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Analysis of geotechnical data and ambient noise records to assess site response in Viña del Mar (Chile).

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Abstract

Historical and recent Chilean earthquakes (1906, 1960, 1985, 2010) showed similar building damage distribution in Viña del Mar city related to ground conditions and building height A detailed analysis of 122 geotechnical reports has allowed us to obtain their geotechnical parameters and the V_S surface ground structure (calculated from N_{SPT} data) up to a depth of 30 m in 62 of these sites. The site predominant period (T_p) was estimated from ambient noise records (with the HVSR technique) in 84 points regularly spaced (Δ ~200 m). The highest values (T_p > 0.8 s) were found nearby the Marga-Marga fault trace, and gradually decrease on both sides up to 0.4 s close hill zones, being less than 0.2 s at the hills. Two estimates of the basement depth (V_S> 800 m/s) from the V_S(z) and H/V observed curves show similar results: depth > 60-70 m in one-third of the plain area, reaching 120 m in the center of the basin. The spectral amplification obtained in 12 representative sites by computing the 1-D response of the shallow Vs structure exceeds a factor of 4 in the area with greater thickness and is greater than 3 in the remaining area for the corresponding key periods.

Keywords: Viña del Mar; Maule 2010 earthquake; local conditions; ambient noise; geotechnics and seismological characteristics.

1. Introduction

The influence of surface geology on spatial distribution of earthquake ground amplification and building damage in Viña del Mar city (VdM hereinafter) has been repeatedly observed in past damaging historical earthquakes (e.g. 1906, 1960, 1985). The city is placed at one of the most dangerous seismic zones in Chile. Recently, the gigantic 2010 Chile earthquake (Mw 8.8, Imax = IX-EMS), tested a lot of facilities and structures of this city causing damage on certain type of buildings and specially in zones of its plain urban area. This city is located on the northern edge of the rupture zone of the 2010 earthquake, and mostly founded on alluvial deposits.

In this work we analyze the geotechnical data to obtain the V_S surface ground structure and the predominant period (T_p) estimated from ambient noise records (with the HVSR technique). The thickness of the sedimentary filling has been estimated from *Vs(z)* and H/V observed curves in order to provide the basement morphology. We compare the spectral amplification obtained by computing the 1-D response of the shallow *Vs* structure with estimated that applying SSR and HVSR methods to 2010 event records. Finally, we discuss if a correction of the mean seismic amplification based on VS_{30} estimates is needed when local seismic hazard assessment is sought.

2. Analysis of geotechnical data

Viña del Mar is a coastal city located at the mouth of the Marga Marga river, formed by deposits of marine and especially alluvial materials (consisting mainly of sand and gravel, sand mixed with silt and anthropic filling).

The analysis of geological and geotechnical data from 122 borehole sites and N_{SPT} measures at 62 of these sites (Figure 1), most of them located at the flat part of the urban area, has allowed us to obtain the surface ground structure to a depth 20-30 m (Figure 2). A first simple classification of the city soils (focused on seismic

response) considers three types: intrusive rocks, consolidated and unconsolidated sediments. These sedimentary deposits reach up to 100-130 m thick (Figure 7) and the water table depth is generally less than 6 m (Figure 2).

