



El Proyecto RESIS-II:

Reducción de Riesgos Sísmicos en Guatemala, El Salvador y Nicaragua con Cooperación Regional a Honduras, Costa Rica y Panamá

Soil characteristics identification of urban areas in San Salvador (El Salvador) using H/V spectral ratio technique

1 Introduction

The city of San Salvador (El Salvador) is threatened by a considerable seismic and volcanic activity mainly related to the subduction process between the Caribbean plate and the Cocos plate. The urban area of San Salvador is covered with sediments mainly coming from volcanic deposits. The growing urban development in combination with the high seismic hazard in the region stresses the importance of improving the knowledge on local subsol characteristics (sedimentary thicknesses H , shear wave velocities vs, predominant frequencies f_n) and the connected soil amplification potential. Therefore, in 2007, the Norwegian government funded a cooperation project focused on seismic risk reduction in Central America called RESIS II in which seismic microzonation works in the urban area of San Salvador was proposed.

Thereby, the local urban planning agency of San Salvador (OPAMSS) chose ten areas of 1 x 1 km² size within and around the capital city. The instrumental investigations were accomplished during daytime by using Lennartz LE-3D/5s seismometers in combination with portable 24-bit Nanometrics Taurus digitizers. In each of these investigation areas up to 12 recording sites were selected in order to identify also the spatial variability of subsol conditions within the area. Based on the application of the H/V spectral ratio technique and a hybrid site classification (Lang, 2004; Lang and Schwarz, 2006) predominant frequencies as well as estimates of sedimentary thicknesses H and shear wave velocities vs of the recording sites have been conducted.

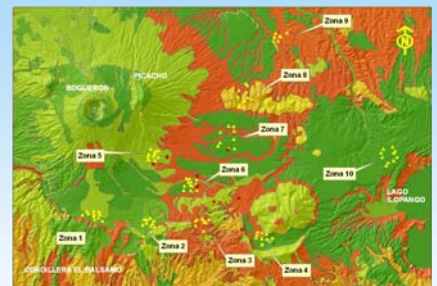
Using the soil classification scheme proposed by Bray and Rodríguez-Marek (1997) a classification of the sites into NEHRP soil classes (International Building Code, 1997) could be carried out. Here, NEHRP soil classes are further subdivided according to ranges of sedimentary thickness H .

The largest sedimentary depths were found in Zone 10 with soil thicknesses H greater than 200 m and shear wave velocities vs between 180 and 360 m/s. The results of the microzonation studies will further be applied in comprehensive seismic risk and loss assessment studies for the entire city of San Salvador.

2 The urban area : Local geology and selection of sites for noise measurement



The local urban planning agency of San Salvador (OPAMSS) selected the study areas in terms of physical and social vulnerability (e.g., population density) or which will be important for future urban development. Ten areas of approximately 1 km² were defined (Zona 1 to 10 in above figure) and between 6 and 10 points were selected for noise acquisition.

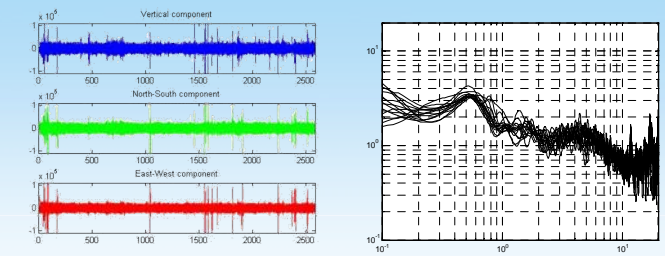


The geology of the urban area is mainly constituted from volcanic materials as can be seen from the geological map. Not many boreholes exists in the region. Some of the existing has been plotted as red points in the map, but the depth of the boreholes is always lower than 10 m, and only information on SPT numbers are available. Geology map provided by the research group of ANDES project <http://redgeomatica.rediris.es/andes/>.

3 Data acquisition and H/V analysis



In February 2008, the instrumental investigations were accomplished during daytime by using Lennartz LE-3D/5s seismometers in combination with portable 24-bit Nanometrics Taurus digitizers. The equipments were kindly provided by the Instituto Geografico Nacional (Madrid, SPAIN). Measurements were carried out in different types of conditions. In most cases the sensor was deployed in a hole dug into the soil and covered with a bucket in order to avoid wind influence. When no soil was available, the sensor was deployed mainly on concrete and also covered with the bucket. Sample frequency was fixed to 100 Hz and the temporal length of the measurement was 30 minutes.



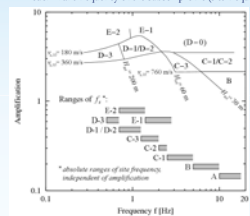
The recorded signal was subdivided in windows of 82 seconds and H/V was computed for each one of the windows, using the algorithm provided by Lang & Schwarz (2006). All the windows containing artificial noise affecting the H/V were removed from the analysis. Finally the H/V obtained from the chosen windows was averaged in order to compute the mean value and the standard deviation, which will be used to identify the predominant frequency of the soil column (Nakamura, 1989).

