence of damage in the structure. The periodically measurement of the frequency of a building is a good procedure to follow in time its "health".
The technique of strengthening which was adopted is effective owing to the fact it increases the building rigidity.
The values of damping found are far from the value of 6% generally adopted in seismic code for the RC frame structures. It is due perhaps to the bad quality of materials. It is recognized that this parameter (damping) is more difficult to estimate than the frequency.
In case of this studied building, we note that the strengthening by jacketing technique rigidified the structure but did not provide a better behaviour to the building against earthquake. The torsion which is the main movement of the initial structure has not disappeared after strengthening and remains preponderant. This weak framed structure resisted all the earthquakes which took place in Algiers region. This is due to its flexibility and the soil characteristics which is compared to firm soil, avoiding thus the resonance phenomena. Strengthening rigidified the structure increasing the building frequencies which

approximates to the soil frequency. This can create a resonance which could generate serious damages to this building.

Finally, without a preliminary study, strengthening of buildings can create problems that may affect the behaviour of the structure against earthquakes.

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