UCLA
Earthquake Engineering

Title
NGA-Subduction site database

Permalink
https://escholarship.org/uc/item/9m8075g1

Authors
Ahdi, Sean K
Ancheta, Timothy D
Contreras, Victor
et al.

Publication Date
2017-01-09

NGA-SUBDUCTION SITE DATABASE

S.K. Ahdi[1], T.D. Ancheta[2], V. Contreras[3], T. Kishida[4], D.Y. Kwak[5], A.O. Kwok[6], G.A. Parker[7], Y. Bozorgnia[8], J.P. Stewart[9]

[1] *Graduate Student, Civil & Environmental Engineering Department, University of California, Los Angeles, USA, sahdi@ucla.edu*
[2] *Modeler, Risk Management Solutions, Inc., tim.ancheta@rms.com*
[3] *Graduate Student, Civil & Environmental Engineering Department, UCLA, USA, vcontreras@ucla.edu*
[4] *Assistant Project Scientist, University of California, Berkeley, USA, tkishida@berkeley.edu*
[5] *Postdoctoral Scholar, Civil & Environmental Engineering Department, UCLA, USA, dykwak@seas.ucla.edu*
[6] *Assistant Professor, National Taiwan University, Taiwan, annieonleikwok@ntu.edu.tw*
[7] *Graduate Student, Civil & Environmental Engineering Department, UCLA, USA, parker@seas.ucla.edu*
[8] *Professor in Residence, University of California, Berkeley, USA, yousef@berkeley.edu*
[9] *Professor and Chair, Civil & Environmental Engineering Department, UCLA, USA, jstewart@seas.ucla.edu*

Abstract

The NGA-Subduction site database, which is currently in development, contains information on site condition and instrument housing for 5520 strong motion stations with recordings that are being used for ground motion model development. The stations are from coastal and inland regions that have recorded subduction zone earthquakes (both interface and intra-slab), mostly in Japan, Taiwan, South America, and the Pacific Northwest and Alaska regions of North America. The principal site parameter is the time-averaged shear wave velocity in the upper 30 m (V_{S30}), which we characterize using geophysical measurements where available (approximately 2486 stations to date) and proxy-based relationships otherwise. A secondary site parameter is basin depth, measured both to the 1.0 and 2.5 km/s shear-wave velocity horizons. Here we document the geophysical data sources that have been leveraged in this process and regional considerations regarding the use of proxies to estimate V_{S30}. We also describe data sources for basin depth and the protocols for assigning V_{S30} and its uncertainty to strong motion recording sites.

Keywords: Shear-wave velocity, site effects, ground motions, subduction zones

1. Introduction

NGA-Subduction is a large multidisciplinary, multi-year research program to develop database resources and ground motion models (GMMs) for subduction-zone earthquakes. Coordinated by the Pacific Earthquake Engineering Research (PEER) Center, the project entails extensive technical interactions among many individuals and organizations from around the world. The database effort is focusing on the synthesis of recordings and supporting source, path, and site metadata. The broader data collection and synthesis effort is described in the companion paper by Kishida et al. [1]. This paper focuses on development of the site database, which is needed to evaluate site effects in the development of GMMs and possible regional variations in site terms.

The major data categories contained in the site database are as follows:

- Station data including location, name, identification numbers, and housing.

- Recommended V_{S30} (time-averaged shear-wave velocity in upper 30 m), codes identifying the basis for the recommendations, and σ_{lnV} (natural log standard deviation of V_{S30}).

- Details related to V_s measurements, including data sources and profile depths (z_p).

- Proxies used to estimate of V_{S30} in the absence of geophysical data. The type of proxies used varies by region, as described further below.

- Basin depths from direct measurement where available or from models for Japan and portions of the Pacific Northwest. Depths are taken as the distance from the surface to shear wave horizons at 1.0 and 2.5 km/s ($z_{1.0}$, and $z_{2.5}$, respectively).

