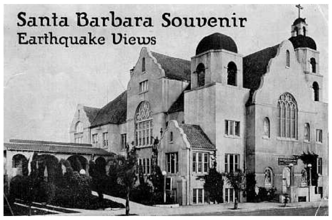

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Towards a Seismic Microzonation of Concepción Urban area based on Microtremors, Surface Geology, and Damage observed after the Maule 2010 earthquake. First Results.

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ABSTRACT

We perform microtremors measurements at the city of Concepción and compute the predominant frequency using horizontal-to-vertical spectral ratio (HVSR). We compare these results with the surface geology and several geothecnical surveys existing in the region, enabling a general characterization of the area. We present and complement these results with observations of damage produce by the Mw 8.8 Maule earthquake. Preliminary results show the presence of fine-grained materials in the area characterized by very low predominant frequency (lower than 1.5 Hz), which might explain the extensive damage observed.

Keywords: Seismic microzonation, Concepción Urban Area, microtremors, Chile

INTRODUCTION

Concepción have witnessed several large earthquakes, many of them with magnitudes larger than 8.0, with a special mention of the earthquakes of 1570 (8.6), 1657 (8.3), 1751 (8.9), 1835 (8.4), 1960 (9.5), and the recent 2010 (Mw 8.8); most of these large events were followed by a destructive tsunami that desolated the coast. All of these earthquakes produced large seismic intensities at Concepción, with estimated values ranging from VIII up to XI (Susa, 2004). For the recent Maule 2010 event, at Concepción was reported an MSK seismic intensity between VII and VIII; while less than 10 km to the North, the neighboring cities of Penco and Talcahuano reported seismic intensities of VI and VII, respectively (Astroza et al., 2010). This difference in the damage produced by the earthquake can only be explained considering local conditions. Similar observations have been made at Santiago where, during the Valparaíso 1906 earthquake (Montessus de Ballore, 1915) and 1985 earthquake (Monge, 1986), presented clear influence of the surface geology. During this last event, Astroza and Monge (1989) reported a difference between 0.5 and 2.0 in intensity within close regions (see, also Menéndez, 1991). Astroza and Monge (1991) showed that the largest amplifications were produced in fine-grained and fluvial deposits, with low grade of consolidation.

Since the early work of Kanai (1957) on the estimation of site amplification using microtremors, many authors have devoted work in order to estimate the site dynamic characteristics in a fast and economic way. Kanai (1957) made the hypothesis that microtremors can be considered with noise in the frequency range of interest (0.1 to 10 Hz); hence, any observed amplification should be produced by the soil. However, Udwadia and Trifunac (1973) noted that the microtremors spectra changed during the day, showing that not only the dynamic response of the soil influenced the spectra, but also the sources (human activity). Later, Nogoshi and Igarashi (1970; 1971) proposed the computation of the horizontal over vertical spectral ratio (HVSR), in order to remove the effect of the source, and applied to urban settlements in Japan. Nakamura (1989; 1996; 2000) extensively popularized this concept, making the use of microtremors' HVSR a corner stone in microzonation studies in large cities (Bard, 1999; Bard and SESAME Workgroup WP02, 2005).

Several studies have shown a correlation between the peak observed in HVSR results and the fundamental frequency of the soil (Lermo and Chávez-García, 1993; 1994; Lachet et al., 1996; Konno and Ohmachi, 1998; Bonnefoy-Claudet et al., 2006a; 2006b; 2008b); however, its amplitudes have not been able to relate to the site amplifications (Field ad Jacobs, 1995; Lachet et al., 1996). Other authors have shown other limitations to the HVSR technique, mainly due to complexities in the subsoil (Chávez-García et al., 2007; Bonnefoy-Claudet et al., 2008a). On the other hand, recently Leyton and Ruiz (2011) have shown similar behavior of the soil observed using strong-motion accelerograms and microtremors, enabling the use of this last method to estimate the seismic response of the site during a large earthquake.