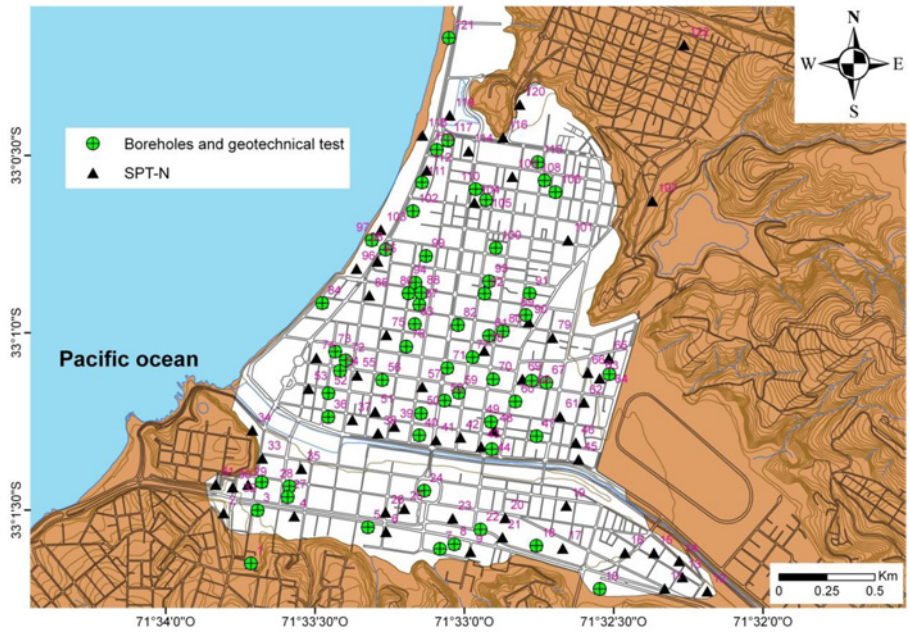

Fig. 1 – Mechanical sounding and geotechnical reports analyzed, georeferenced on SIG, which determine the zone of study for the interpolations (white sector).

Using the V_S- N_{SPT} relationship of Aranda (2015) Vs = 90.08 * $N_{SPT}^{0.30}$, we estimated V_{S10} and V_{S30} values of different sites of the plain. The V_{S10} values are low, between 200 and 260 m/s, and V_{S30} are below 360 m/s. The sites of the plain can be classified as rigid soils, class C, according to Eurocode-8 (EC8) or type B with Chilean seismic code (Nch433), and the soil of the hill districts as type B (EC8) or type D (Nch433).

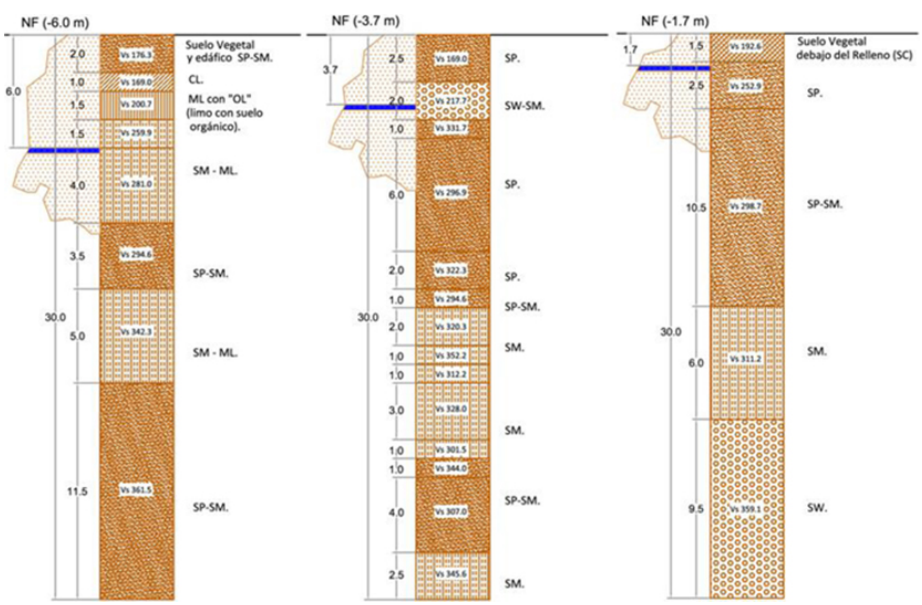

Fig. 2 – Detail of three lithological-geotechnical profiles obtained from mechanical sounding down to 30m, showing the soil type according USCS (2010) and the *Vs* estimated from N_{SPT}. The water-table detected is marked in blue.