Figure 1 shows the regions covered by the project, which include Japan, Taiwan, Pacific Northwest (PNW) and Alaska in the United States, and Central and South America. The current working version of the site database contains information on 5520 recording stations. We have estimated or measured V_{S30} for 4322 of these stations thus far. Of the 4322 V_{S30} values, 2486 (58%) are based on geophysical measurements, with the remainder estimated by proxy techniques described subsequently. The breakdown by region of sites having V_{S30} assignments to-date is shown in Figure 2.
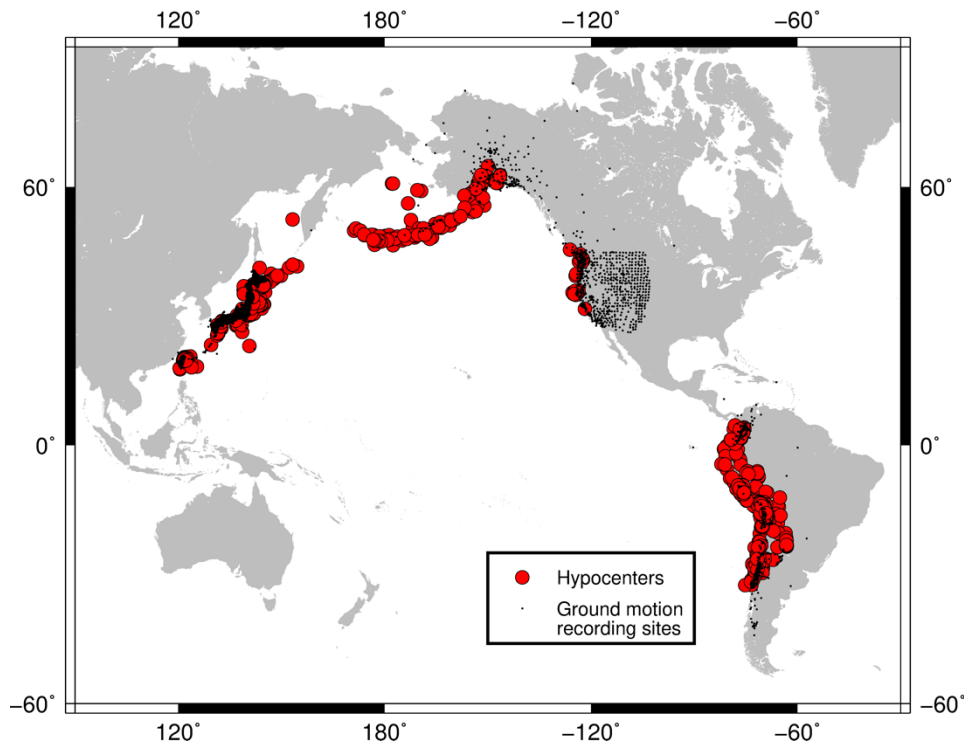
Fig. 1 – Global map showing NGA-Subduction hypocenters and ground motion recording sites.

Subsequent sections of this paper describe data sources for V_S measurements, some considerations related to V_{S30} estimation by proxy, resources for extracting basin depth parameters in the study regions, and an application section that includes protocols for V_{S30} assignments to strong motion recording sites.
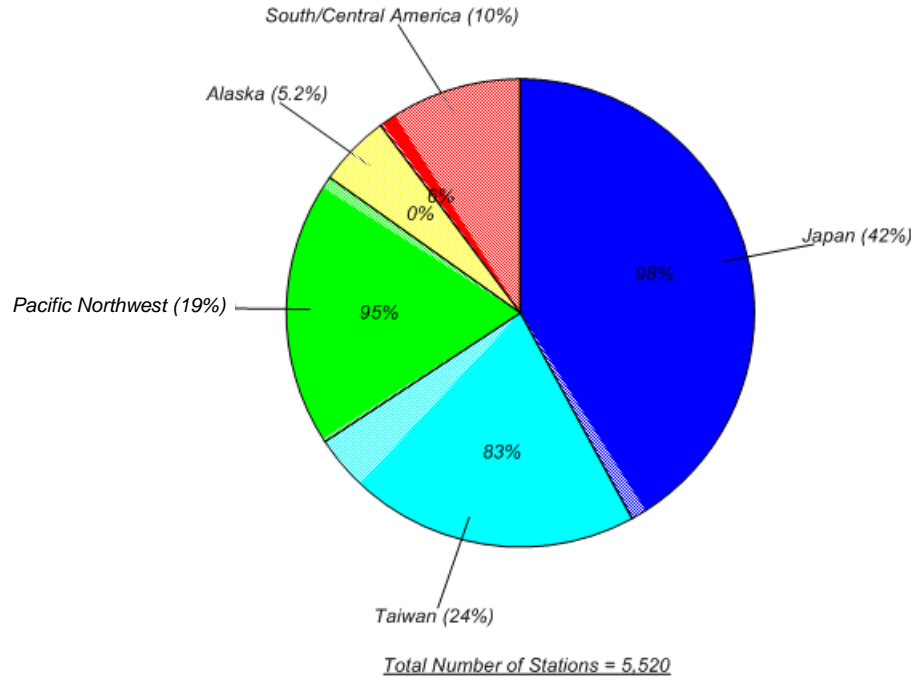