We propose to define a microzonation for Concepción Urban area based on surface geology and predominant frequency obtained from microtremors' HVSR, complemented with observations of damage produced by the Maule 2010 earthquake. In the present study we have focused at the city of Concepción, presenting the first results of the proposed seismic microzonation.

METHODOLOGY

Nakamura (1989, 2000) popularized the used of the horizontal-to-vertical component spectral ratio (HVSR) from microtremors as an effective and economic tool to estimate the fundamental vibration period of the soils. In this study, we used a 3-component 4.5-Hz GVB instrument to make each one of the measurements, which gives a reliable answer down to 0.1 Hz and has been successfully used in these kinds of studies (Leyton et al., 2011; Leyton and Ruiz, 2011). At each point, we recorded for a time window of at least 20 min, depending on the level of human activity, as recommended for microzonation studies (Bard and SESAME Workgroup WP02, 2005). Later, we processed each data in the same way: we divided the total time window into 60-sec subwindows, giving reliable results down to 0.05 Hz. Then, we computed the Fourier transform of each component and added the modulus of both horizontals creating a composed horizontal that assumes perfect coherency between them. Note that this last quantity is the largest possible estimator of the power observed at the horizontal components. Later on, we smoothed the composed horizontal and vertical components with a homogenous filter in log-scale (Konno and Ohmachi, 1998), enabling the computation of the horizontal over vertical spectral ratio. Due to the fact that we used 1 min length subwindows, we get, at least, 20 subwindows without overlapping, and calculated the error for each frequency by means of the standard deviation in the logarithm. Nevertheless, we also computed the HVSR for each horizontal component separately, in order to have an estimator of possible preferred direction; a couple of examples are show in Fig. 1, as discussed in detail in the following paragraph.

In order to see if the estimation of the predominant frequency was biased by noise, we plotted the HVSR of each 1 min window and compared the result of the average. Figure 1 shows the results for 2 cases, the lower part of each panel presents the composed HVSR (continuous line), the HVSR for each horizontal component (dashed lines), and the corresponding standard deviation (gray area). At a first glance, we can see that the error of the second measurement (panels (c) and (d)) is much larger than for the first (panels (a) and (b)), especially at lower frequencies. We plotted the HVSR for each 1 min window, usually considering 20 windows total, as shown in the top panels of (a) and (c); the color is proportional to the spectral ratio, following the scale at the right. From the top panel in (a) we can see that almost all 1 min windows present the peak at 0.8 Hz, except from the first one, probably influenced by the deployment at the field. On the other hand, the top panel at (c) presents most windows with a peak at 0.7 Hz; nevertheless, windows 1, 7, 12, and 20 have high HVSR at low frequencies, increasing the error in this range. Further testing is performed in panels (b) and (d) for both measurements, respectively. These panels present the number of 1 min windows that exceeds the corresponding HVSR value, following the scale at the right. Following this, the white color represents 10 windows having an HVSR lower or equal, and other 10 being higher, representing the statistical mode. Panel (b) shows a sharp transition from red to blue, reflecting that the change is fast; while panel (d) shows a slow degradation of color, representing a very diffuse transition. Hence, we conclude that most of the windows have the same HVSR for the first measurement (reflected in the low standard deviation), while the second measurement have different HVSR for every 1 min window, resulting in a high standard deviation. We processed each measurement in the same way, in order to discard those ones without a consistent estimation of the predominant frequency.

