



**Turkish Earthquake Foundation - Earthquake Engineering Committee
Prime Ministry, Disaster And Emergency Management Presidency**

EXPECTED GROUND-RC BUILDINGS RESONANCE PHENOMENA IN THE COMMUNE OF KHARROUBA (BOUMERDES)

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ABSTRACT

The main purpose of this paper is to estimate the expected residential buildings resonance phenomena in the commune of Kharrouba in the north of Algeria during future earthquakes, taking into account the predominant frequency of soil obtained from Nogoshi-Nakamura method using microtremor measurements and the predominant frequency of residential buildings using also microtremor measurements for some buildings and empirical method for the others. In other words, elaborate a vulnerability map for the residential buildings in terms of soil-building resonance that can be used for the evaluation of seismic risk in Kharrouba. Furthermore, the constitution of this map has been useful not only to evaluate the dynamic behavior of buildings in the commune of Kharrouba, but also for quantitative and prompt damage evaluation of buildings after a future earthquake.

The map of probable resonance phenomena in Kharrouba elaborated in this paper shows that a significant number of buildings are able to have dominant frequencies close to the ground motion ones and consequently resonant phenomena would be able to appear if an earthquake occurs in this zone.

INTRODUCTION

Seismic site effects are a major issue in the field of earthquake engineering, since the local amplification of the seismic motion can be very large. These phenomena can amplify the incident seismic motion and increase the consequences on structures and buildings. Soft sediments are found to amplify ground motion during earthquakes and are hence more prone to earthquake damage than ground with hard strata. Over the last two decades, many cities have grown considerably and demographists expect a similar trend for at least the two next decades. These urban areas are very often built on soft sediments, and a large number is unfortunately located in seismic areas. The Mexico Earthquake of September 19, 1985 is a good example of earthquake damage to a modern city built on soft sediment. Though the earthquake epicenter was located around 350 km from the city, the sites with soft clay deposits exhibited a huge amplification of ground motion resulting in severe damage (Seed et al., 1988). During the earthquake of 1985, the seismic waves were trapped in the soft strata.

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The soft soil layer allowed the upward propagating shear waves to propagate easily; however, the hard strata at the bottom acted like a reflector and bounced back the downward propagating waves. This kind of trapping of waves created a resonance and consequently resulted in an enormous amplification of the ground motion. As a result, the lake bed area suffered catastrophic damage; however, in the southwest part of the city, ground motions were moderate and building damage was minor. The acceleration recorded in the hill-zones were relatively low-amplitude, short period ground motions compared to high amplitude and long period ground motions recorded at stations located in the lake zone (Seed et al., 1987). Similar kinds of site amplification of ground motion were observed in the Loma Prieta Earthquake in October 1989 (Benuska, 1990). Deep clay deposits underlying sites around the perimeter of the San Francisco Bay area amplified the ground motion tremendously in the San Francisco and Oakland area causing severe damage. The San Francisco-Oakland Bay Bridge, founded on a deep clay site, was extensively damaged in this earthquake.

During the May 21, 2003 earthquake, The closest free-field stations to the epicenter, which recorded the main shock, are the two Keddara stations located in the commune of Kharrouba, 20km from the epicenter, and the site effects are confirmed by the high Peak Ground Acceleration (PGA) values recorded at these stations (compared to other stations in the same range of distances) located in the Mitidja quaternary basin. This suggests the existence of strong site effects that may affect buildings in this area, emphasizing the need for a careful and reliable assessment of site resonance frequency and amplification phenomena. The resonance of the ground during an earthquake can knock down a small building and spare the skyscraper.

This issue has been addressed for a long time by scientists and engineers who developed many techniques to identify the main characteristics of site responses for soft deposits (i.e., resonance frequencies and amplification factors). Among these techniques used is the simple horizontal to vertical Fourier amplitude spectral ratio (H/V) based on ambient noise recordings (Nogoshi and Igarashi, 1971, Nakamura, 1989, Kudo, 1995). This technique became more and more popular over the last decades as it offers a convenient, practical and low cost tool to be used in urbanized areas.

The main purpose of this paper is to estimate the expected residential buildings resonance phenomena in the commune of Kharrouba during future earthquakes, taking into account the predominant frequency of soil obtained from Nogoshi-Nakamura method using microtremor measurements and the predominant frequency of residential buildings using also microtremor measurements. The result is extrapolated from measurement at some buildings using an empirical method. We elaborate a kind of vulnerability map for the residential buildings in terms of soil-building resonance. This map can be used for the evaluation of seismic risk of Kharrouba. Furthermore, this map will be useful not only to evaluate the dynamic behavior of buildings in the commune of Kharrouba, but also for quantitative and prompt damage evaluation of buildings after a future earthquake.

GEOGRAPHICAL LOCATION AND GEOLOGICAL SETTING

The commune of Kharrouba, known by its important water dam Keddara that serves the capital Algiers, is situated in the north of Algeria which is located on the northern edge of the African plate, which is converging with the European plate since the Mesozoic, with a shortening rate of about 5–6 mm/yr. This convergence between Africa and Eurasia is the reason for the recent tectonic and seismic activity.