Fig. 2 – Regional distribution of the number of stations in the NGA-Subduction database. Darker color shades correspond to the percentage of sites that have been assigned a V_{S30} value (by measurement or proxy) to date.

2. Measurement-Based Shear-Wave Velocity Data Sources

In Japan, all of the V_S profiles obtained for this work are from strong motion recording sites within the K-NET and KiK-Net arrays ([2]; http://www.kyoshin.bosai.go.jp) and PARI array ([3]; http://www.eq.pari.go.jp/kyosin/). There are 1667 profiles with profile depths ≥ 10 m. In the K-NET array, typical profile depths are 10-20 m, whereas for KiK-Net and PARI these are 100-200 m and < 200 m, respectively. If geotechnical investigations (e.g., SPT or CPT) at a site are available but geophysical investigations are not, models correlating V_S with penetration resistance and effective stress are used to estimate V_S data. This method is applied to 42 sites of the PARI array in Japan.

In Taiwan, the available V_S profiles are again entirely from locations of strong motion recording sites owned and maintained by the National Center for Research in Earthquake Engineering (NCREE) or the Central Weather Bureau (CWB). There are 451 profiles with depths > 10 m, with the most typical depth being approximately 30 m. The measurements were made using suspension logging methods [4]. All V_S data is available at http://egdt.ncree. org.tw/, and digital versions of these profiles were provided by Dr. C.-H. Kuo [5] for the present work.

In the Pacific Northwest and Alaska regions of the U.S., 1016 V_S profiles have been compiled from a variety of sources [6]. Only 104 of these are co-located with strong motion recording instruments, with 77 of these measured to a depth of 30 m or greater. Compilation of V_S profiles for sites other than strong motion recording sites is of interest for the development of proxy-based V_{S30} estimation procedures, as discussed further in Section 3.0. Profile depths range from 5 to 457 m, with an average depth of about 44 m. A number of major data sources are used [7, 8, 9, 10, 11, 12, 13, 14, 15,16], which encompass a variety of down-hole, cross-hole, and surface wave techniques used in these investigations.

The available data from South America is limited at present to a single study measuring 31 V_S profiles at Chilean strong motion recording sites [17]. Further information is being compiled principally by the third author in collaboration with colleagues at the University of Chile (R. Boroschek).

In cases where V_S profiles extend to depths < 30 m, the time-averaged velocity to the profile depth is computed (V_{SZ}), which is then used with z_p to estimate V_{S30} using methods by Dai et al. [18] (Japan), Kuo et al. [4] (Taiwan), and Boore [19] (Pacific Northwest). Additional methods to extrapolate V_{SZ} to V_{S30} will be investigated for the PNW data.