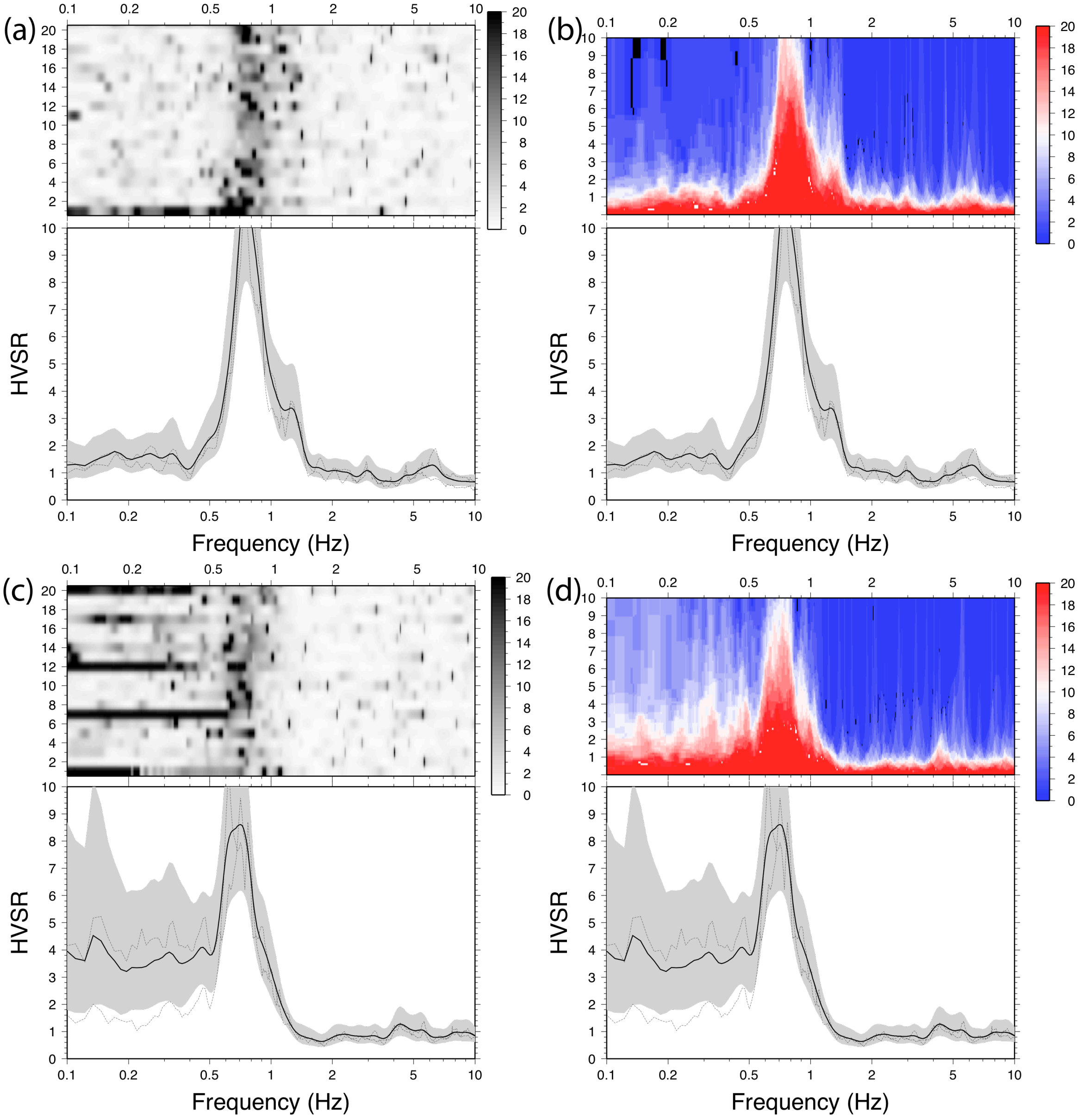

Fig. 1. Examples of microtremors' horizontal-to-vertical spectral ratio (HVSR) performed at Concepción. Lower panels show the average HVSR (continuous line), HVSR for each horizontal component (dashed lines), and the standard deviation in log-scale (gray area). Lower panels: (a) and (c) show the HVSR for each 1 min subwindow, being the color proportional to HVSR following the scale on the left, (b) and (d) show the number of subwindows exceeding the corresponding HVSR value, following the scale on the right. This way, white represents the statistical mode. Note that (c) and (d) represent a measurement with high level of noise at lower frequencies.