Kharrouba is located in the eastern part of the Mitidja quaternary basin where the soil is classified as soft. The Mitidja is one of the rich coastal plains in the Tellian Atlas and was formed during the Miocene in a NS distension. It has been evolving in a NS and NNW-SSE compression context, from the end of the Villafranchian up to now, with a shape of a Plio-Quaternary syncline (Ouyed, 2010). During the Pliocene marine conditions persisted in the Mitidja. Blue marls and sandstones were deposited (1000 m). An extension of about 100 km from east to west, and a width of 20 km, the Mitidja basin is bordered in the NW by the Algiers block, in the south by the Blidean Atlas and in the east by the crystalline Thenia block (fig.1).

The north-eastern boundary of Mitidja is marked by the Thenia Fault (TF) that would be the site of a seismic activity. The study area can be affected also by the Kabylie (KF), the South Mitidja

(SMF) and a reverse fault located offshore Faults. This later would be the prolongation of the south Mitidja fault through the sea and it caused the May 21, 2003 earthquake, the most important that affected the region of Boumerdes (Meghraoui et al., 2004).

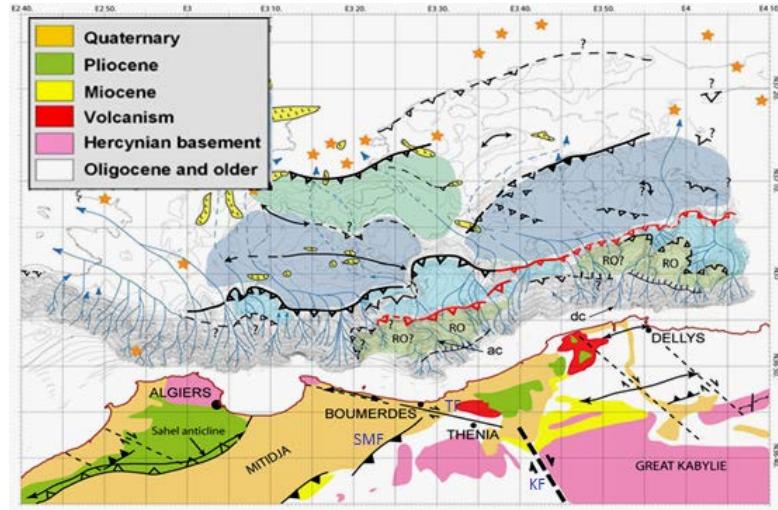


Figure 1. Map showing the quaternary deposit distribution and the main active faults in the Algiers–Boumerdes region (Deverchere et al., 2005)

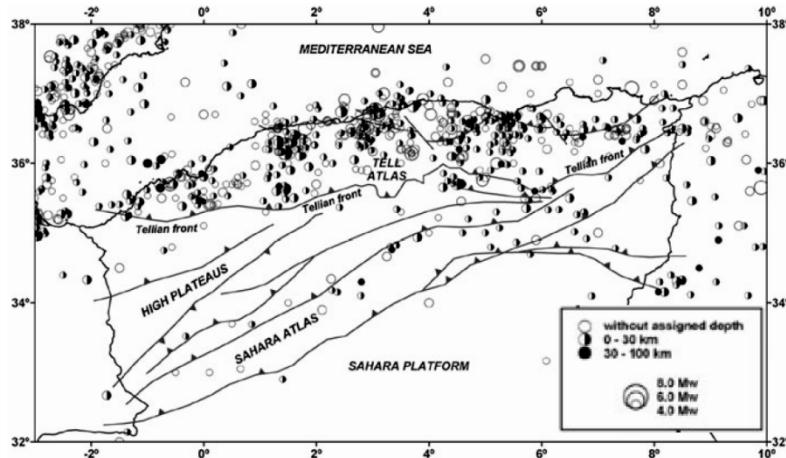


Figure 2. Seismicity and tectonic setting of northern Algeria (Hamdache et al., 2010)

The north of Algeria is an area prone to earthquakes, as evidenced by the map of seismicity in Figure 2 (Hamdache et al., 2010). During the last two decades, northern Algeria experienced several destructive moderate to strong earthquakes. The study area, where the limits are shown in figure 3, has a medium or medium-high level of seismic hazard (zone IIb) according to the classification of Algerian building code (RPA 99) with peak ground acceleration (PGA) of 0.35g. A big earthquake can cause serious damage to buildings and urban facilities in the commune of Kharrouba like those caused by the May 21, 2003 earthquake; the most significant recent event in the northeast of Algiers that caused considerable damage and over 2300 lives and 11450 injured. The totality of buildings in this area is made of reinforced concrete column-beam type in which the highest buildings comprise 5 floors.

DATA ANALYSIS

Ambient noise recordings were carried out in two days at 52 points within the commune of Kharrouba. Because microtremor spectra can be affected by near sources, as machinery, special care were taken, whenever possible, to work as far as possible of close disturbances such as cars, heavy machinery

facilities, household appliances, etc. The points of measurements are spaced at about 100-200 m (fig.3). In some cases it was impossible to find an appropriate site for the measurement and the distribution of points of measurements was designed to achieve good quality of the contour maps to show the distribution of the fundamental site frequency.