The distributions of V_{S30} values from strong motion recording sites in the site database derived from measurements and proxy-based assignments is shown in Figure 3. Note the paucity of firmer sites: only 192 sites have V_{S30} > 760 m/s. This means that the V_{S30}-scaling ultimately derived as part of NGA-Subduction site terms will likely be poorly constrained for fast sites.
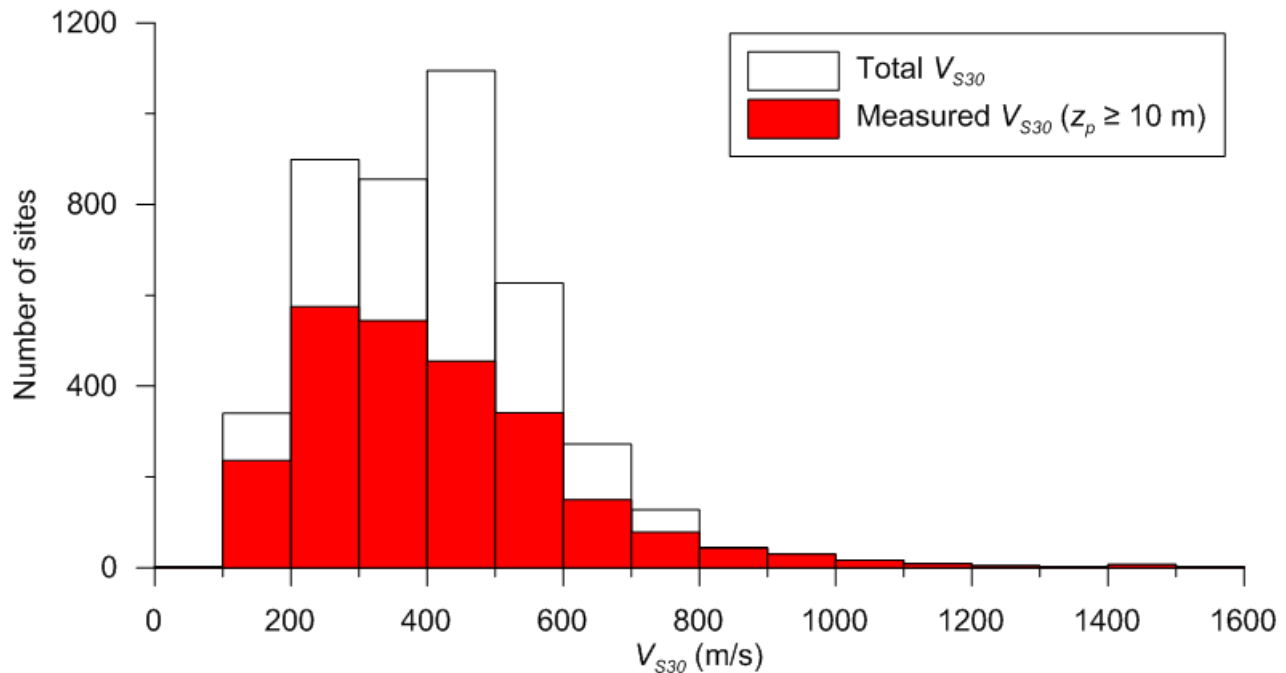

Fig. 3 – Histogram showing V_{S30} values (by measurement or proxy) at all sites in database to date.

3. Estimation of V_{S30} by Proxy

The development of proxy-based methods for estimation of V_{S30} is highly variable across the study regions. Our view is that region-specific models are needed due to the significant variability in geological conditions. The development of these methods is crucial to the project, because globally only 58% of the recording sites have a measurement-based V_{S30} (with a far lower percentage in some critical regions, including the PNW and Chile).

Table 1 summarizes the proxy-based methods considered in this study, which is organized by region. For each region, proxies not selected for use are in grey font, as indicated in the table caption. For Japan we have used proxy relationships in the literature. For Taiwan and the Pacific Northwest, we have developed new V_{S30} prediction equations based on surface geology from local (large-scale) maps in combination with ground slope and other parameters. The details of these proxy-based methods are as yet unpublished, and are referred to in Table 1 as 'this study'. For those regions, we have also adapted a geomorphic terrain classification scheme [20], previously used for V_{S30} estimation in California [21, 22], for the local conditions. Some categories retain the California-based values, while other categories are customized based on within-category natural log means derived using V_{S30} data from the target region. For Alaska, due to a paucity of V_S profile data, we apply geology-based classifications for the Pacific Northwest. Prediction equations for V_{S30} in Chile and other regions of central and South America remain under development as of this writing.

