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FUNDAMENTAL PERIOD RELATIONSHIP OF RC-BUILDINGS IN ALICANTE PROVINCE (SPAIN). A FIRST STEP TO SOIL-STRUCTURE RESONANCE MAPS

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Abstract. *South and South-East of Spain are the regions with a higher seismic hazard in Spain Consequently, all the municipalities in Alicante province has to develop seismic emergency planning. Besides, the south of Alicante province and, in particular, the cities of Elche and Alicante are located in a sedimentary deposit, which can reach hundreds of meters, so site effects can be important. Additionally, most of the building stock belongs to periods without seismic normative, increasing, therefore, their vulnerability. Furthermore, following the damage caused by earthquakes in Spain, it has been observed that there are significant differences in the spatial distribution of damage from site to site in buildings with similar seismic behavior, located in a similar site. Hence, many authors have stated that the main factor responsible for the different damage distribution could be the building height. The seismic response of a building depends on its dynamic characteristics (fundamental period, T, damping ratio, ξ, and modal shape) and on the input ground motion. Among the existing methods to determine the T and ξ parameters, the best ones probably are to record weak earthquakes (or near explosions) or induced vibrations inside the building. However, both techniques need a very expensive and time-consuming effort when it is applied to a large number of buildings. A possible alternative is the measurement of ambient vibrations. In this work, ambient vibration measurements were performed at the geometrical center of the plan on the top floor of buildings with different height and year of construction in the municipality of Alicante and Elche (both in the Alicante province), assuming that this point coincides with the mass center of the floor. The preliminary results follow a linear relationship between the number of stories and the fundamental period. Finally, the results have been used to estimate the probability of resonance in several districts of both municipalities.*

1 INTRODUCTION

Spain has a moderate seismic hazard, compared with other European countries like Italy or Greece. However, South and South-East regions had been affected by damaging earthquakes and according to the updated seismic hazard map developed by [1], the expected peak ground acceleration (PGA) for an exceedance probability of 10% in 50 years is 0.24g (Granada province) and 0.23g (Alicante province). In this work, we have chosen two of the most important cities of Alicante province, in terms of population and number of buildings, that is, Elche and Alicante cities. Both cities are located above a sedimentary deposit with hundreds of meters deep, making it possible to feel the effects of small to moderate shallow earthquakes (5 to 10 km), which are very common in this area. According to the update of the seismic hazard maps [1], the PGA for exceedance probability of 10% in 50 years is 0.18g for Alicante and 0.20g for Elche.

The last damaging earthquake in Spain was the Lorca earthquake (May 11, 2011 with a moment magnitude of Mw = 5.2 and a focal depth of 4.6 km). Although the magnitude was not severe, the observed damage was very high. More than 300 buildings were demolished and many others repaired. Concretely in this city, [2] analyzed the dynamic behavior of the buildings before and after the Lorca earthquake. They concluded that the fundamental period of the buildings shows a permanent increase following a process of damage such as an earthquake. The fundamental period (T) is a parameter widely used to evaluate the seismic response of the buildings.

In contrast, the damping factor is not usually used as an indicator of damage in structures. The damping assessment is a complex problem due to all the variables involved. That fact is due to depending on many factors such as structure and soil characteristics [3].

Several studies have used the recorded ambient vibrations to obtain the seismic response of the building, e.g., [2, 4, 5, 6, 7, 8, 9, 10, 3, 11 and 12]. In essence, their results do not differ from other methods such as earthquake registration or forced vibration techniques.

Therefore, the main objective in the present work is to develop an empirical relationship between the fundamental period and the number of floors using the recorded ambient vibration on the top floor of the buildings in Alicante and Elche cities. Both cities represent the construction model of the Mediterranean coastal area. The obtained relationship will be used not only to establish the fundamental period of the current building stock but also to compare its evolution if damaging earthquakes would happen in the area.