The seismometers used for data collection are the 1 Hz to 100 Hz passband lennartz LE-3Dlite coupled with Kinematics K2 digitizers. At each point of measurement, ambient vibrations were registered for a duration of 30 or 10 minutes according to the level of noise. For points at the bottom of buildings in which measurements have been made for assessing their resonant frequencies , the duration of measurement was 30 minutes. These measurements have been recorded at a data sampling rate of 250 samples per second. The seismometer was always placed directly on top of soil. The microtremors in the buildings are measured on the roof in the longitudinal directions. Concerning buildings where no measurement has been made, we have collected buildings height data and we have estimated the natural period of building from the period-number of stories relationship:

$$T(s) = \frac{\text{Number of Stories}}{10} \quad (1)$$

The H/V curves were calculated using the software Geopsy (<http://www.geopsy.org>) and the calculation parameters have been selected to meet the recommendations of the SESAME consortium to determine the reliability of the H/V curves (*Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations - measurements, processing and interpretations. SESAME European research project, deliverable D23.12, 2005*). Because high instrumental noise can limit the exploitability of the seismic noise at frequencies lower than the sensor corner frequency and affect the estimate of the fundamental resonance frequency of the site from the peak in H/V, it is better to analyze the Power Spectral Densities (PSD) of the three components of ground motion recorded by the instrument (lennartz LE-3Dlite) together with the world noise model (Peterson, 1993) before moving on to the H/V Technique.

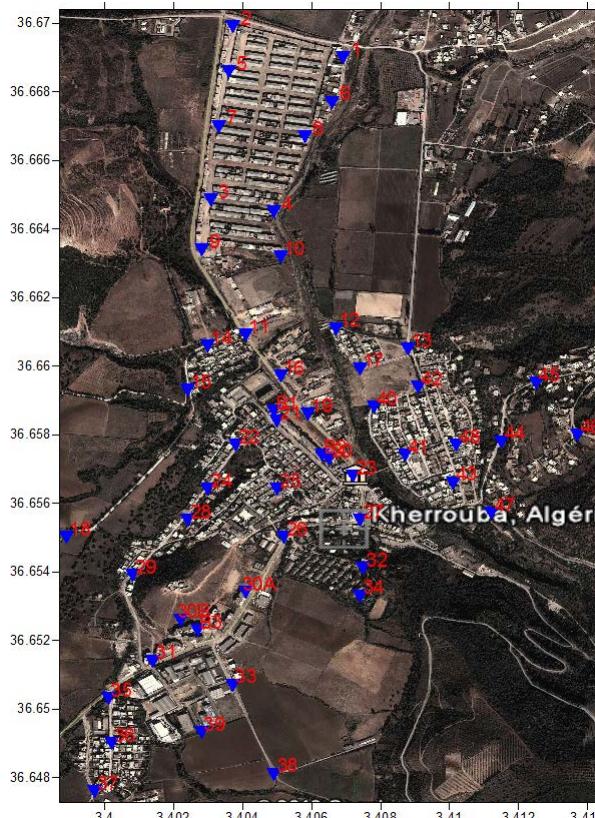


Figure 3. Points of free -field measurement distribution map in the area of study (commune of Kharrouba)

Figure 4 shows an example of ambient noise recordings and the associated H/V curve. The majority of the calculated H/V curves for the commune of Kharrouba exhibit a clear peak for the predominant frequency of soil f_0 which can be interpreted. It seems obvious that the site under study presents a large impedance contrast at depth, and is very likely that the ground motion will be amplified. f_0 is the fundamental frequency of the site. It is expected that the actual site amplification for the Fourier spectra, around the fundamental frequency f_0 , is larger than the H/V amplitude (SESAME, 2004); amplification starts at $f_0/2$, is expected to be maximum at f_0 , but may occur at higher frequencies even though the H/V amplitude remains small. If the local thickness is known, the average S-wave velocity of the surface layer may be estimated with the formula $V_s = f_0 \cdot 4h$

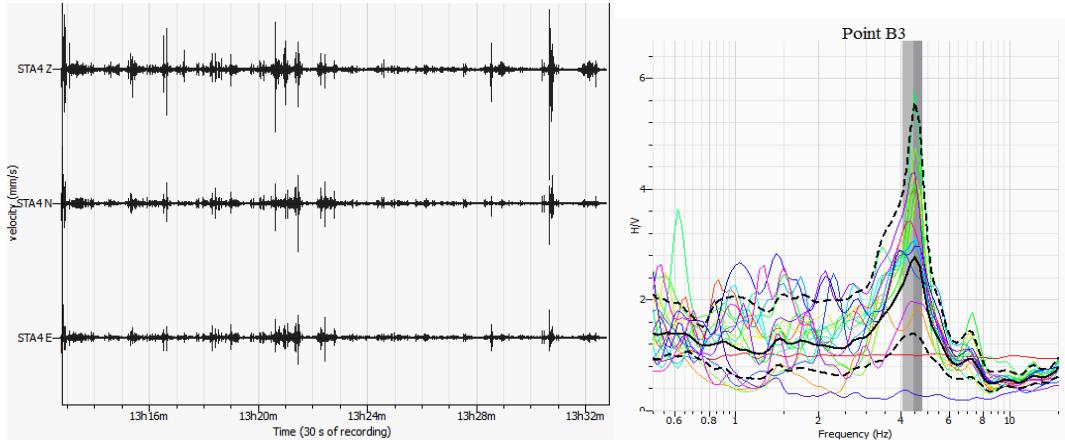


Figure 4. Ambient noise recordings at measuring point B3 and respective H/V curve