Table 1 – Regional proxy-based methods for estimating V_{S30} (un-selected methods in grey)

Region	Proxies Considered	No of Groups	References	Description/Notes
PNW	Surface Geology and Slope	17	*This study*	Surface geology from maps at largest available scale, ranging from 1:24,000 to 1:250,000. 30 arc-sec slope.
	Terrain Categories	16	*Iwahashi and Pike [20], Yong et al. [21], Yong [22], Customized for PNW in this study*	Surface morphology categorized by slope gradient, local convexity, and surface texture. DEM at 1 km grid spacing.
Taiwan	Surface Geology, Slope, Elevation	3	*This study*	Surface geology classified according to 1:50,000-scale maps (where available; otherwise 1:250,000). 30 arc-sec slope.
	Terrain Categories	16	*See PNW. Customized for Taiwan in this study*	See PNW.
	Geomatrix 3rd letter	5	Chiou et al. [23]; Seyhan et al. [24]	Geotechnical site categories.
Japan	Geomorphic/Geologic maps (JEGM)	22	*Matsuoka et al. [25]* *Matsuoka & Wakamatsu [26]* *Wakamatsu & Matsuoka [27]*	National geomorphic/geologic maps digitized at 7.5 arcsec. V_{S30} predicted from JEGM category, slope gradient, elevation, and distance from mountain/hill.
	Terrain Categories	16	*See PNW. Customized for Japan in this study*	See PNW.
	Geomatrix 3rd letter	5	*See Taiwan*	Geotechnical site categories.
Global	Topographic Slope	8	Wald & Allen [28]; Allen and Wald [29]	30 arcsec slope

An issue that we have considered in deciding upon the region-specific relationships in Table 1 is the degree of correlation of the V_{S30} predictions. This is important when there are many possible prediction relationships, such as Japan. This correlation is computed from the residuals of the predictions, computed as:

$$R_i = \ln\left(V_{S30}\right)_i - \overline{\ln\left(V_{S30}\right)}_{(proxy,i)} \qquad (1)$$

where $\ln\left(V_{S30}\right)_i$ is the measurement-based V_{S30} for site i and $\overline{\ln\left(V_{S30}\right)}_{(proxy,i)}$ is the proxy-based estimate for site i (the overbar indicates that we take the mean in natural log units). The standard deviation of residuals is denoted σ_{lnV}. Figure 4 shows examples of relatively weakly and strongly correlated residuals using data from Japan. Ideally, selected proxy relationships should be uncorrelated (or weakly correlated) with each other, so that the predictions are as distinct as possible. We generally find weak correlations between predictions derived from surface geology and those derived from proxies associated with surface morphology (terrain/slope), strong correlations among metrics derived from surface morphology, and strong correlation between morphology and geotechnical proxies. These correlations studies have thus far been completed only for Japan.
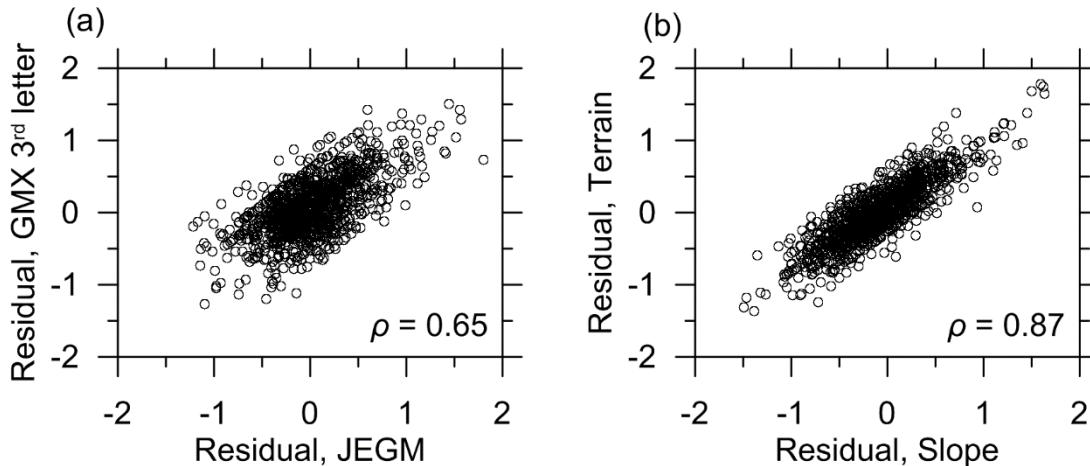

Fig. 4 – Correlations of residuals from proxy-based V_{S30} estimates using data from Japan. (a) example of relatively modest correlation using geotechnical- and geology-based proxies; (b) example of strong correlation using terrain- and slope-based proxies.

