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# $V_S$ PROFILE DATABASE AND PROXY-BASED MODEL FOR $V_{S30}$ PREDICTION IN CHILE FOR NGA-SUBDUCTION

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## ABSTRACT

A major component of the Next-Generation Attenuation Subduction (NGA-Sub) project is the development of a database that compiles source data, ground motion data, and data from earthquake recording sites in subduction regions around the world. This paper describes work undertaken to assign site parameters for ground motion recording stations in Chile for the NGA-Sub project. The primary site parameter required for NGA-Sub model development is the time-averaged shear wave velocity in the upper 30 m, or  $V_{S30}$ . This work has two major tasks: (1) develop a database of shear-wave velocity profiles in Chile, whether they are at ground motion recording stations or not; (2) use the available data to either validate the use in Chile of a proxy-based  $V_{S30}$  prediction model developed for another region, or to develop a Chile-specific model. For Task 1, we have compiled geotechnical data for locations where shear-wave velocity profiles and associated  $V_{S30}$  values were measured with geophysical methods. The various velocity data sources include a compilation of more than 1,100 measured  $V_S$  profiles. Task 2 provides a proxy-based model for  $V_{S30}$  prediction, needed for the stations without in situ  $V_{S30}$  measurements. Work to date is based on a proxy-based model based on geomorphic terrain classes and follows an approach applied previously in other regions, in which a natural log mean and standard deviation is assigned for up to 16 terrain classes. We find a Chile-specific model is warranted by the data, and demonstrate regional effects based on site location in an arid region in north Chile (*Norte Grande* and *Norte Chico*) versus more fertile regions to the south. Using data where available and proxies where needed, we provide estimates of natural log means and standard deviations of  $V_{S30}$  for NGA-Sub recording stations in Chile.

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# $V_S$ profile database and proxy-based model for $V_{S30}$ prediction in Chile for NGA-Subduction

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## ABSTRACT

A major component of the Next-Generation Attenuation Subduction (NGA-Sub) project is the development of a database that compiles source data, ground motion data, and data from earthquake recording sites in subduction regions around the world. This paper describes work undertaken to assign site parameters for ground motion recording stations in Chile for the NGA-Sub project. The primary site parameter required for NGA-Sub model development is the time-averaged shear wave velocity in the upper 30 m, or  $V_{S30}$ . This work has two major tasks: (1) develop a database of shear-wave velocity profiles in Chile, whether they are at ground motion recording stations or not; (2) use the available data to either validate the use in Chile of a proxy-based  $V_{S30}$  prediction model developed for another region, or to develop a Chile-specific model. For Task 1, we have compiled geotechnical data for locations where shear-wave velocity profiles and associated  $V_{S30}$  values were measured with geophysical methods. The various velocity data sources include a compilation of more than 1,100 measured  $V_S$  profiles. Task 2 provides a proxy-based model for  $V_{S30}$  prediction, needed for the stations without in situ  $V_{S30}$  measurements. Work to date is based on a proxy-based model based on geomorphic terrain classes and follows an approach applied previously in other regions, in which a natural log mean and standard deviation is assigned for up to 16 terrain classes. We find a Chile-specific model is warranted by the data, and demonstrate regional effects based on site location in an arid region in north Chile (Norte Grande and Norte Chico) versus more fertile regions to the south. Using data where available and proxies where needed, we provide estimates of natural log means and standard deviations of  $V_{S30}$  for NGA-Sub recording stations in Chile.