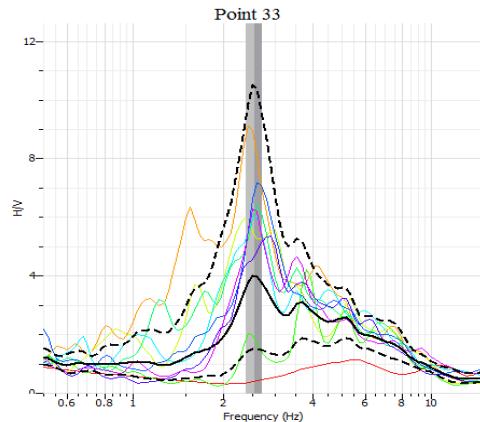


Figure 5. The H/V curves estimated at the point 33

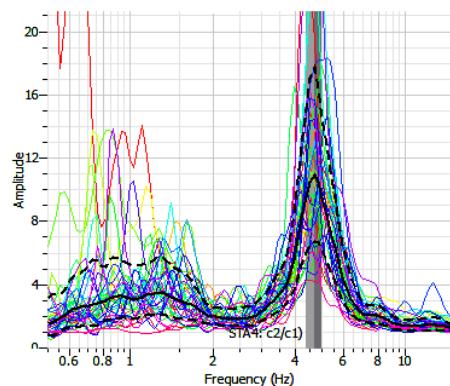


Figure 6. Spectral ratio evaluated using horizontal data measured in building of 5 stories B1

Nevertheless, results in some points of measurements are different to that cited above and the peak is unclear. The H/V curves estimated as an example at the point 33 (see fig.3) are plotted in figure 5. The curves don't exhibit a single value of resonant frequency but a wide range of resonant frequencies (2.5Hz-4Hz).

Using data measured in buildings and surrounding ground surface, predominant frequencies of buildings are calculated through the estimation of the transfer function of the building by computing the spectral ratio between the input and the output signals. Figure 6 shows an example of the spectral ratio evaluated using horizontal data measured in building of 5 stories B1 (fig.3) where the corresponding frequency is 4.57 Hz.

RESULTS AND DISCUSSION

In order to assess the probable resonance phenomena in the commune of Kharrouba, we have compared fundamental frequency of residential buildings with the predominant frequency of soil at the building site. When both frequencies are in agreement; the ratio between predominant frequency of soil f_0 and natural frequency of RC buildings f_{bg} is included between 0.8 and 1.2; we consider that a strong building resonance effect is highly probable; these buildings are marked in a vulnerability map with red color. On the other hand, if the frequencies are very different; the ratio between f_0 and f_{bg} is less than 0.5 or more than 1.5; building resonance effects are less likely and the corresponding buildings are marked with green color. Between these two situations, buildings are tagged by orange color.

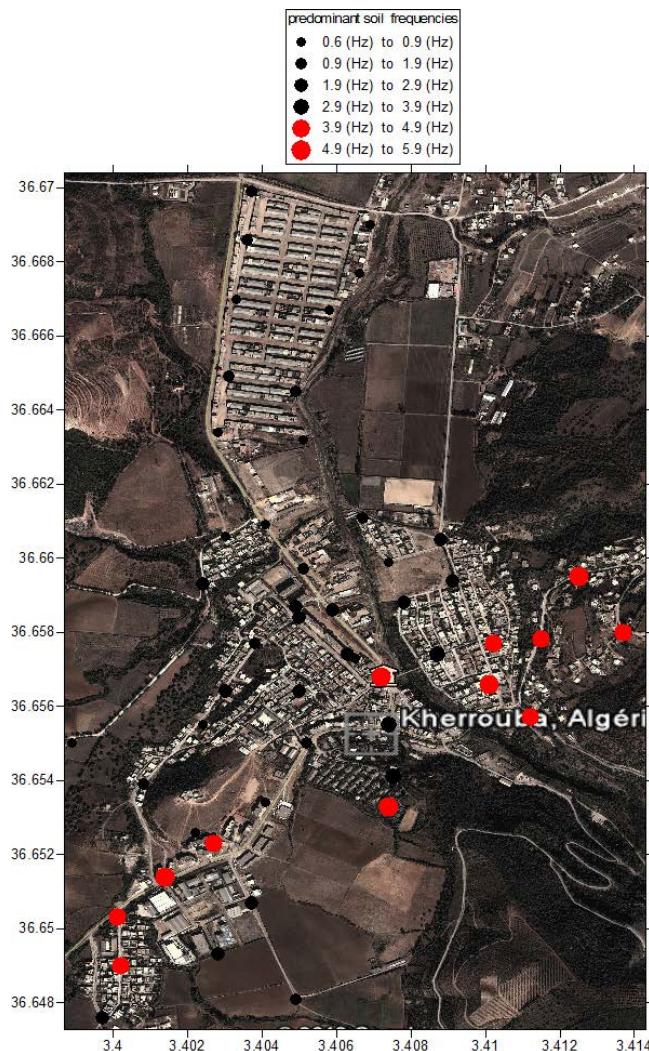


Figure 7. Spatial distribution map of predominant site frequencies in the commune of Kharrouba