2 DATA ACQUISITION AND ANALYSIS

Alicante and Elche have approximately 24,162 and 34,395 buildings respectively. The height of the buildings can be classified as low-rise (1 to 3 stories) with a 49 % for Alicante and 67 % for Elche; mid-rise (4 to 6 stories) with a 30 % for Alicante and 21 % for Elche and high-rise (>6 stories) with a 21 % for Alicante and 11 % for Elche. For this study, we have carried out a random selection of reinforced concrete buildings in both cities. Table 1 shows the selected buildings with information about the height, year of construction, and location.

The fundamental period of the buildings was estimated through ambient vibration measurements using a three-component digital seismometer Güralp 6TD. This is a broadband instrument with an on-board 24-bit digitizer and configurable output. The duration of the records was 10 minutes and the equipment was located on the top floor of the buildings (Figure 1). If some disturbance occurred during the recording time, the duration of the measurement was increased by 5 more minutes. [13] was used to compute the Fourier amplitude spectra and the fundamental period for each longitudinal direction. Finally, the building period was assigned as the average of both horizontal components.

Building number	Cadastral reference	Number of storeys	Year of construction
no 1	1474122YH0317C	2	2007
no 2	4377901YH0347G	2	2004
no 3	4204101YH2540C	2	> 2007
no 4	7463801YH1476C	3	> 2007
no 5	0175726YH2407E	3	2007
no 6	1671701YH0317B	4	1986
no 7	1278012YH0317G	4	1960
no 8	0791301YH0309B	4	1960
no 9	1083323YH0318C	5	1959
no 10	0891608YH0309B	5	1960
no 11	1274701YH0317C	5	1968
no 12	2787301YH0328F	5	1979
no 13	0889504YH0308H	6	1976
no 14	0878314YH0307H	6	1971
no 15	1183715YH0318C	6	1989
no 16	4677303YH0347H	7	2005
no 17	7663901YH1476D	7	1983
no 18	7662807YH1476B	7	1985
no 19	1479009YH0317G	8	1977
no 20	2789710YH0328H	8	1975
no 21	7662802YH1476B	8	1984
no 22	9788403XH9398H	9	2006
no 23	0487603YH0308E	9	1975
no 24	7666501YH1476F	9	1983

Table 1: Information of the selected buildings in Alicante and Elche.

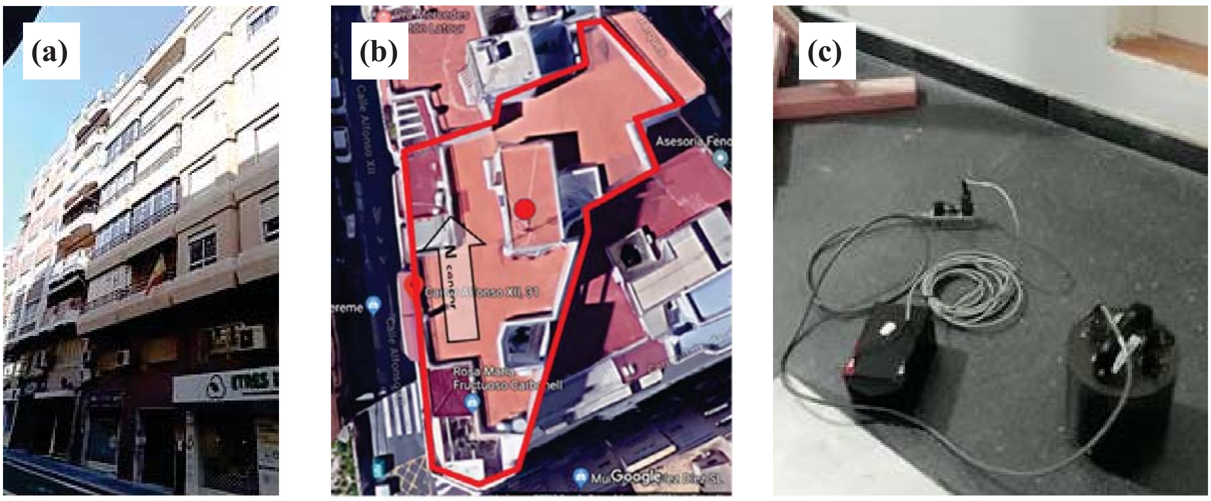

Figure 1: a) Main front of one of the studied buildings (no 19). b) Aerial view of the building with the location of the sensor and its orientation. c) Equipment arrangement during measurement inside the building.

