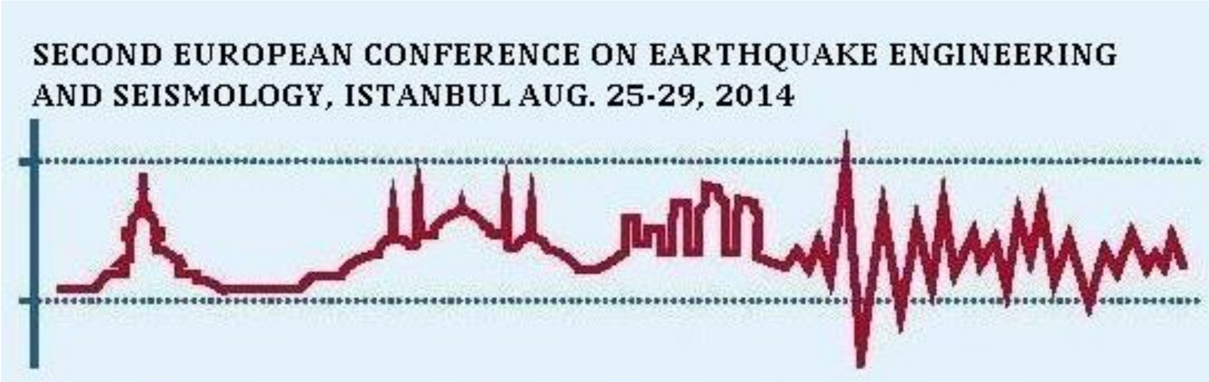

GROUND CONDITIONS INFLUENCE ON EARTHQUAKE DAMAGE IN VIÑA DEL MAR CITY

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The influence of surface geology on the spatial distribution of earthquake ground amplification and building damage in Viña del Mar city has been repeatedly observed in past damaging historical earthquakes (e.g. 1906, 1960, 1985). 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 area. This city is located on the northern edge of the rupture zone of the 2010 earthquake, and mostly founded on alluvial deposits.

A detailed assessment of the 2010 shake intensity in the city showed a variation from VI to VII-VIII (EMS) (Carrasco and Nuñez, 2013), being VII-VIII in a reduced zone of the plain (of thick sedimentary deposits) and lower than VII in surrounding zones. The lowest intensity values were found in the hills, where the bedrock is near the surface. The quake reached a PGA of 0.35g and 0.43 g in two strong motion stations of the city, CEVM (in the downtown) and MMVM, respectively. The acceleration picks were higher than 0.15 g for more than 20 s and serious damage on several buildings were observed, especially tall reinforced concrete (RC) buildings, mainly those sited along the coast and river Marga Marga shores, already an indicator of the influence of site conditions and possible resonance effects. In this work we analyse the variations of ground conditions (from lithological and geotechnical data), the characteristics of soil response (from ambient noise measurements and strong motion records) and the characteristics of buildings (from key structural parameters), in order to see the influence of ground motion and possible resonance effects on building damage.

Viña del Mar is a coastal city located at the mouth of the river Marga Marga, formed by deposits of marine and especially alluvial materials (consisting mainly of sand and gravel, sand mixed with silt and anthropic filling). Most of buildings are founded on the plain area (named Plan de Viña). These sedimentary deposits reach up to 100-125 m thick and the water table depth is generally less than 6 m. The other districts of the city are placed on surrounding hills, which mainly are rock or hard soil out-crops. The analysis of geological and geotechnical data from 53 geotechnical reports of this flat area has allowed us to obtain the surface ground structure to a depth 20-30 m. A first simple classification of the city soils (focused on seismic response) considers three types: intrusive rocks, consolidated and unconsolidated sediments. Using the V_S- N_{SPT} relationship of Hasancebi and Ulusay (2007) we estimated V_{S10} and V_{S30} values of different sites of the plain. The V_{S10} values are low, between 210 and 280 m/s (Figure 1 left), and V_{S30} are below 360 m/s, sites classified as stiff soils, class C according to Eurocode-8 (EC8). The soil of the hill districts was classified as type B (EC8).