A map showing the spatial distribution of predominant site frequencies as a solid red and black circle with its diameter proportional to the value is shown in Figure 7. The soil frequencies in Kharrouba vary between 0.64 and 5.8 Hz. One can see that 77% of the frequency measurements have fundamental site frequencies below 4 Hz (with black circle in figure 7) which is in agreement with the expectations due to the quaternary character of the sediments in the region. The area with frequency values higher than 4 Hz (red color in figure 7) correspond to the border hill sides. These results explain the high accelerations recorded in this region during the 21 may 2003 Boumerdes earthquake (0.58 and 0.35g in the E–W and N–S directions, respectively). Generally, sediments are thick next to the river Wadi banks. For this reason, lower fundamental frequencies are observed near the Wadi in the centre of the commune.

A map showing iso-frequency contours, i.e., contours of equal predominant site frequency, was also plotted with SURFER Software (surfer, 2004) as part of this study. This map is shown in Figure 8. However, for this map, caution has to be taken when using data based on interpolation between measuring stations. This is particularly important where topography and geology can vary very quickly over short distances.

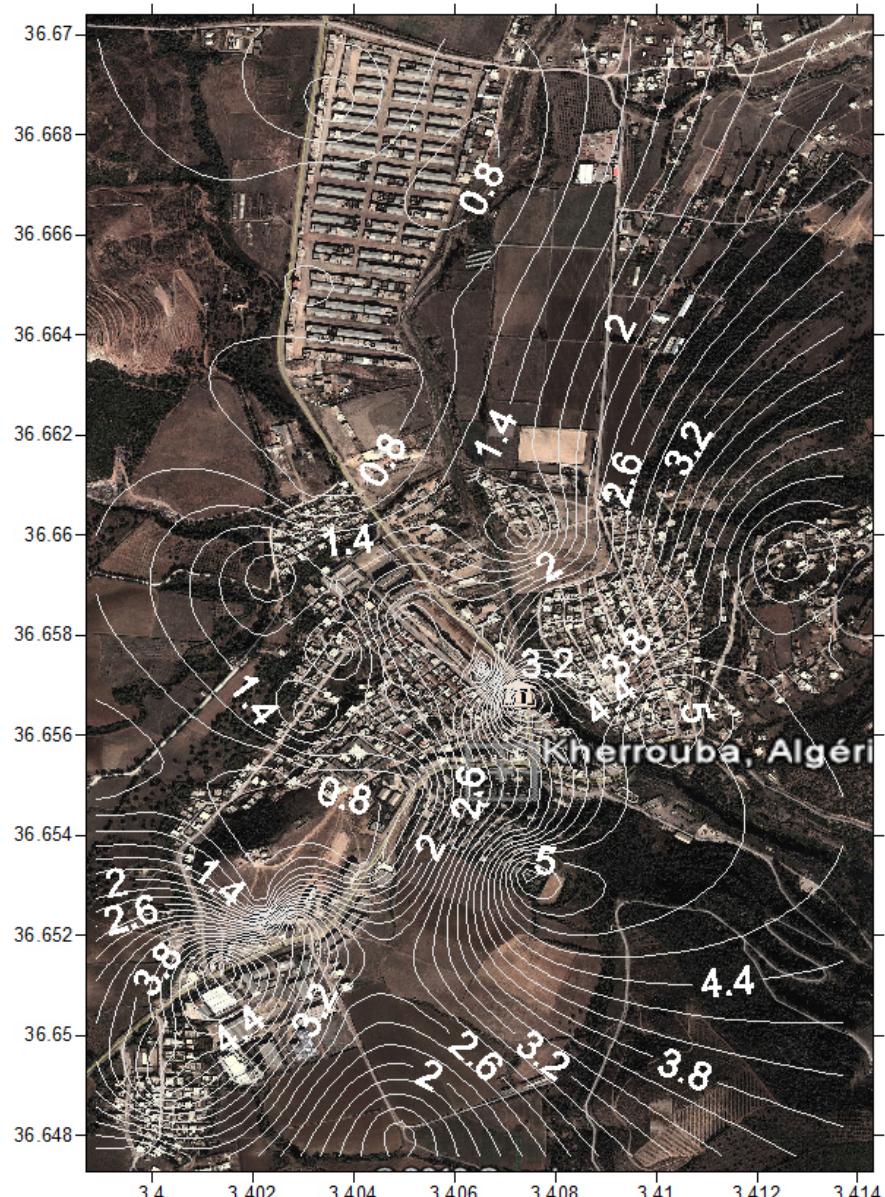


Figure 8. Map of the predominant iso-frequencies for the commune of Kharrouba

The expected level of buildings resonance phenomena in the commune of Kharrouba were estimated as well. A map with expected excitation of resonance phenomena during future earthquakes is shown in figure 9. This map is comparing predominant frequency of soil f_0 and natural frequency of RC buildings f_{bg} . It shows that a significant number of buildings (red color in the map) have dominant frequencies close to the expected ground motion ones and consequently resonant phenomena would strongly excite the buildings if an earthquake occurs in the zone. Buildings marked by yellow color in the map are assumed to be less affected by resonant phenomena. Concerning the green color, it means that resonance frequency of the soil and building is very different.