Additionally, microzonification campaigns in urban areas of both cities were carried out using a 1 Hz Mark L-4C-3D seismographs connected to a Reftek digitizer. Regarding the number of H/V measurements, a total number of 123 and 90 measures were taken for Alicante and Elche, respectively. In both cases, the measurements were carried out leaving a separation of about 500 meters between them. In this case, attending to the expected resonant frequencies and the recommendations proposed in [14] the duration of the records was set up to 30 minutes.

3 FUNDAMENTAL PERIOD

To determine the fundamental period of the selected buildings of Alicante and Elche, the sensor was located in the available highest part of these buildings. In this way, the sensor records all the vibrations that pass through the building, assuming that the sensor is in the mass center of the floor [2].

The recorder noise can be produced by environmental factors (e.g. wind) or coming from different artificial sources such as traffic noise, elevators, presence of people, etc. The method is based on the fact that these sources of noise, excluding strong harmonic sources close to the instrument, contain energy with a broad spectrum and the building acts as a filter enhancing its dynamic properties [2].

Once the data were collected, the power spectral density of both horizontal components was determined for each building. An example is shown in Figure 2. As it can be observed, the steeper peak indicates the fundamental frequency of the building in that direction. However, erroneous peaks may appear as a result of the interaction with adjacent buildings or due to the building's own geometry, so the analysis has to be performed carefully.

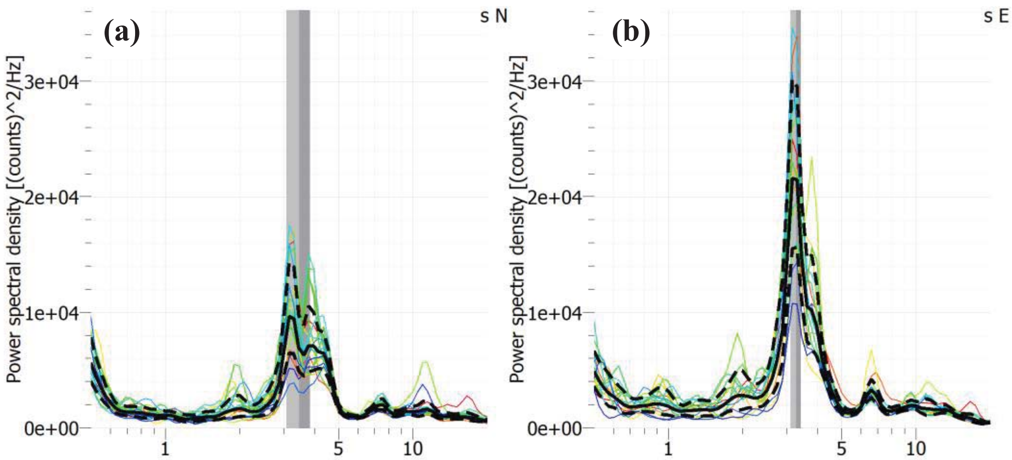

Figure 2: Power spectral density for North and East components of the building no 19.

The obtained results for the buildings of both cities show that the natural vibration period increases with the number of storeys (Table 2). In Table 2 it can be seen that the lowest value of the average fundamental period is 0.13 ± 0.06 sec for buildings with two floors and the highest value is 0.40 ± 0.14 sec for buildings with nine floors.

N (storeys)	T (sec)
2	0.13 ± 0.06
3	0.15 ± 0.02
4	0.16 ± 0.03
5	0.20 ± 0.03
6	0.23 ± 0.05
7	0.37 ± 0.01
8	0.36 ± 0.04
9	0.40 ± 0.14

Table 2: Average value of the fundamental periods obtained for buildings with different number of storeys.