The ground predominant period (Tp) is a key factor in the prediction of earthquake damage especially when it is close to the fundamental period of buildings founded on it. We have applied the

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spectral ratio between the horizontal and vertical components (also called HVSR technique or Nakamura method) of long ambient noise records to estimate Tp in 84 points regularly spaced (Δ ~200 m) in the city, mainly on the flat area. The estimated Tp values of the plain are between 0.4 and 1.2 s and lower than 0.4 s at the surrounding hill zones (Figure 1 right). The highest Tp values were found in sites near the river and coast shores. The Tp values are well correlated with the basement depth obtained by Aguirre and Perez (2004) from gravimetric data (Figure 1 right). Results are in agreement with the seismic microzonation performed by Carrasco and Nuñez (2013).

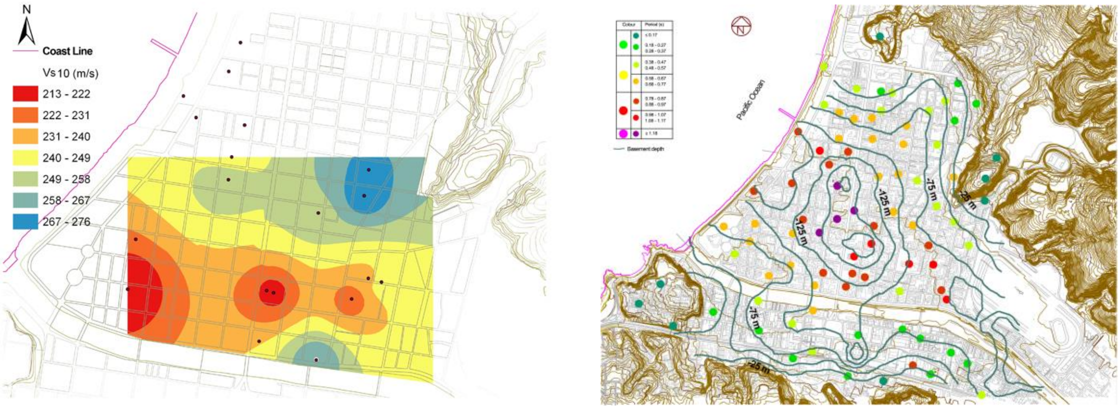

Figure1. Left) Vs velocities of the upper 10 m (V_{S10}) estimated from N_{SPT} data. Right) Ground predominant period of the city obtained from ambient noise long records. Green lines show the basement depth.

The earthquake records of the CEVM and MMVM seismic stations placed at the Viña del Mar downtown and east border, respectively, were used to obtain the characteristics of the ground transfer function. We used two empirical known methods: The standard spectral ratio (SSR) or reference station method and the H/V spectral ratio (HVSR) method. A near strong motion station installed on bedrock (UTFSM) belonging to the Universidad Tecnica Federico Santa Maria was used as reference station. Other station (El Almendral, EALM), neighbouring to Viña del Mar, sited on sandy soil was rejected. Both methods show similar site amplification results for both stations. Spectral amplification is above a factor of 4 for periods of 0.4-1.2 s (CEVM) and 0.35-1.6 s (MMVM).

Midorikawa and Miura (2011) found also significant ground amplification in 4 sites of the city (one of them was CEVM station) applying HVSR method to several 2010 aftershocks (Figure 2 left). The Tp values are within the amplification period ranges found by these authors for these sites. We obtained acceleration and velocity response spectra (SA, SV) and elastic input energy spectra (IES) of the 2010 mainshock in CEVM and MMVM stations (Figure 2 right). The calculated IES show different level of energy with peaks at different periods (CEVM 0.4-1.1 s and MMVM 0.4-1.5 s). Both IES could be representative of sites of the plain city areas with sedimentary deposits of different thickness. All mentioned parameters have great interest to analyse the damage.