4. Basin Depth

The basin depth parameter z_x is the depth to a shear-wave isosurface having $V_S = x$ km/s. The site database will include basin depth using parameters $z_{1.0}$ and $z_{2.5}$, which define the depth in meters to shear-wave velocities of 1.0 and 2.5 km/s, respectively. These depth parameters are established from published three-dimensional models except for sites having V_S profiles that penetrate the velocity horizon, in which case we use the site-specific value.

The regions for which basin depth parameters are expected to ultimately be provided are Japan, portions of Taiwan, and portions of the Pacific Northwest. The Japan models are presented by Fujiwara et al. [30, 31] and cover depths for $x = 0.35$ to 3.0 km. The depth parameters are provided at http://www.j-shis.bosai.go.jp/en/. In Taiwan, NCREE researchers are working on estimating $z_{1.0}$ and $z_{2.5}$ using P-S logging data, microtremor array measurement, receiver function analyses of strong-motion data, and microtremor H/V spectra ratio modeling [32]. Results of this work are not yet available. In the Pacific Northwest, basin models are available for the Seattle and Everett basins [33, 34].

5. Application and Summary

The process by which "preferred" V_{S30} values are assigned from available data is as follows (the list number corresponds to codes in the site database file):

0. Assign V_{S30} from measured velocity profile with $z_p \geq 30$ m.
1. Estimate V_{S30} from measured velocity profiles with depths $10 \leq z_p < 30$ m using $V_{SZ}-V_{S30}$ relationships given in Section 2.0.
2. Estimate V_{S30} from standard penetration test blow counts and local correlations between V_S and penetration resistance/effective stress (this correlation is only used in Japan [35]).
3. Infer V_{S30} from one or two proxy relationships that vary by region, as shown in Table 1. Mean estimates of V_{S30} from the proxy relations are applied. Typically, approximately equal weight is applied when two proxies are used. Although in some regions like Japan more than two proxy relationships are available, only two are selected due to strong correlations among model predictions.

Standard deviations σ_{lnV} accompany each V_{S30} value. For Code 0 sites, we assign 0.1 based on observed within-site variability of measured V_{S30} values [24]. For Code 1 sites, the uncertainty of 0.1 is increased to account for additional uncertainty in the depth-extrapolation (details in [24]). For Code 2 sites (Japan only), σ_{lnV} is given as 0.26-0.38. For Code 3 sites, σ_{lnV} is assigned based on the standard deviation of residuals, and is usually in the range of 0.3-0.4.

The site database compilation effort is not complete as of this writing. This paper presents the major components of the database and the process by which its data fields will be populated. The anticipated completion date is Fall 2016/Winter 2017.

6. References

[1] Kishida T, Bozorgnia Y, Abrahamson N, Ahdi SK, Ancheta T, Boore D, Campbell K, Chiou B, Darragh R, Gregor N, Kamai R, Kwak D, Kwok A, Lin P, Magistrale H, Midorikawa S, Parker G, Si H, Silva W, Stewart J, Tsai C, Wooddell K, Youngs R (2017): Development of NGA-Subduction Database, *16th World Conference on Earthquake Engineering*, Santiago, Chile, January 9th to 13th 2017, Paper No 3452.

[2] Aoi S, Kunugi T, Fujiwara H (2004): Strong-motion seismograph network operated by NIED: K-NET and KiK-net. *J. Jpn. Assoc. Earthq. Eng.*, **4**(3), 65-74.

[3] Ichii K, Sato, Yu., Sato Yo., Hoshino Y, Iai S (1999): Site characteristics of strong-motion earthquake stations in ports and harbours in Japan (Part VI). *Technical note of the port and harbor research institute No 935*, Ministry of Transport, Japan.