Linear regression has been made using the commonly applied expression, T = a N, where T is the period and N is the number of storeys. The obtained relationship is as follow:

$$T = 0.045 \text{ N with } \sigma = 0.035 \tag{3.1}$$

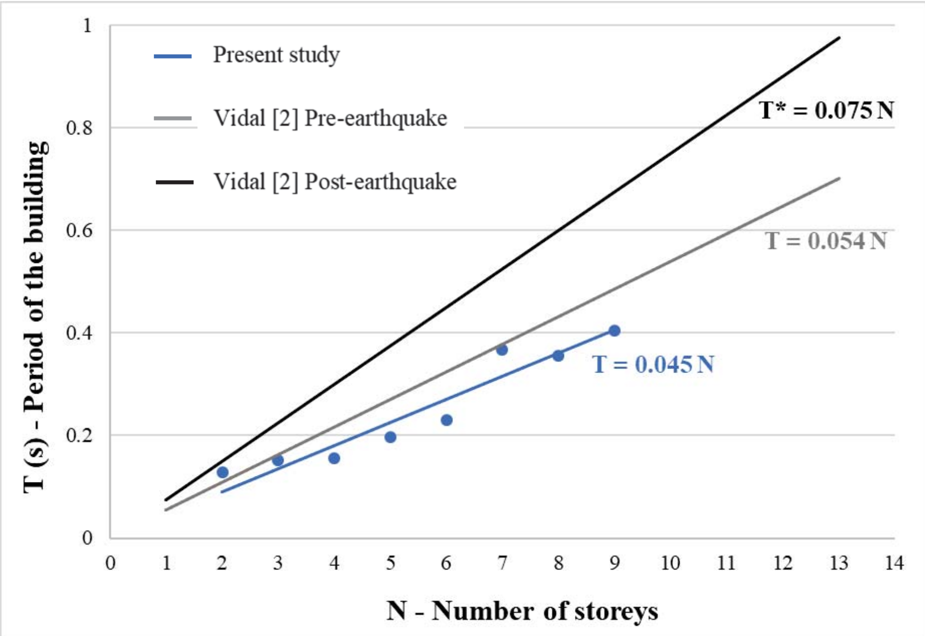

Figure 3: Relationship between the period of the building (T) and the number of storeys (N). Blue line represented the one obtained in this study while black a grey line represents the one obtained by [2] before (T) and after earthquake (T*).

Equation (3.1) has a correlation coefficient of R^2 = 0.912 and an average standard deviation of σ = 0.035. In Figure 3, the obtained relation is compared with the ones obtained by [2] in the Lorca city before and after the 2011 earthquake. The comparison shows that the obtained linear adjustment presents the lowest slope, providing a period of 0.39 sec for a 9 storeys building while [2] will assign 0.49 sec. As [2] used buildings with height up to 13 storeys, the difference can be due to a lack of data in our results so future studies will include buildings with higher height. If we assume that the slope increases for damaged buildings, our lower slope will also be indicative of a lower vulnerability of the reinforced-concrete buildings analyzed. The obtained results are also quite similar to other previous studies carried out in Europe using ambient vibrations, e.g., [4, 5 and 12].

4 RESONANCE PROBABILITY

The phenomenon of resonance occurs when the fundamental period of the buildings coincides with the predominant period of the soil. Resonance phenomenon results in an amplification of the movement of the structure, increasing the damage in the building. If the fundamental period of the building and the predominant period of the soil are different enough, the phenomenon of resonance will not exist.

In the present study, the predominant period of the soil was obtained using the H/V technique [15]. In Figure 4, an example is shown.

The probability of resonance (IR) of each of the buildings has been assigned using the ratio (in percentage) between the fundamental period of the building and the natural period of the soil. Thus, we have assumed the following classification: no resonance for IR <60%; slight resonance for IR between 60% and 75%; moderate for IR between 75% and 90% and full resonance for IR higher than 90%.