## Introduction

The Next-Generation Attenuation (NGA) projects provide uniformly-processed ground motion data and supporting metadata related to source, path, and site parameters for earthquakes recorded in different tectonic settings and regions around the world. Currently, the Pacific Earthquake Engineering Research Center (PEER) is conducting the NGA-Subduction project (NGA-Sub), which is a major multi-year international project to develop database resources and ground motion models for subduction-zone earthquakes. The regions for which these efforts

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have primarily been focused include the Pacific Northwest (PNW) and Alaska regions of North America, and Japan, Taiwan, Mexico, New Zealand, and much of Central and South America. An overview of the NGA-Sub project and the description of the NGA-Sub ground motion database are presented in companion papers [1] and [2], respectively. Chile exists along an active seismogenic margin, where the primary tectonic interaction is the subduction of the oceanic Nazca plate beneath the continental South American plate. This convergence has created two main orogenic belts: the volcanic Andes Mountains and the Chilean Coastal Cordillera, with coastal plains and tectonic basins distributed along an intermediate depression spanning the much of the length of the country.

This paper describes work undertaken to assign site parameters for ground motion recording stations in Chile for the NGA-Sub project. The primary site parameter needed for NGA-Sub model development is  $V_{S30}$ , or the time-averaged shear wave velocity in the upper 30 m. This work has two major tasks: (1) develop a database of shear wave velocity profiles in Chile, whether they are at ground motion recording stations or not; (2) use the available data to either validate the use in Chile of a proxy-based  $V_{S30}$  prediction model developed for another region, or to develop a Chile-specific model. Work to date has focused on the development of a geomorphic terrain class-based proxy model, and future work will investigate the effects of surficial geology and topographic slope on  $V_{S30}$ , among other potential predictor variables.

### **$V_S$ Profile Database for Chile**

For Task 1, we have compiled geotechnical data for locations where shear-wave velocity profiles and associated  $V_{S30}$  values were measured with various geophysical methods. A majority (approximately 97%) of the profiles were derived from active and passive surface-wave methods, with additional profiles derived from body-wave and downhole methods. The various velocity data sources include a compilation of more than 1,100 measured  $V_S$  profiles from a database contributed mostly by the second author and various research reports and papers presenting profiles measured at recordings stations [3,4]. Fig. 1 shows the location of the profile database sites with differentiation by  $V_{S30}$  values. Most measurements are located in central Chile, which might provide sampling bias considering the expected differences in soil characteristics in the arid region in north Chile encompassing *Norte Grande* and *Norte Chico* versus more fertile regions to the south. Fig. 1 also shows a histogram of  $V_{S30}$  values which illustrates the concentration of data at values near 500 m/s, typical of medium to stiff soils.

In all, we have approximately 100 recording stations with measured profiles, most of which are derived using surface-wave methods. This represents only 25% of the total number of ground motion stations in Chile contributing data to NGA-Sub, which highlights the need of having a method for estimating  $V_{S30}$  for the stations without in situ measurements.

### **Proxy-Based Model for $V_{S30}$ Prediction**

Task 2 is used to provide a proxy-based model for  $V_{S30}$  prediction. Such a model is needed for the approximately 300 stations in Chile that lack in situ  $V_{S30}$  measurements. We have considered proxies based on secondary information such as surficial geology, topographic slope, and geomorphic terrain classes. However, work to date is based on terrain classes and follows an

approach applied previously in California, the Pacific North West (PNW), Taiwan, and Japan, in which a natural log mean and standard deviation is assigned for up to 16 terrain classes. We have utilized the geomorphic terrain classes defined from digital elevation models (DEM) by Iwahashi and Pike (2007, IP07) [5] on the basis of slope gradient and metrics of convexity and texture. Future work will investigate the effects of surficial geology and topographic slope on  $V_{S30}$ , among other potential predictor variables.

