Preliminary Soil Characterization of the Most Affected Coastal Villages after the 16 April 2016 Mw 7.8 Pedernales Earthquake, Ecuador

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1. Introduction.-

On April 16, 2016, a large part of the Ecuadorian coast was shacked by an Mw7.8 earthquake, affecting nearly 30,000 homes and public buildings. Understanding soil characteristics of these affected areas is a necessary and useful aid to reconstruction efforts. To this end, the Instituto Geofísico at the Escuela Politécnica Nacional (IG-EPN) undertook data collection work with the aim of generating a reliable and freely accessible database consisting of dynamic soil characteristics for eigth villages located in the provinces of Manabí and Esmeraldas (Ecuador, Figure 1). The study consisted in the installation of seismic station arrays for approximately **7 days** in each village, during which time various **measurements of ambient noise** and **seismic profiles** were made. Here we employ various methods to assess soil characteristics, including: single-sensor horizontal over vertical component **(H/V)** spectral ratios, relative spectral ratios at various sites of interest with respect to a reference site **(SSR)**, and linear arrays for multi-channel analysis of surface waves **(MASW)**. These experiments were conducted within the **first six months after the earthquake** (Figure 2).

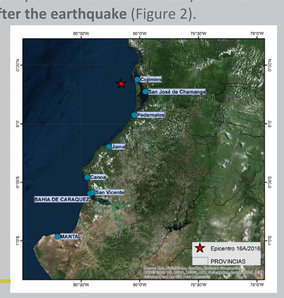


Figure 1: Map of the villages for which the study was conducted.

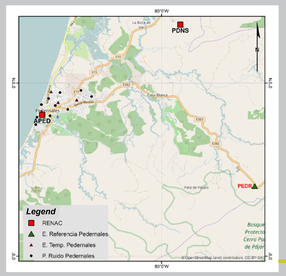


Figure 2: Example of the Pedernales village: Location of temporary stations and ambient noise measurements.

2. Methodology.-

The fundamental soil frequency, and shear wave velocity profiles for the populations that were part of the study were all obtained. These parameters then allow us to identify which zones share similar dynamics characteristics, which we then **correlate with the Ecuadorian Construction Norms (NEC-15) to determine the soil type** (Table 1 and 2).

Tipo de perfil	Descripción	Definición
A	Perfil de roca competente	Vs ≥ 1500 m/s
B	Perfil de roca de rigidez media	1500 m/s > Vs ≥ 760 m/s
C	Perfiles de suelo muy densos o roca blanda, que cumplan con el criterio de velocidad de la onda de corte o	760 m/s > Vs ≥ 360 m/s
	Perfiles de suelo muy densos o roca blanda, que cumplan con cualquiera de los dos criterios	N ≥ 50, Su ≥ 100KPa
D	Perfiles de suelo rígidos, que cumplan con el criterio de velocidad de la onda de corte o	360 m/s > Vs ≥ 180 m/s
	Perfiles de suelo rígidos, que cumplan con cualquiera de los dos criterios	50 > N ≥ 15, 100KPa > Su ≥ 50 KPa
E	Perfil que cumplan con el criterio de velocidad de la onda de corte o	Vs < 180 m/s
	Perfil que contiene un espesor total H mayor de 3 m de arcillas blandas	IP > 20, w ≥ 40%, Su < 50KPa
F	Los perfiles de suelo tipo F requieren una evaluación realizada explícitamente en el sitio por un ingeniero geotécnista	

Table 1: The different soil types in the NEC-SE-DS in section 3.2. N corresponds to the hit number with SPT-type investigation; Su: Not drained cutting resistance; IP: Plasticity index; w: water content in%.

$$f_0 = \frac{V_{S_{30}}}{4H_{30}}$$

Tipo de perfil	Velocidad onda de corte	Frecuencia fundamental
A	Vs ≥ 1500 m/s	f0 ≥ 12.5 Hz
B	1500 m/s > Vs ≥ 760 m/s	12.5 Hz > f0 ≥ 6.33 Hz
C	760 m/s > Vs ≥ 360 m/s	6.33 Hz > f0 ≥ 3.0 Hz
D	360 m/s > Vs ≥ 180 m/s	3.0 Hz > f0 ≥ 1.5 Hz
E	Vs < 180 m/s	f0 < 1.5 Hz

Table 2: Proposal for classification of Ecuadorian soils.