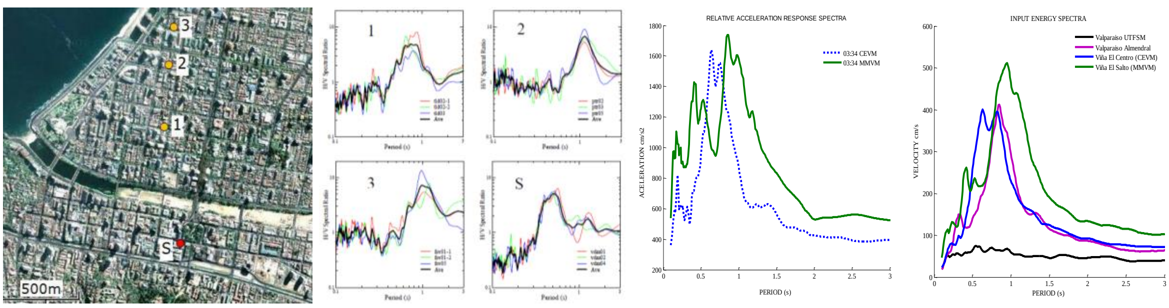

Figure 2. Left) Amplification period bands obtained by Midorikawa and Miura (2011) in four sites (S is CEVM station) applying HVSR method to several 2010 aftershocks. Right) Acceleration response and input energy spectra of the 2010 earthquake ground motion in CEVM and MMVM stations and its comparison with UTFSM.

After the 2010 earthquake, 2054 buildings on the plain area of the city were inspected. 252 of them were damaged, and required a more detailed analysis (Aranda et al., 2012). Damage was assessed considering: building type, number of storeys, stiffness (*h/T*), wall density, soil type and shake period range. Damage grade was estimated using the EMS scale and HAZUS methodologies.

We have used the empirical relationship between the building periods (T) with their number of storeys (N) obtained by Midorikawa (1990) to estimate T of the 2054 analysed buildings (Figure 3 left). After the 2010 earthquake, we have obtained a new T/N relationship, T = 0.057 N, by using ambient noise measurements on the top of 99 RC buildings (with 3<N<25), showing that fundamental periods of buildings apparently undamaged have slightly shifted (~ 15 %).

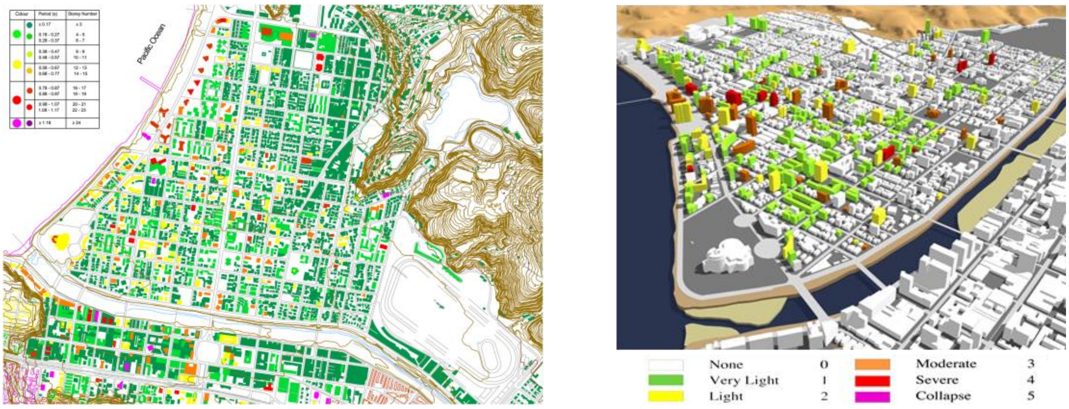

Figure 3. Left) Fundamental period (before 2010 earthquake) and number of storeys of all analysed buildings. Right) 3D view (from the SW) of damaged buildings of the plain area. Damage dependence on the buildings height and location on the softest and thicker soils is observed. Grade of damage (0-5, EMS scale) is shown in different colours.

The most noteworthy aspect is the fact that, in spite of clearly reaching degree of VII-VIII (MM) in the plain area of the city, most buildings (87.7%) did not suffered substantial damage. Only 1.6 % experienced damage grade 3 or 4 (EMS scale). A certain dependence on the level of damage to the structural type, time of construction and fundamental period of building was appreciated. Only 0.9% of the buildings with N ≤3 storeys (the most abundant, 74.2 % of all inspected buildings) were damaged and only 0.4 % with grade 3 or 4. However, buildings N ≥ 4 storeys, mainly RC structures, less abundant (25.75 % of total), by 11.3 % were damaged and 1.2 % with severe damage (grade 3 or 4 EMS). Severe damage affected to RC structures mainly between 10 and 24 storeys being built before the 1985 earthquake and with fundamental period close to the predominant ground period. The geographic distribution of buildings with structural damage (grade ≥ 3) was restricted to areas of fluvial and marine deposits, indicating an influence of soil response on building damage. This damage pattern is similar to that observed in the 1985 earthquake.

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