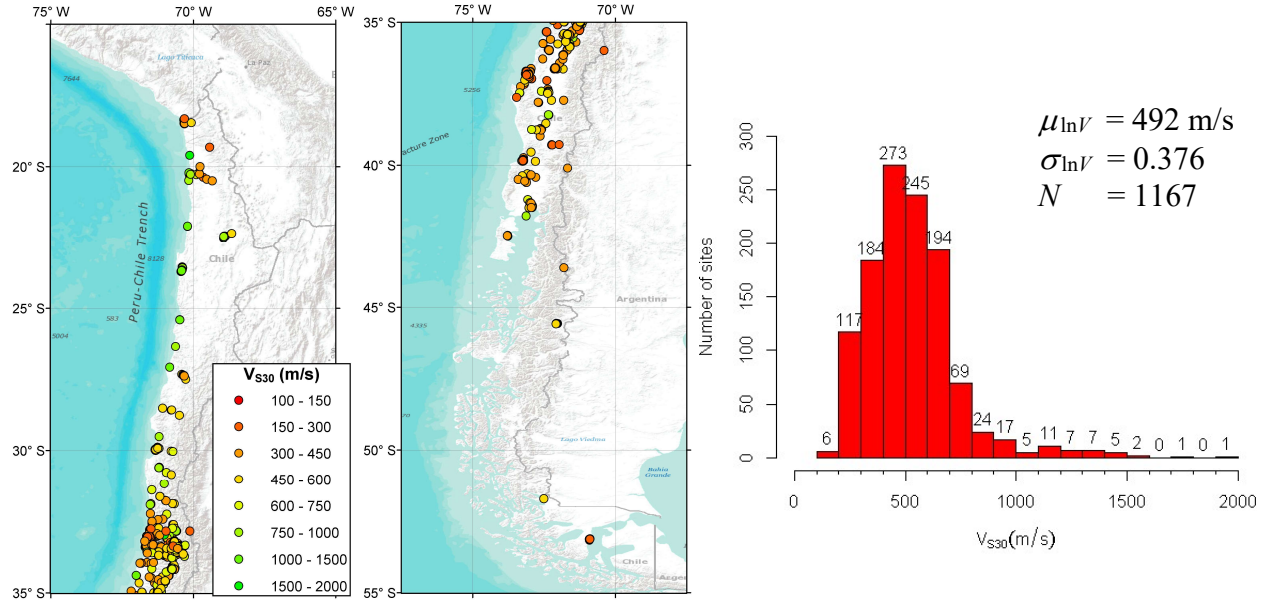


Figure 1. Left: Map of Chile showing the geographical distribution of the profile database sites; Right: Histogram of the  $V_{S30}$  values for all the sites in the profile database. Mean  $V_{S30}$  ( $\mu_{\ln V}$ ), standard deviation of  $V_{S30}$  in natural log units ( $\sigma_{\ln V}$ ), and number of sites ( $N$ ) are indicated.

Fig. 2 presents the distribution of the profile database sites within the 16 IP07 terrain classes. This figure also shows a comparison of our results with previous studies in California (Yong 2016, Y16) [6] and the PNW (Ahdi et al. 2017, AEA17) [7]. For most terrain classes, the 95% confidence interval on the natural log mean of  $V_{S30}$  for Chilean data does not encompass the means from these other regions. As a result, we conclude that a Chile-specific model is warranted. Data from IP07 terrain classes 2 and 14 have been excluded from the analysis due to the limited number of sites within these classes.

Chile extends more than 4000 km in a north-south orientation and spans a wide array of climates and geomorphologies. Arid climates generally produce stiffer soil deposits near the ground surface due to processes such as soil cementation (with calcium carbonate) and high-energy debris flows generating denser alluvial fan deposits. To test the hypothesis of regional effects in the arid region (*Norte Grande* and *Norte Chico*) versus other southern regions in Chile, we have divided the profile database into Northern Chile and Southern Chile, as shown in Fig. 3, for IP07 terrain classes 3, 7, and 11. The geographic limit was set at 32°S based on the contrast between the climates of these regions. We find the regional effect to be statistically significant based on the bias of the residuals, with slower velocities within these terrain classes in the south. These trends were also observed for terrain classes 4 and 8 as shown in Table 1. The data for

other terrain classes were too limited in number to investigate regional effects.