The dynamic behavior of buildings suffers variations when the shaking amplitude increases. Their modal properties, i.e. resonance frequencies, are modified with increasing damage (Michel et al., 2011). Recently, study of the subject matter is rekindled with the premise that fundamental frequency varies with the amplitude of shaking (Calvi et al., 2006, Dunand et al., 2006, Todorovska et al., 2006). Many authors show a decrease in the fundamental frequency in reinforced concrete buildings (in Michel et al., 2011). The opening of cracks in the construction material produces a transient or permanent decrease in stiffness and therefore a decrease in the fundamental frequency.

Dunand (2005) estimated the drop of resonance frequency in some buildings damaged by the May 21, 2003 Boumerdes earthquake (Algeria) and noted that the orange buildings can be reclassified in green or red based on the decrease of the fundamental frequency. The authors found that the frequency drop can reach 30% for buildings classified green, between 10% and 70% for those classified orange and between 50% and 70% for those classified red. Michel and Gueguen (2010) noticed that a quick frequency drop followed by a slower increase is shown in the R. Millikan Library (Pasadena, California) and attributed to a loss of stiffness. A transient drop of 20 to 35% in N and E directions, respectively, were observed whereas the permanent drop was of 7 and 16.6%, respectively.

Because of the unavailability of data measurements before and after an earthquake in the studied area and according to the aforementioned bibliography, we assume, in this work, a transient drop of 35% and 16.6% for the permanent drop for all the RC buildings in the commune of Kharrouba.

In figure 10, the expected level of buildings resonance phenomena is shown taking into account the transient frequency drop of 35% caused by the opening of cracks in the construction material during a strong motions. We can see that some green and orange buildings can be classified as red based on the decrease of the fundamental frequency. A similar observation can be done when taking into account the permanent frequency drop of 16.6% (fig.11). It is important to take into account the drop of resonance frequency in buildings for damage evaluation after an earthquake, because the change of the natural frequency after the earthquake is related to the stiffness degradation of structural elements of the building (Navarro et al., 2004).

The implementation of these maps might be used in disaster risk reduction through the introduction of mitigating measures of vulnerable buildings. Local authorities can also use the information provided by such maps for prioritization of actions to take.

CONCLUSION

The site effects and the vulnerability of residential buildings in the commune of Kharrouba to resonance phenomena were assessed and discussed in this paper. Results clearly indicate the existence and the importance of site effects in the area. It is found that 77% of the measured soil frequencies in Kharrouba are below 4 Hz which is in accordance with the expectations due to the quaternary character of the sediments in the region. The map of expected excitation of resonance phenomena in Kharrouba elaborated in this thesis shows that a significant number of buildings are able to have dominant frequencies close to the resonance of the ground. Consequently resonant phenomena in buildings are expected to be strong excited if an earthquake occurs in this zone. It is important to take into account the drop of resonance frequency in buildings for the damage evaluation of buildings after an earthquake.

Geotechnical data and ambient vibration measurements as a geophysical tool are necessary in order to develop models that can be used to estimate site response in Kharrouba. Strong motion recordings are needed in order to verify numerical results.