4 Soil classification using the H/V results

Following the procedure of Lang and Schwarz (2006), the soils were classified using the sub-categorization of NEHRP site classes (BSSC, 1995) according to ranges of sedimentary layer thickness as proposed by Bray and Rodríguez-Marek (1997).

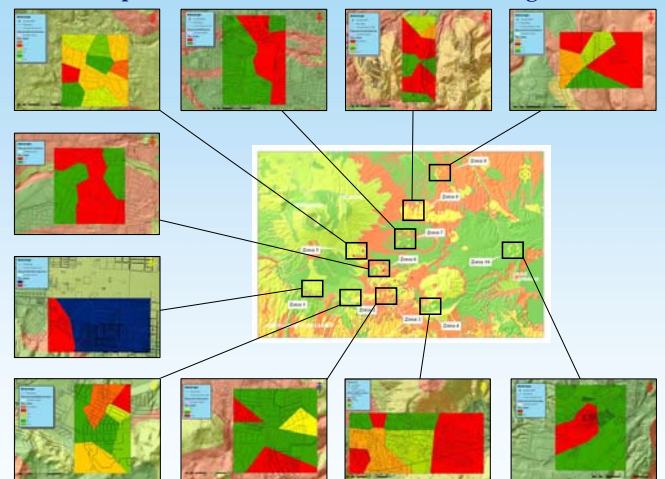
NEHRP site class	Soil Description	Range of shear wave velocity v_s (m/s)	Constraint on layer thickness H (m)	f_n (Hz)
A	Hard, strong, intact rock	$v_s > 1500$ m/s	-	0.10
B	Rock (most California rock cases)	$v_s > 900$ m/s or $H < 6$ m of soil	5.0	0.10
C-1	Well-sorted, clean sand	$v_s > 300$ m/s	$H < 6-30$ m	2.5
C-2	Shallow soft soil	$v_s > 300$ m/s	$H < 6-30$ m	2.0
C-3	Intermediate depth soft soil	$v_s > 300$ m/s	$H < 30-60$ m	1.25
D	Deep soft Holocene soil	$v_s > 180$ m/s	$H < 60-200$ m	0.7
D-1	Deep soft Pleistocene soil, other sand or clay	$v_s > 180$ m/s	$H < 60-200$ m	0.7
D-2	Deep soft Pleistocene soil, other sand or clay	$v_s > 180$ m/s	$H > 200$ m	0.7
E	Very deep soft soil	$v_s > 180$ m/s	Soft clay layer: $H < 3-12$ m	0.4
D-3	Deep soft soil layer	$v_s > 180$ m/s	$H > 12$ m	0.7
F	Special, e.g. potentially liquefiable sand or peat	see specific	see specific	0.1

* Refined NEHRP site classes according to Bray and Rodríguez-Marek (1997).
** Predominant frequency of the subsol profile (site frequency).



Qualitative ranges of possible peak locations of one-dimensional transfer functions for refined NEHRP site classes by Bray & Rodríguez-Marek (1997).

5 GIS implementation and zonation of results using Tesselation



6 Conclusions

- The use of ambient noise measurements and the application of the H/V spectral ratio technique has been shown as a useful method in order to obtain predominant site frequencies as well as to conduct a soil classification of the San Salvador metropolitan area (AMSS) into NEHRP soil classes.
- The instrumental results illustrate that the majority of the investigated areas are covered with soils of type C ($v_s = 360-760$ m/s) and D ($v_s = 180-360$ m/s), while the thickest sedimentary layers are found in Zone 10 (class D3).
- In principle, no borehole information is available which could be used to calibrate the instrumental results. The only information available consists of Standard Penetration Test (SPT) values down to 10 m soil depth. However, good correlations exist between the derived results and the local topography.
- Thiessen Polygons used to draw the equal soil area will be used as a first approximation in order to identify places where more detailed studies have to be conducted and will be used to select the soil type in the districts of the future seismic risk study evaluation.
- Finally all the results and compiled information have been implemented into a GIS (ArcGIS) which will allow the local agency (OPAMSS) to take better future decision about urban planning and which will be also updated with future studies.

References

Bray, J.D., and A. Rodríguez-Marek (1997). Geotechnical site categories, Proceedings of the First PEER PG&E Workshop on Seismic Reliability of Utility Lifelines, San Francisco/California, 1997.

Building Seismic Safety Council BSSC (1995). NEHRP recommended provisions for seismic regulations for new buildings, FEMA 223A/223A, Vol. 1 (Provisions) and Vol. 2 (Commentary), developed for the Federal Emergency Management Agency, Washington, D.C.

International Conference of Building Officials ICBO (1997). Uniform Building Code (1997-UBC). Whittier/CA, United States of America, 1997, 492 pp.

Lang, D.H. (2004). Damage potential of seismic ground motion considering local site effects, Scientific technical reports 1 (ISBN 3-86068-227-X). Dissertation. Earthquake Damage Analysis Center, Bauhaus-University Weimar, 2004, 293 pp.

Lang, D.H. and J. Schwarz (2006). Instrumental subsol classification of Californian strong motion sites based on single-station measurements. Proceedings of the 8th U.S. National Conference on Earthquake Engineering, San Francisco, United States, 2006.

Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface, QR of RTRI 30 (1), February 1989.

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