3. Ground predominant period

The ground predominant period (T_p) is a key factor in the prediction of earthquake damage especially when it is close to the fundamental period of buildings founded on it, since seismic motions shall produce a resonance with buildings that can greatly increase the stresses in the structure. We applied the spectral ratio between the horizontal and vertical components (also called HVSR technique or Nakamura method) (Figure 3) of long ambient noise records to estimate T_p in 84 points regularly spaced (Δ ~200 m) in the city, most of them sited on the flat area. The estimated T_p values (with Geopsy software) are less than 0.2 s at the hills, 0.2- 0.4 s at close hill zones, and 0.4-1.3 s at the plain city area (on Quaternary sediments The highest values (T_p > 0.8 s) were found in the central part of the basin, nearby the Marga-Marga fault trace, and, in general, gradually decrease with distance towards both sides).

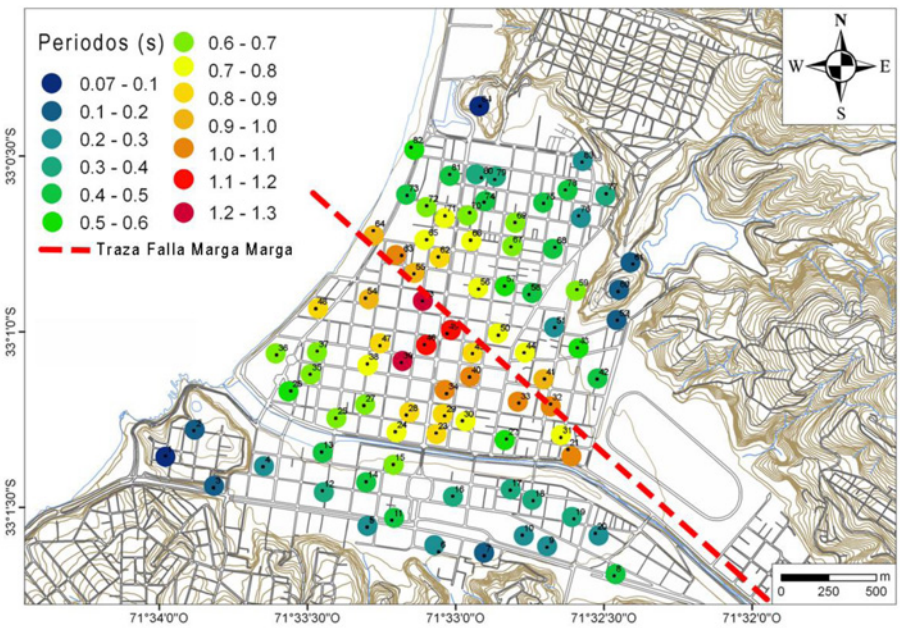

Fig. 3 – Map of predominant periods obtained from microtremor measurement at 84 points in the city. The red-dashed line is the fault Marga-Marga trace.

4. Basement depth and H/V Inversion

To characterize the strong earthquake, it is necessary to build a structural model of the subsurface modeling. We use an H/V method proposed by Sanchez-Sesma et al. (2011) based on the theory of fuzzy fields and considers all contributions to wavefield. The inversion algorithm used is the Simulated Annealing (Kirkpatrick et al., 1983) and implementation of these methods performed by Pineapple (2015) and Garcia-Jerez et al. (2013, 2015) was used.