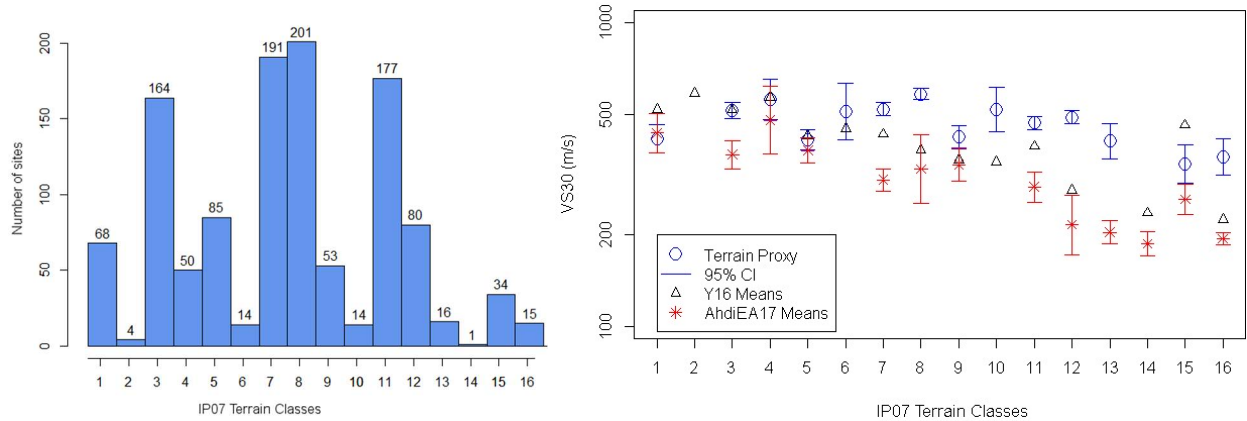


Figure 2. Left: Distribution of the profile database sites within the terrain classes defined by IP07; Right: Mean  $V_{S30}$  values (with confidence intervals) for each terrain class obtained from the profile database (in blue) and as given by Y16 and AEA17.