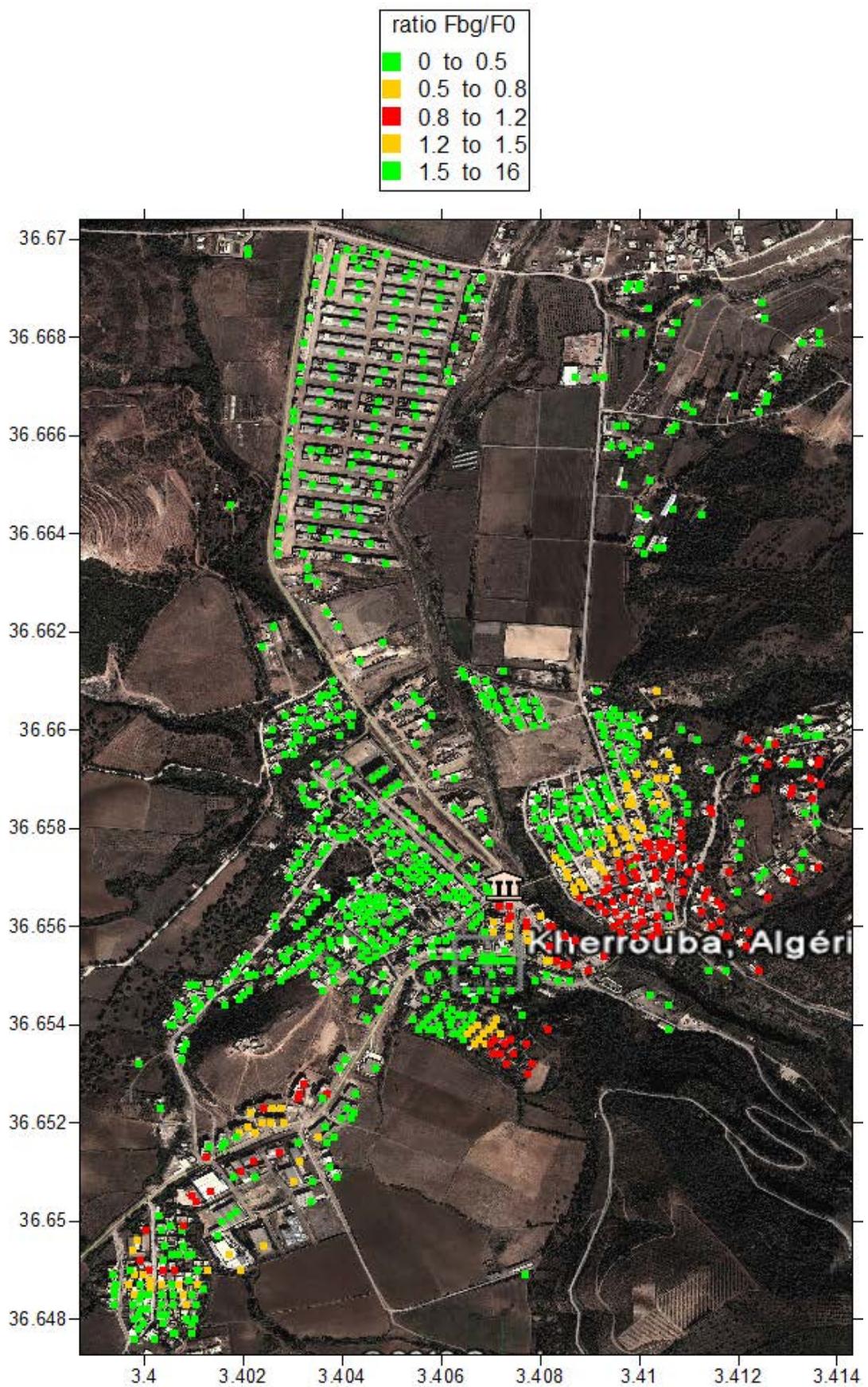


Figure 9. Expected excitation of building resonance phenomena during future earthquakes in Kharrouba