[4] Kuo C-H, Wen K-L, Hsieh H-H, Lin CM, Chang T-M (2011): Characteristics of Near-Surface S-wave Velocity. *NCREE Report # NCREE-11-022*, National Center for Research on Earthquake Engineering, Taiwan, R.O.C.

[5] Kuo C-H (2016). Personal communication.

[6] Ahdi SK, Stewart JP, Ancheta TD, Mitra D, Kishida T, Bozorgnia Y (2016): Estimation of V_{S30} from Geology-Based Proxy Developed for the Pacific Northwest. *Seismological Research Letters*, **87** (2B), 476 (abstract).

[7] Cakir R, Walsh TJ (2009): Shallow-seismic site characterizations of near-surface geology at 20 strongmotion stations in Washington State. *Final Technical Report submitted to the USGS, USGS/NEHRP Award Number G09AP00021*, Washington State Department of Natural Resources, Olympia, Washington, USA.

[8] Cakir R, Walsh TJ (2010): Shallow seismic site characterizations at 23 strong-motion stations sites in and near Washington State. *Final Technical Report submitted to the USGS, USGS/NEHRP Award Number G10AP00027*, Washington State Department of Natural Resources, Olympia, Washington, USA.

[9] Cakir R, Walsh TJ (2011): Shallow seismic site characterizations at 25 ANSS/PNSN stations and compilation of site-specific data for the entire strongmotion network in Washington and Oregon. *Final Technical Report, USGS/NEHRP Award Number G11AP20045*, Washington State Department of Natural Resources, Olympia, Washington, USA.

[10] Bilderback EL, Palmer SP, Folger DS, Poelstra JL, Magsino SL, Niggemann RA. (2008): Shear-wave Database for Quaternary and Bedrock Geologic Units, Washington State. *Open File Report 2008-2.*, Washington State Department of Natural Resources, Division of Geology and Earth Resources, Olympia, Washington, USA.

[11] Madin IP, Burns WJ (2013): Ground motion, ground deformation, tsunami inundation, coseismic subsidence, and damage potential maps for the 2012 Oregon Resilience Plan for Cascadia Subduction Zone Earthquakes. *Open file O-13-06*, Oregon Department of Geology and Mineral Industries (DOGAMI), Portland, Oregon, USA.

[12] Wong IG, Stokoe II KH, Cox BR, Lin Y-C, Menq F-Y (2011): Shear-Wave Velocity Profiling of Strong Motion Sites That Recorded the 2001 Nisqually, Washington, Earthquake. *Earthquake Spectra*, **27**(1), 183-212.

[13] Hunter JA, Burns RA, Good RL, Pelletier CF (1998): A compilation of shear wave velocities and borehole geophysics logs in unconsolidated sediments of the Fraser River Delta, British Columbia. *Open File 3622*, Geological Survey of Canada, Ottawa, Canada.

[14] Cox BR, Wood CM, Hazirbaba K (2012): Frozen and Unfrozen Shear Wave Velocity Seismic Site Classification of Fairbanks, Alaska. *Journal of Cold Regions Engineering*, **26**(3), 118-145.

[15] Kayen RE, Thompson EM, Minasian D, Moss RES, Collins BD, Sitar N, Dreger D, Carver G (2002): Geotechnical Reconnaissance of the 2002 Denali Fault, Alaska, Earthquake. *Earthquake Spectra*, **20**(3), 639-667.

[16] Dutta U, Biswas N, Martirosyan A, Nath S, Dravinski M, Papageorgiou A, Combellick R (2000): Delineation of spatial variation of shear wave velocity with high-frequency Rayleigh waves in Anchorage, Alaska. *Geophysics Journal International*, **143**, 365-375.

[17] Kayen RE, Carkin BD, Corbet S, Pinilla C, Ng A, Gorbis E, Truong C (2014): Seismic velocity site characterization of thirty-one Chilean seismometer stations by spectral analysis of surface wave dispersion. *PEER Report 2014/05*, Pacific Earthquake Engineering Research Center, Berkeley, California, USA.

[18] Dai Z, Li X, Hou C (2013): A shear-wave velocity model for V_{S30} estimation based on a conditional independence property. *Bull. Seism. Soc. Am.*, **103**(6), 3354-3361.