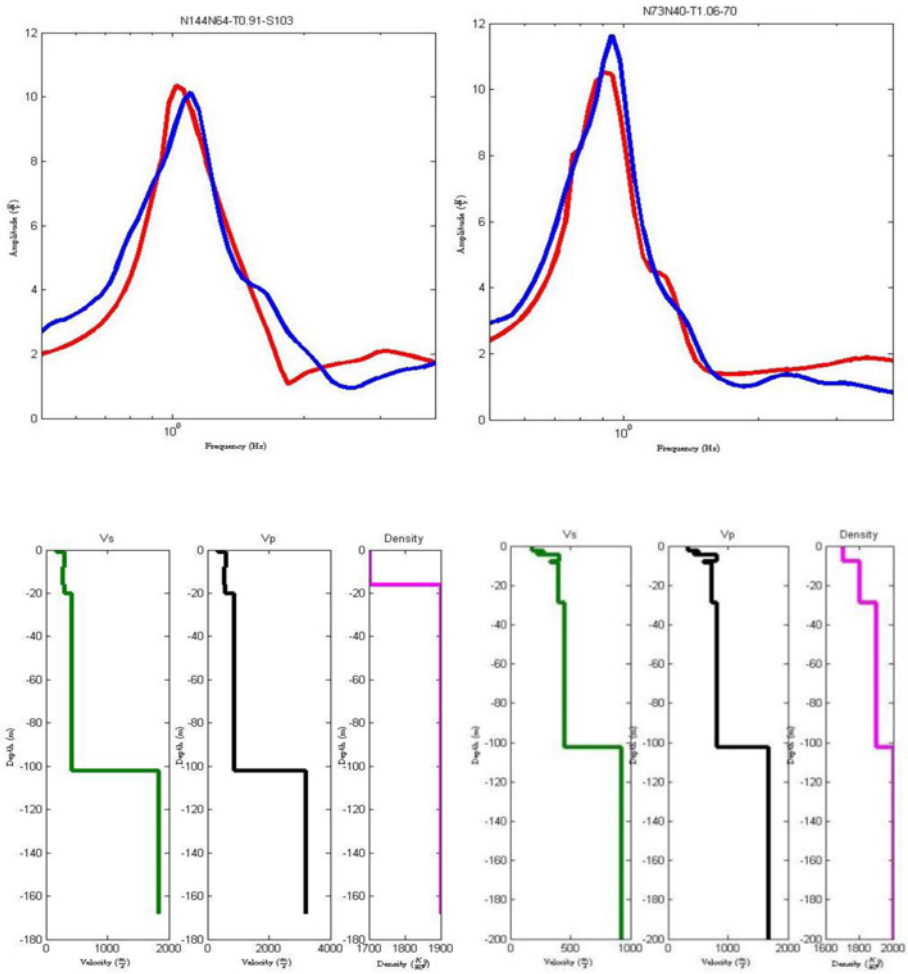

Fig. 4 – Two examples of H/V curves and the corresponding velocity structures obtained. Top: experimental microtremor H/V spectra (blue) and simulated from the velocity structure (red). Bottom: Vp (black) and Vs (green) structures inverted from the microtremor H/V spectra at each site.

The program seeks the shell model that best reproduces the curve H/V respecting the prior information and giving output as model of horizontal layers (i. e. thicknesses, densities, V_S and V_P). The criterion for identifying the depth to the basement is that V_S is greater than or equal to 800 m / s. In Figure 4 two examples of curves H/V experimental and simulated model structure obtained and structures V_P and V_S inverted at each site are shown. Once invested models 50 points, these are interpolated to obtain the map of Figure 5.

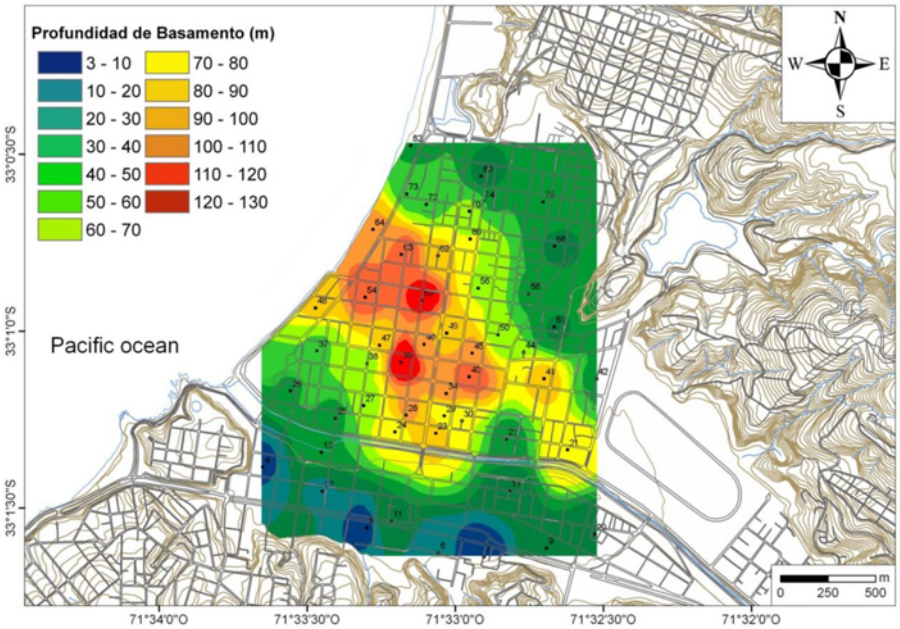

Fig. 5 – Approximate basement depth of the Viña del Mar basin obtained by inversion of the H/V curves. It is noteworthy that the sediment thickness is higher than 60 m in more than one third of the basin.