After processing all the measurements, we classified all the results into 6 groups, as shown in Fig. 2, having the following preliminary classification:

a) A small amplitude peak (ranging from 3 and 5), with frequency between 1.5 and 2.5 Hz
b) A small amplitude peak, with frequency above 2.5 Hz
c) A small amplitude peak, with frequency below 1.0 Hz
d) A large amplitude peak (above 5), with frequency between 0.5 and 1.0 Hz
e) A large amplitude peak, with frequency between 1.0 and 1.5 Hz
f) A large amplitude peak, with frequency between 1.5 and 2.5 Hz

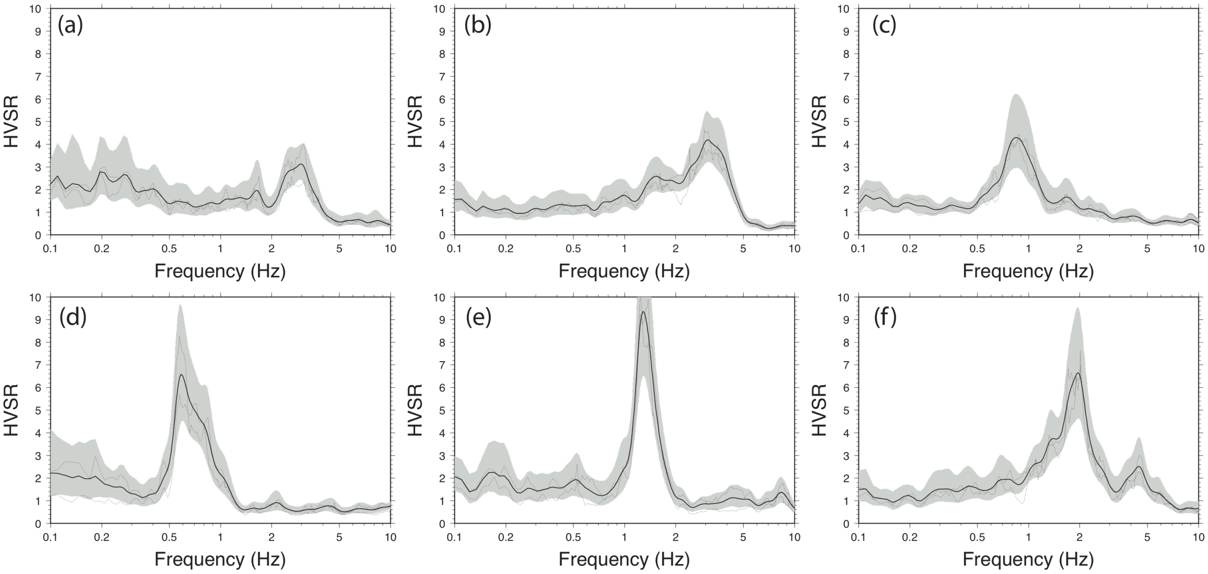

Fig. 2. Taxonomy of HVSR curves observed in Concepción urban area (see text for details).

Previous studies have shown that the presence of large a amplitude peak is related to a high impedance contrast between the sedimentary cover and the basement, while a low amplitude peak is related to a lower contrast, indicating the presence of a hard soil (Woolery and Street, 2002; Bonnefoy-Claudet et al, 2006a; 2008b); in such cases, the observed peak in the HVSR is a good estimator of the predominant frequency of the soil (Tokimatsu, 1997; Bonnefoy-Claudet et al., 2006a; 2008b). Woolery and Street (2002) have interpreted the presence of more than one peak as more than one impedance contrast at depth, while Bonnefoy-Claudet et al. (2008a) relate them to higher modes. Our data present 16 measurements with low amplitude (ranging from 3 to 5, cases (a) to (c) from Fig. 2) and 36 with large amplitude (greater than 5), representing 31% and 69% of the data, respectively. From all of these is possible to estimate the predominant frequency of the soil, having 76% of the total values lower than 1.5 Hz (cases (d) and (e) from Fig. 2).