[19] Boore DM (2004): Estimating V_{S30} (or NEHRP Site Classes) from shallow velocity models (depths < 30 m). *Bull. Seism. Soc. Am.*, **94**(2), 591-597.

[20] Iwahashi J, Pike RJ (2007): Automated classifications of topography from DEMs by an unsupervised nested-means algorithm and a three-part geometric signature. *Geomorphology*, **86**, 409-440.

[21] Yong A, Hough SE, Iwahashi J, Braverman A (2012): Terrain-based site conditions map of California with implications for the contiguous United States. *Bull. Seism. Soc. Am.*, **102**(1), 114-128.

[22] Yong A (2016): Comparison of Measured and Proxy-Based VS30 Values in California. *Earthquake Spectra*, **32**(1), 171-192.

[23] Chiou BSJ, Darragh R, Dreger D, Silva WJ (2008): NGA project strong-motion database. *Earthquake Spectra* **24**(1), 23-44.

[24] Seyhan E, Stewart JP, Ancheta TD, Darragh RB, Graves RW (2014): NGA-West2 Site Database. *Earthquake Spectra*, **31**(3), 1007-1024.

[25] Matsuoka M, Wakamatsu K, Fujimoto K, Midorikawa S (2006): Average shear-wave velocity mapping using Japan Engineering Geomorphologic Classification Map. *Str. Eng. Earthq. Eng.*, **23**(1), 57-68.

[26] Matsuoka M, Wakamatsu K (2008): Site amplification capability map based on the 7.5-arc-second Japan Engineering Geomorphologic Classification Map. *No. H20PRO-93*, National Institute of Advanced Industrial Science and Technology, Intellectual property management.

[27] Wakamatsu K, Matsuoka M (2013): Nationwide 7.5-arc-second Japan Engineering Geomorphologic Classification Map and VS30 zoning. *Journal of Disaster Research*, **8**(5), 904-911.

[28] Wald DJ, Allen TI (2007): Topographic slope as a proxy for seismic site conditions and amplification. *Bull. Seism. Soc. Am.*, **97**(5), 1379-1395.

[29] Allen TI, Wald DJ (2009): On the Use of High-Resolution Topographic Data as a Proxy for Seismic Site Conditions (VS30). *Bull. Seism. Soc. Am.*, **99**(2A), 935-943.

[30] Fujiwara H, Kawai S, Aoi S, Morikawa N, Senna S, Kudo N, Ooi M, Hao KX-S, Hayakawa Y, Toyama N, Matsuyama N, Iwamoto K, Suzuki H, Ei R (2009): A study on subsurface structure model for deep sedimentary layers of Japan for strong-motion evaluation. *Technical note of the National Research Institute for Earth Science and Disaster Prevention, No. 337* (in Japanese).

[31] Fujiwara H, Kawai S, Aoi S, Morikawa N, Senna S, Azuma H, Ooi M, Hao KX-S, Hasegawa N, Maeda T, Iwaki A, Wakamatsu K, Imoto M, Okumura T, Matsuyama H, Narita A (2012): Some Improvements of Seismic Hazard Assessment based on the 2011 Tohoku Earthquake. *Technical Note of the National Research Institute for Earth Science and Disaster Prevention, No. 379* (in Japanese).

[32] Lin C-M and Kuo C-H (2016). Personal Communication.

[33] Stephenson WJ (2007): Velocity and density models incorporating the Cascadia subduction zone for 3D earthquake ground motion simulations, Version 1.3. *Open-File Report 2007–1348*, U.S. Geological Survey, Earthquake Hazards Ground Motion Investigations, 24 p.

[34] Delorey AA, Vidale JE (2011): Basin Shear-Wave Velocities beneath Seattle, Washington, from Noise-Correlation Rayleigh Waves. *Bull. Seism. Soc. Am.*, **101**(5), pp. 2162-2175.

[35] Kwak DY, Brandenberg SJ, Mikami A, Stewart JP (2015): Prediction Equations for Estimating Shear-Wave Velocity from Combined Geotechnical and Geomorphic Indexes Based on Japanese Data Set. *Bull. Seism. Soc. Am.*, **105**(4), 1919-1930.