Estimated basement depth ranges from 10 to 120-130 m in the flat area of the city, where the greatest depths are concentrated and reaches a maximum of about 120 m in a relatively small central area of the plain. The depths obtained are greater than 60 m in one-third of the study area. As we move away from the central area and the hills we approach the depth decreases, becoming less than 10 m in some points southwest.

5. Characteristics of the ground transfer function

To obtain the characteristics of the ground transfer function in Viña del Mar we used two known empirical methods: The standard spectral ratio (SSR) and the H/V spectral ratio (HVSR) methods by using earthquake acceleration records of the 2010 earthquakes.

We analyzed the characteristics of the 2010 mainshock ground motion recorded at two stations in Viña del Mar (Viña Centro (CEVM) and Viña El Salto (MMVM) (Figure 6) and other two stations neighbouring to the city: El Almendral and Valparaiso UTFSM. The UTFSM station, sited on bedrock, was used as reference station. SSR and HVSR methods show small differences in site amplification values between both Viña del Mar stations. The spectral amplification is above a factor of 4 for periods of 0.4-1.2 s at CEVM site, and 0.35-1.6 s at MMVM site (Figure 7).

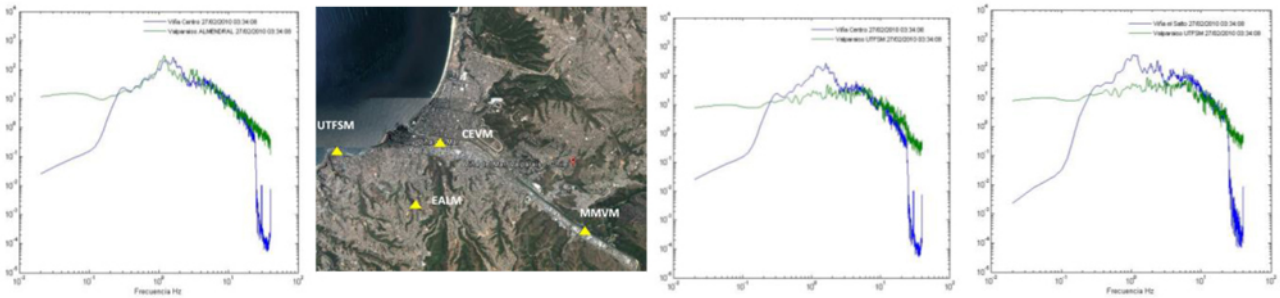

Fig. 6 – The 2010 mainshock acceleration spectra obtained in four strong motion stations of Viña del Mar and Valparaiso.

We also calculated engineering ground motion frequency-dependent parameters (response spectra, SA, SV, and input energy spectra, IES) of the mainshock to test the frequency-amplification obtained with the methods mentioned above. The results show amplification for the same range of frequencies previously obtained.