SURFACE GEOLOGY

The main geomorphologic structures found in the area correspond to mountain belts formed by intrusive and sedimentary rocks that form to the Concepción Basin, along with the fluvial sedimentary basin prairie formed by the Bio-bío and Andalién rivers (Galli, 1967). Few isolated hills are found within the basin, which are believed to be related to covered normal faults, trending NE (Ramírez and Vivallos, 2009). The main geologic units found in the area are shown in Fig. 3, corresponding to the following brief description:

- **Eocc**: Sandstones and continental lutites with coal lenses.
- **Kq**: Calcareous sandstones with marine fossil.
- **La**: Lake.
- **PzSE**: Metamorphic rocks (schist, phyllite, slate).
- **Pzg**: Granitic rocks (tonalities).
- **Qbt**: Mud, peat, and other poorly drained materials (wetlands).
- **Qtc**: Colluvial deposits.
- **Qtfa**: Andalién sands.
- **Qtfb**: Bio-bío sands.
- **Qtm**: Marine sand deposits.
- **Ra**: Anthrophic fills (artificial deposits).
- **Tras**: Siliceous sands.
- **Trg**: Igneous rocks (granites).

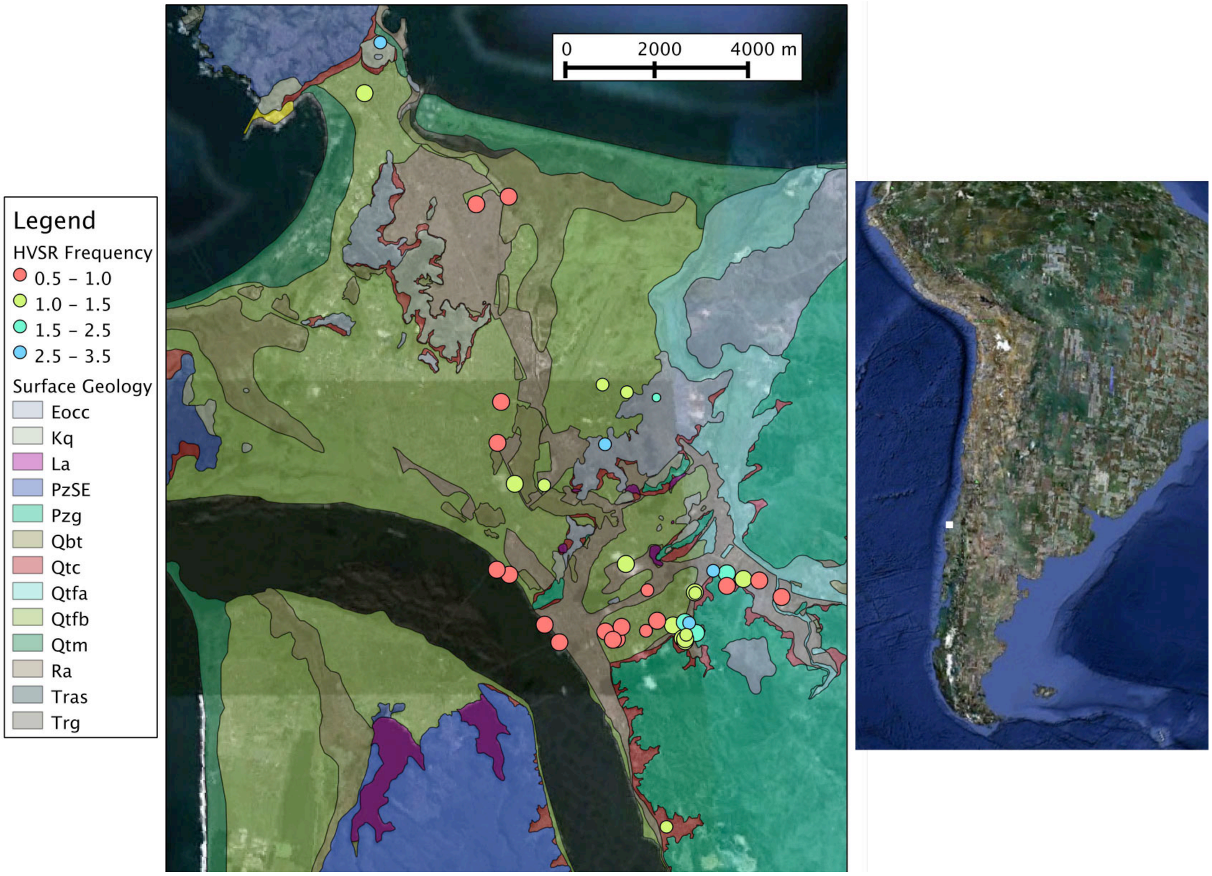

Fig. 3. Aerial photograph with the surface geology of Concepción urban area (modified from Galli, 1967; Gajardo, 1981). To the left is shown the legend while at the right is present a map of South America with the location of the study area (white square). Circles show the location of a microtremors measurement, with the color proportional to the predominant frequency (see legend) and the size to the HVSR amplitude.