(a)

(b)

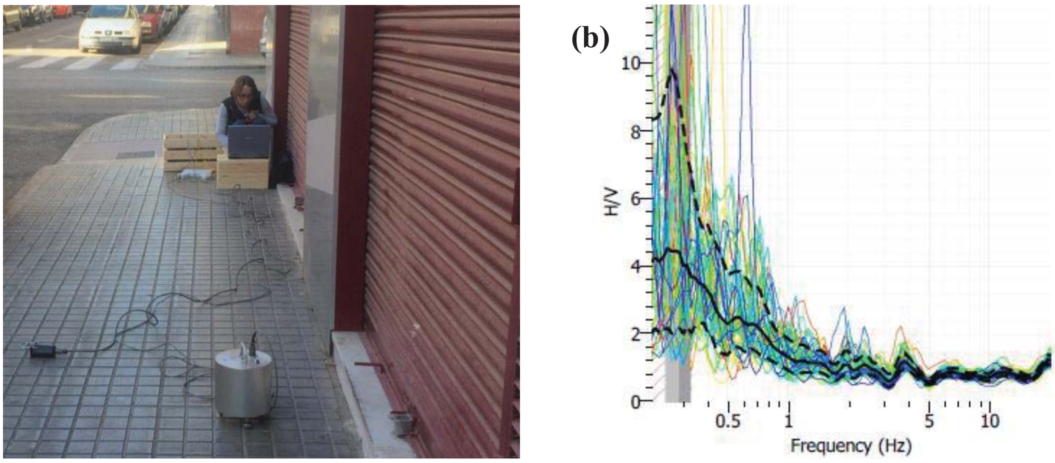

Figure 4: Example of the ambient noise measurements carried out in the vicinity of the building shown in Figure 1 (no 19). a) Field measurement and b) obtained H/V curve.

Table 3 shows the obtained fundamental period for the buildings and the predominant period of the soil as close as possible to the position of the building. In the right column is indicated the probability of resonance. Table 3 shows that, only one of the studied buildings is classified like moderate. The rest of the buildings do not show probability of resonance.

Building number	Storeys	T(s) Building	T(s) Soil	Resonance probability
no 1	2	0.088	3.690	no resonance
no 2	2	0.102	3.440	no resonance
no 3	2	0.196	3.850	no resonance
no 4	3	0.163	3.330	no resonance
no 5	3	0.141	0.270	no resonance
no 6	4	0.185	3.330	no resonance
no 7	4	0.132	3.500	no resonance
no 8	4	0.153	3.100	no resonance
no 9	5	0.196	3.270	no resonance
no 10	5	0.156	3.100	no resonance

no 11	5	0.214	3.690	no resonance
no 12	5	0.221	0.260	**moderate**
no 13	6	0.218	2.940	no resonance
no 14	6	0.290	3.070	no resonance
no 15	6	0.185	0.070	no resonance
no 16	7	0.372	3.030	no resonance
no 17	7	0.359	3.330	no resonance
no 18	7	0.373	3.230	no resonance
no 19	8	0.307	3.500	no resonance
no 20	8	0.372	0.260	no resonance
no 21	8	0.389	3.230	no resonance
no 22	9	0.492	2.670	no resonance
no 23	9	0.241	3.470	no resonance
no 24	9	0.481	3.330	no resonance

Table 3: Fundamental periods measured in Alicante and Elche and the probability of resonance.

5 CONCLUSIONS

Ambient vibration measurements have been carried out in reinforced concrete buildings within the urban areas of Alicante and Elche in order to obtain the fundamental period and a relationship with the height of the building. From the obtained results, it can be concluded:

a) The obtained period-height relationship shows a similar behavior than the obtained by [2] in Lorca, but our slope is lower. This can be due to the lack of data in the regression or it may indicate a lower vulnerability of the reinforced-concrete buildings chosen for Alicante and Elche when compared with Lorca city.
b) Our period-height relationship has been used to propose a probability of soil-structure resonance and only one of the studied buildings has been assigned moderate resonance probability.

The next step in this research will be to continue the data acquisition to a higher number of buildings (also with higher heights), what will improve the estimated linear regression. Additionally, this will allow us to compute resonance probability maps for the whole cities using not only the fundamental period of the soil but also, considering the secondary peaks observed in the HV curves of some areas. These secondary peaks may appear due to the presence of more superficial contrasts and might have additional effects on certain buildings.

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