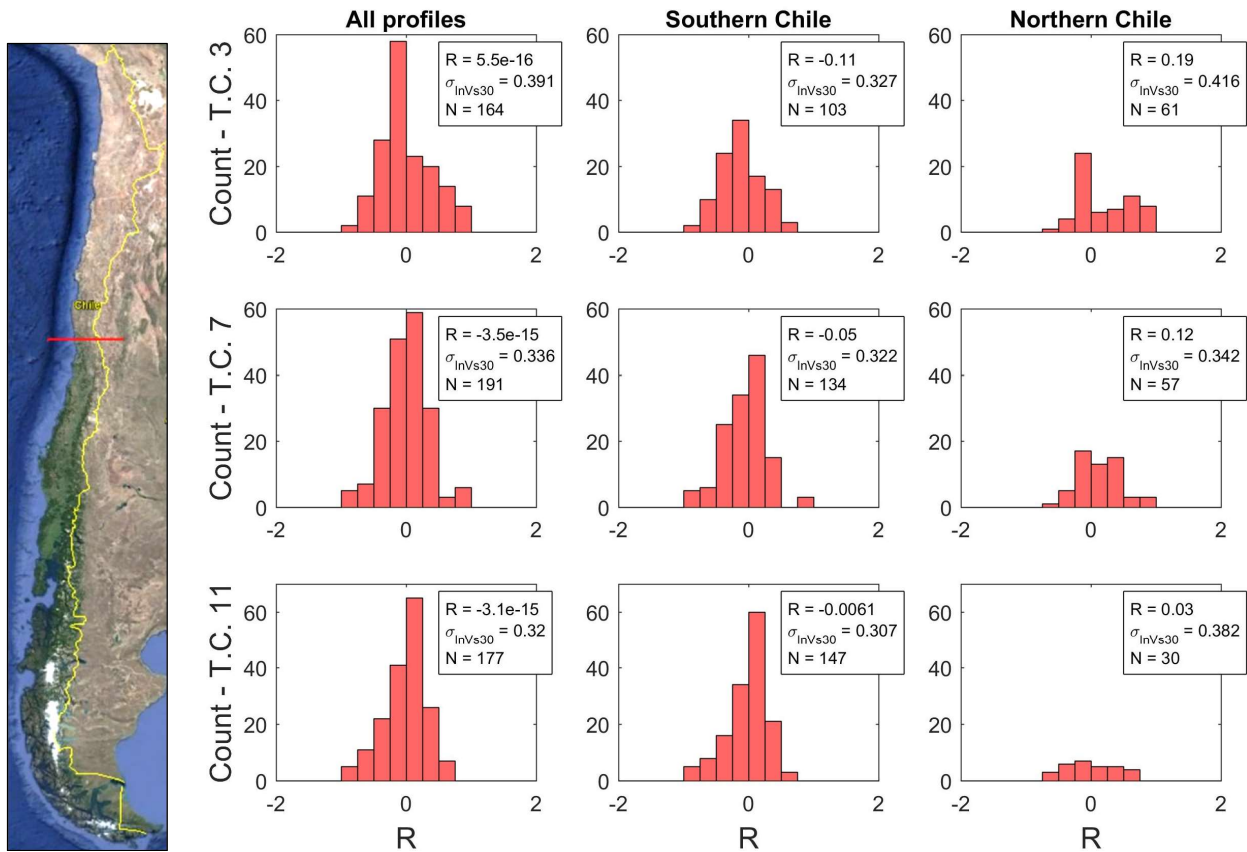


Figure 3. Left: Map of Chile showing the geographic limit that defines the two regions analyzed (Northern and Southern Chile); Right: Residual analysis of terrain classes 3, 7 and 11 for testing regional effects.

Table 1 shows summary statistics and our recommendations for  $V_{S30}$  moments for each terrain class. In some cases, we group terrain classes when the terrain descriptions are similar and the average velocities are also similar. This applies in three cases shown in Table 1. We recommend using the values in the “Regional Effects” columns when applicable; otherwise, values in the columns labelled “All Sites” should be used.

Table 1. Summary of terrain class-based proxy for  $V_{S30}$  in Chile (NA = not applicable).

Terrain Class	Number of Sites			All Sites		Regional Effects*			
	Total	North	South	$V_{S30}$ (m/s)	$\sigma_{\ln V_{S30}}$	Northern Sites		Southern Sites	
						$V_{S30}$ (m/s)	$\sigma_{\ln V_{S30}}$	$V_{S30}$ (m/s)	$\sigma_{\ln V_{S30}}$
<b>1</b>	68	5	63	415	0.451	NA	NA	NA	NA
<b>2</b>	4	4	0	NA	NA	NA	NA	NA	NA
<b>3, 7</b>	355	118	237	517	0.362	605	0.382	479	0.325
<b>4</b>	50	15	35	559	0.546	1087	0.428	421	0.274
<b>5, 9, 13</b>	154	2	152	414	0.342	NA	NA	NA	NA
<b>6, 10</b>	28	1	27	515	0.362	NA	NA	NA	NA
<b>8</b>	201	15	186	583	0.293	745	0.497	571	0.262
<b>11</b>	177	30	147	467	0.32	482	0.382	465	0.307
<b>12</b>	80	1	79	489	0.213	NA	NA	NA	NA
<b>14</b>	1	0	1	NA	NA	NA	NA	583	NA
<b>15</b>	34	0	34	343	0.426	NA	NA	NA	NA
<b>16</b>	15	4	11	362	0.267	NA	NA	NA	NA

\*The model considering regional effects is only applicable for well-populated terrain classes, i.e. having a statistically significant number of sites.

### Conclusions

We present a  $V_S$  profile database for Chile and the development of a preliminary proxy for estimating natural log mean  $V_{S30}$  and its standard deviation conditional on geomorphic terrain class and geographic location. Future work will seek to develop models based on surface geology and topographic slope, as justified by the data. This information is being used in the NGA-Sub database [2].

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