In the Concepción urban area, we found mostly Bio-bío sands (Qtfb) along with artificial deposits (Ra), mostly characterized by very low (0.2 to 1.0 Hz) to low (1.0 to 1.5 Hz) predominant frequencies, respectively, as shown in Fig 3. The Bio-bío sands (Qtfb) are mostly fine-grained materials, with increasing fine content towards the South. The sedimentary cover ranges between 50 to 130 m (Ramírez and Vivallos, 2009); while SPT geotechnical surveys show, in average, a high level of compaction for sands at a 6 m depth: 40 hits for a 30 cm penetration length (Inostroza, 2004). On the other hand, the artificial deposits (Ra) are fine-grained sands with abundant silts interbedded by several clay layers. These deposits have more than 4 m of a heterogeneous mix of organic matter, clay, debris, and other fine-grained material with different levels of compaction. They present an average sedimentary thickness of 50 m depth (Ramírez and Vivallos, 2009), with very low SPT resistance in the upper 5 m (Inostroza, 2004).

Other deposits found in the area are colluvial deposits (Qtc) located at the foothills, which are interbedded by fluvial and aeolian sands with abundant silts. The SPT surveys present low levels of compaction, reaching 30 hits for 30 cm of penetration at depth below 10 m (Inostroza, 2004). Some areas of the granitic rocks (Pzg) present strong degradation forming soils with high presence of clay.