3. Results.-

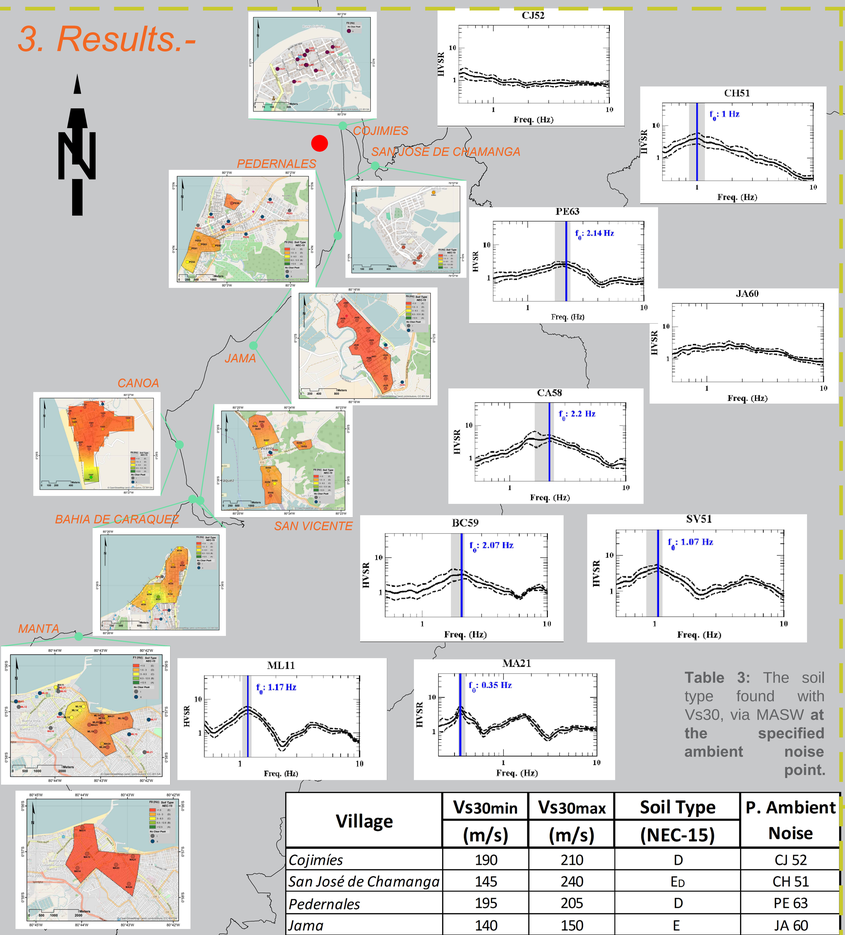
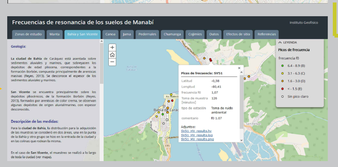


Table 3: The soil type found with Vs30, via MASW **at the specified ambient noise point.**

Village	Vs30min (m/s)	Vs30max (m/s)	Soil Type (NEC-15)	P. Ambient Noise
Cojimíes	190	210	D	CJ 52
San José de Chamanga	145	240	E_D	CH 51
Pedernales	195	205	D	PE 63
Jama	140	150	E	JA 60
Canoa	X	X	X	CA 58, 59
San Vicente	X	X	X	SV 51, 52
Bahía de Caráquez	220	235	D	BC 59
Manta	180	240	D_E	ML 11

The dispersion curves used to obtain the velocity profiles of the share wave were obtained using the multichannel analysis surface waves.

4. Web Resources.-



Figures web resources: Database collected, and freely accessible in: **www.igepn.edu.ec**

5. Conclusions.-

1. Most of the cities studied showed considerable damage in the April 16 earthquake, as indicated by the intensity assigned (Table 4).

   One of the factors for the assigned intensity grade can be understood with the average values obtained for Vs30; which, in this case is indicative of soft soils (Soil type E or D).

2. Preliminary soil characterization by means of resonance frequencies (f0) is an easy and reliable method to use, especially in soft soils.

Village	Intensity (EMS)	$Vs30_{pro}$ (m/s)
Cojimíes	6	200
San José de Chamanga	9	193
Pedernales	9	200
Jama	8-9	145
Canoa	8-9	X
San Vicente	*6*	X
Bahía de Caráquez	8	228
Manta	8-9	210

Table 4: Intensities of Singaucho et al. (2018). Observations of the 2016 Pedernales earthquake. Macroseismic Intensities. Article in preparation.

Village	Soil Type (Vs30-MASW)	Soil Type (f0)	Comparison
Cojimíes	D	*ND*	*ND*
San José de Chamanga	E_D	E	Aprox.
Pedernales	D	D	OK
Jama	E	*ND*	*ND*
Canoa	*ND*	D	*ND*
San Vicente	*ND*	E	*ND*
Bahía de Caráquez	D	D	OK
Manta	D_E	E	Aprox.

Table 5: Comparison between the soil type found with fo and Vs30; ND: Undetermined.

6. References.-

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7. Future work.-

* To realize the standart spectral ratio (SSR) at each village.
* Re-processing some ambient noise points.
* To repeat some measurements ambient noise and seismic profiles.
* To find the transfer fuction.