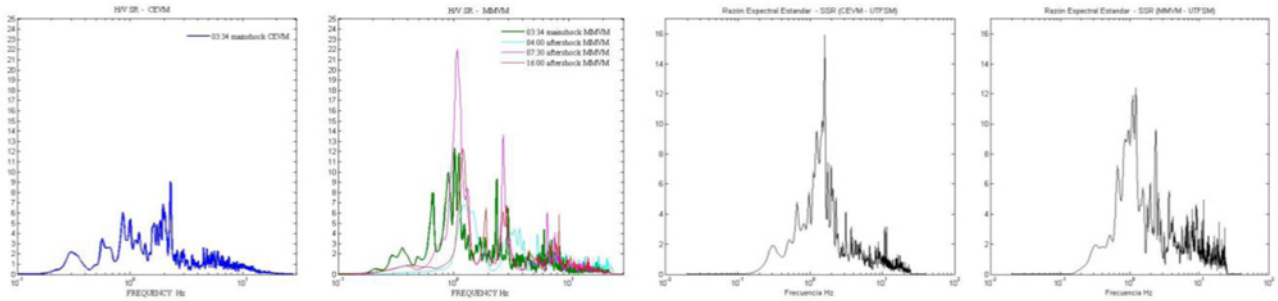

Fig. 7 – Local ground response in CEVM and MMVM sites using HVSR (left) and SSR methods (right) using UTFSM as reference station in both cases.

Finally, we found the spectral ground amplification in 12 sites of the city by computing the 1-D response of the shallow Vs structure (obtained previously) using the method of Thomson-Haskell implemented in DEGTRA A4 (Ordaz and Montoya, 2002) (Figure 8). The amplifications occur in periods that match the dominant periods observed in ambient noise measurements and the largest ones in zones with longer periods (and greater sediment thickness). Near the trace of Marga Marga fault the spectral amplification factor is greater than 4.

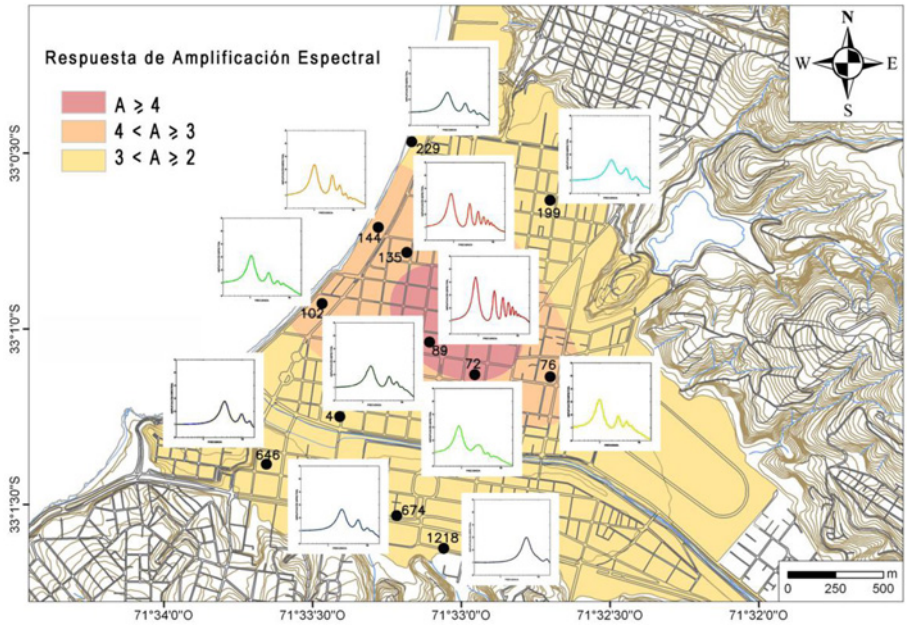

Fig. 8 – Site seismic response obtained from 1-D models at different points in the basin.

6. Conclusions

- The analysis of the geological, and geotechnical data indicates that the surface soils of the Viña del Mar plain area consists of alluvial deposits (sands and silty sands). At the top there are fillings (topsoil, manmade and sludge) with variable thickness from 0.5 to 5.5 m and very low bearing capacity. The other districts of the city are placed on surrounding hills (which mainly are rock or hard soil out-crops).