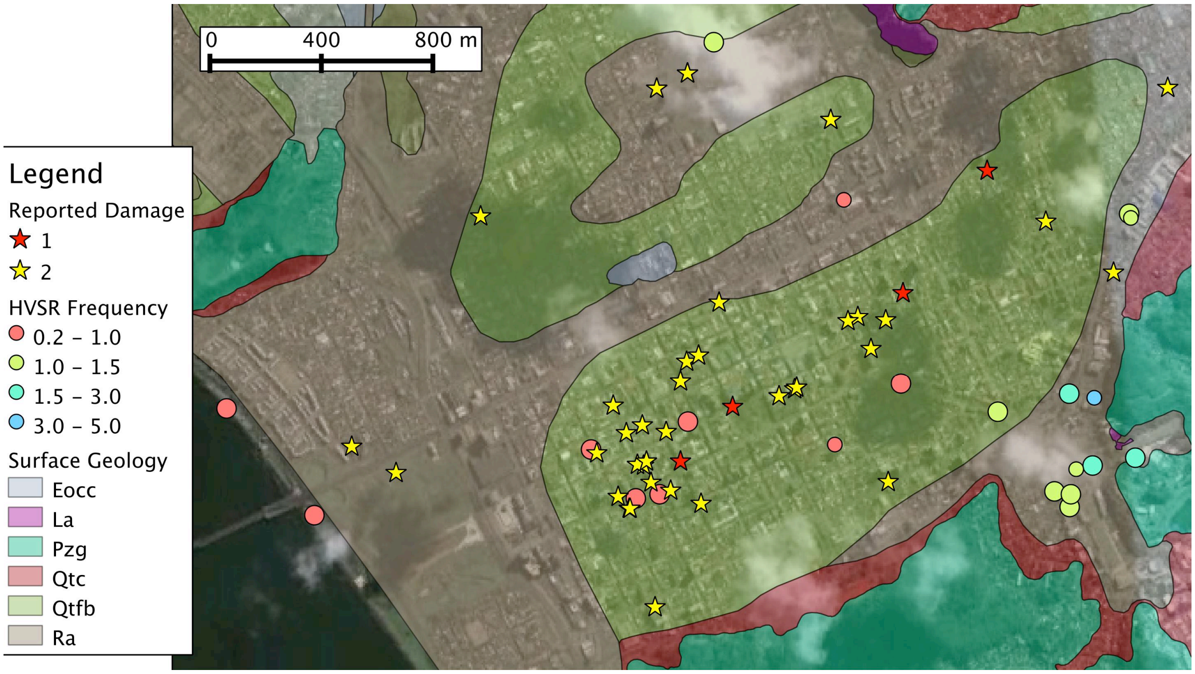

Fig. 4. Aerial photograph with the surface geology found in Concepción (modified from Galli, 1967), the corresponding legend is shown to the left. The stars mark the location of severely damage buildings after the Maule 2010 earthquake (see text for details). Circles show the location of a microtremors measurement, with the color proportional to the predominant frequency (see legend) and the size to the HVSR amplitude.

DAMAGE OBSERVED AFTER THE MAULE 2010 EARHTQUAKE

On February 27, 2010, Central Chile witnessed one of the largest earthquakes ever recorded (Mw 8.8) that produced strong damage over a region of more the 400 km length (Astroza et al, 2010). After this large earthquake, 58 buildings at Concepción presented sever damage: 1 of them completely collapsed, 7 were on the brink of collapse, and the remaining 50 show sever structural damage. Figure 4 shows two levels of reported damage: level 1 group those with collapse and almost collapse and level 2 those with severe structural damage, information given by the Municipality of Concepción. Based on these data, Ramirez and Falcón (2010) proposed the limitation of height within Zone I of the microzonation proposed by Ramirez and Vivallos (2009), composed mainly Bio-bío sands (Qtfb). This suggestion is based on the strong correlation of high intensity of observed damage and predominant periods larger than 1 sec (Troncoso, 1992) for building with more than 5 stories; however, further and detailed studies should be performed.

The extent and intensity of damage at Concepción was very large, as shown in Fig 5. In this Fig., we also show present same examples of liquefaction widely observed in this area, especially in wetlands (Qbt) and antrophic fills (Ra).

Fig. 5. Damage observed at the city of Concepción after the Maule 2010 large earthquake in: buildings, house due to lateral spreading, and evidence of liquefaction.

CONCLUDING REMARKS

Damage observed afte the Maule 2010 earthquake (Mw 8.8) at Concepción was very large, especially in tall buildings. This phenomenon is probably related to the local conditions because was observed that nearby localities presented a seismic intensity of 0.5 to 1.0 points lower. We performed microtremors measurements mostly at the city of Concepción and correlated with local surface geology. Our first results confirm the presence extensive deposits of fine-grained materials characterized by low fundamental frequencies (lower than 1.0 sec).

At this study, we made a robust estimation of predominant frequency from microtremors, using a 3 component, 4.5 Hz geophone, at an urban enviroment. This was possible analyzing the statistics of the horizontal-to-vertical spectral ratio at many subwindows, looking for values that were predominat throughout most of the signal and discardng any transients. After processing all the measurements, we were able to identify very low predominant frequency at Bio-bío sands (Qtfb) and the anthropic fills (Ra), being most of periods larger thatn 0.67 sec and a 43% larger than 1 sec. We believe that these low predominant frequencies are probably the responsibles of the extensive damage observe in the area.

Although the depth and shape of the basin is likely to have a significant influence in the surface strong motion of Concepción urban area, this aspect is currently being studied by the authors and is out of the scope of this work. Preliminary work on this matter show reasonable agreement between measured fundamental periods and rock depths.

In this study we present preliminary results of a seismic microzonation of Concepción, having a large task to address the rest of the greater urban area, including Hualpén, Talcahuna, Chiguayante, and San Pedro de la Paz. Preliminarly, we found that the local geology at Concepción show the presence of fine-grained materials characterized by low frequencies (lower than 1.0 Hz). This feature should be compared with the rest of the localities.

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