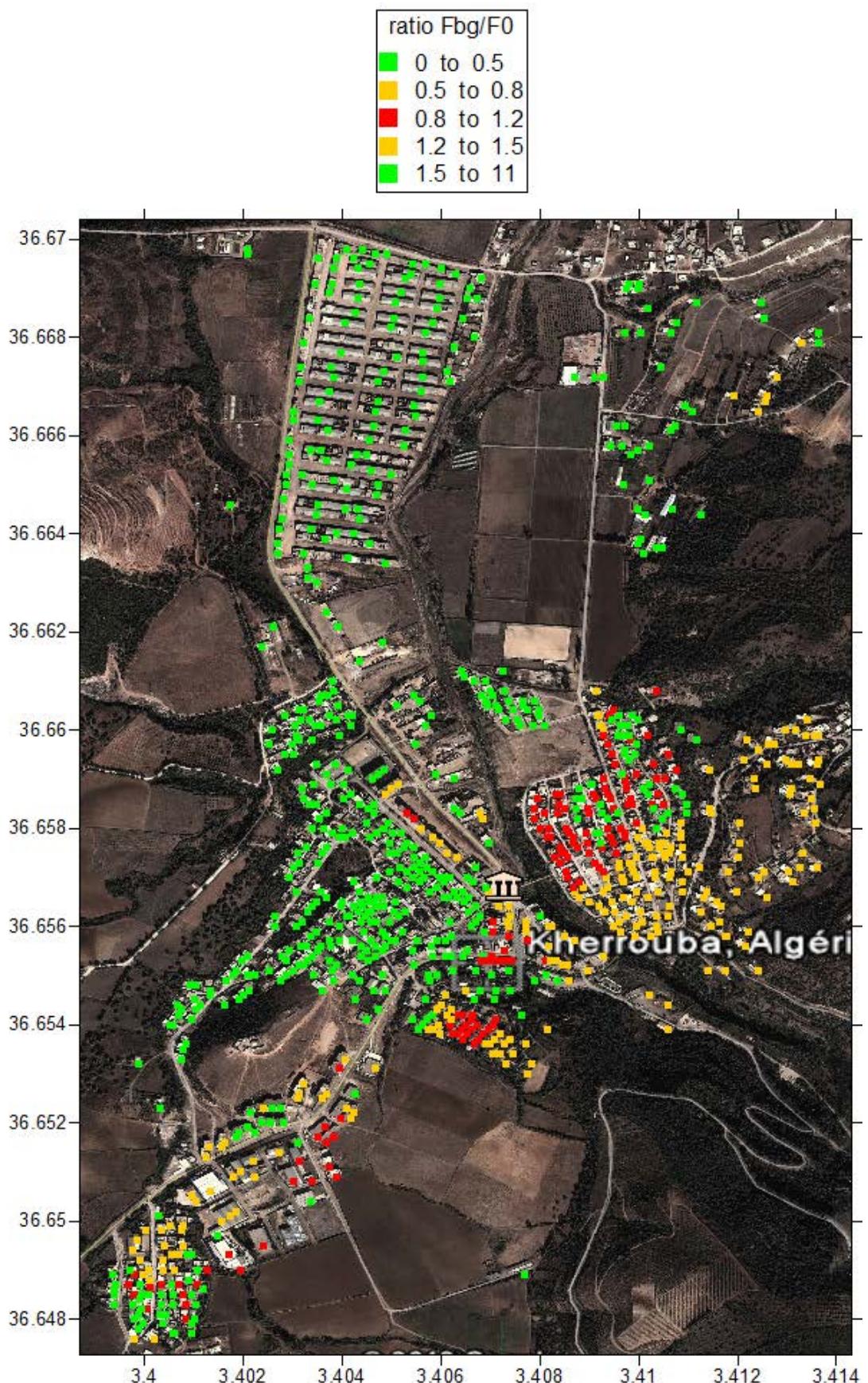


Figure 10. Expected excitation of building resonance phenomena taking into account the transient frequency drop in the commune of Kharrouba

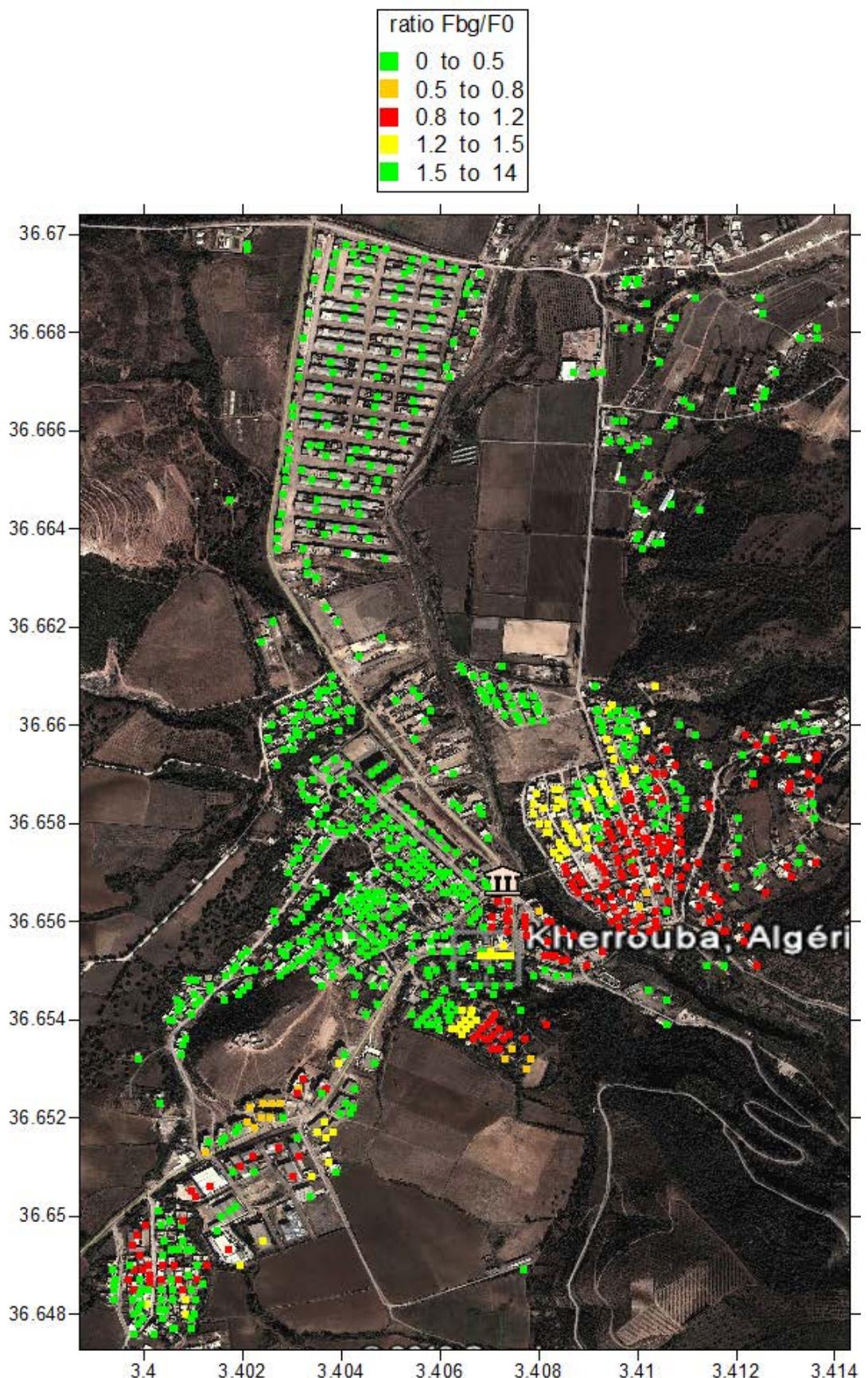


Figure 11. Expected excitation of building resonance phenomena taking into account the permanent frequency drop in the commune of Kharrouba

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