- The water table depth is very low, and generally varies between 2 and 8 m, being the most representative depth about 6 m. This superficiality is a major risk factor in case of earthquake. The most serious damage in the 2010, 1985 and 1960 earthquakes are related to city areas of soft soils and low water table depth.
- A V_{S30} microzoning of the city show high values of this engineering parameter at the hill areas, and medium to low values at the plain city area. No significant lateral differences are detected in this plain area when V_{S30} soil classification is applied.
- The predominant ground periods T_p of the plain area of the city (on Quaternary sediments) are between 0.4 and 1.3 s, the highest values (T_p > 0.8 s) were found in the central part of the basin on zones nearby of Marga Marga fault, and, in general, gradually decrease towards both sides with distance from it. T_p values are less than 0.2 s at the surrounding hill zones and between 0.2 and 0.4 s close hill zones. T_p values are well correlated with the basement depth but are far from those estimated from V_{S30} data and they show clearly lateral differences of soil behavior.
- The HVSR and SSR empirical methods show spectral amplification above a factor of 4 for periods of 0.4 - 1.2 s (CEVM) and 0.35-1.6 s (MMVM). Several tested sites show maximum amplification around the T_p.
- The analysis of the SV, SA and IES spectra of the 2010 event show the highest energy of the ground motion was in the range of 0.4 to 1.4 s in the city sites, in agreement with the amplification here obtained
- The soils of the Viña del Mar plain area are type C according to V_{S30} classification of EC-8. The average seismic response estimates from V_{S30} values do not gives appreciable differences among sites, but damage distribution and HVSR of the 2010 aftershocks (Aranda et al, 2014) and of the ambient noise measurements do it.
- The predominant period map show the highest values (Tp > 0.8 s) in the central part of the basin, nearby the Marga-Marga fault trace, and, in general, gradually decrease towards both sides with distance from it. Tp values are well correlated with the basement depth here obtained but are far from those estimated from V_{S30} data.
- Ground transfer functions estimated in different sites by computing the 1-D response of the sedimentary structure show similar T_p values to those obtained from microtremor and allow us to confirm spectral amplification factor from acceleration records.
- Estimated basement is deeper than 60 m in one-third of the basin, reaching a maximum of about 120 m in a small central area of the plain. Our depth values are slightly larger than those obtained by Aguirre and Perez (2004) and smaller than those of Verdugo (1995).

7. References

[1] USCS (2010). Standard Practice for Classification of Soils for Engineering Purposes. Tech. Rep. D2487-–06, American Society for Testing Materials.

[2] NCh433 (1996). Diseño sísmico de edificios. *Norma Chilena Oficial. Instituto Nacional de Normalización* .

[3] EC–8 (2005). Eurocode 8: Design of structures for earthquake resistance–Part 3: Assessment and retrofitting of buildings (EN 1998-3: 2005). *European Committee for Normalization, Brussels*.

[4] Sánchez-Sesma, F. J., Rodríguez, M., Iturrarán-Viveros, U., Luzón, F., Campillo, M., Margerin, L., García-Jerez, A., Suarez, M., Santoyo, M. A. & Rodríguez-Castellanos, A. (2011). A theory for microtremor H/V spectral ratio: application for a layered medium. *Geophysical Journal International* **186**(1), 221–225.

[5] Kirkpatrick, S., Gelatt, C. D., Vecchi, M. P. *et al.* (1983). Optimization by simulated annealing. *Science* **220**(4598), 671–680.

[6] García-Jerez, A., Piña, J., Sánchez-Sesma, F., Luzón, F. & Perton, A. (2015). A computer code for forward and inverse computation of the H/V spectral ratio under the diffuse field assumption. in press.

[7] García-Jerez, A., Luzón, F., Sánchez-Sesma, F. J., Lunedei, E., Albarello, D., Santoyo, M. A. & Almendros, J. (2013). Diffuse elastic wavefield within a simple crustal model. Some consequences for low and high frequencies. *Journal of Geophysical Research: Solid Earth* **118**(10), 5577–5595.

[8] Aranda, C., Vidal, F., Alguacil, G., Navarro, M. & Valverde, I. (2014). Ground conditions influence on earthquake damage in Viña del Mar city. En: *Second European Conference on Earthquake Engineering and Seismology*. Istanbul, Turkey.

[9] Aguirre, C. & Perez, P. (2004). Seismic Microzoning Based on Earthquake Records Amplification. *13th World Conference of Earthquake Engineering. Vancouver, Canada*.

[10] Verdugo, A. I. (1995). Estudio geofísico de los suelos de fundación para una zonificación sísmica de Valparaíso y Viña del Mar. *Universidad de Chile*.

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