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NGA-SUBDUCTION SITE DATABASE

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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.

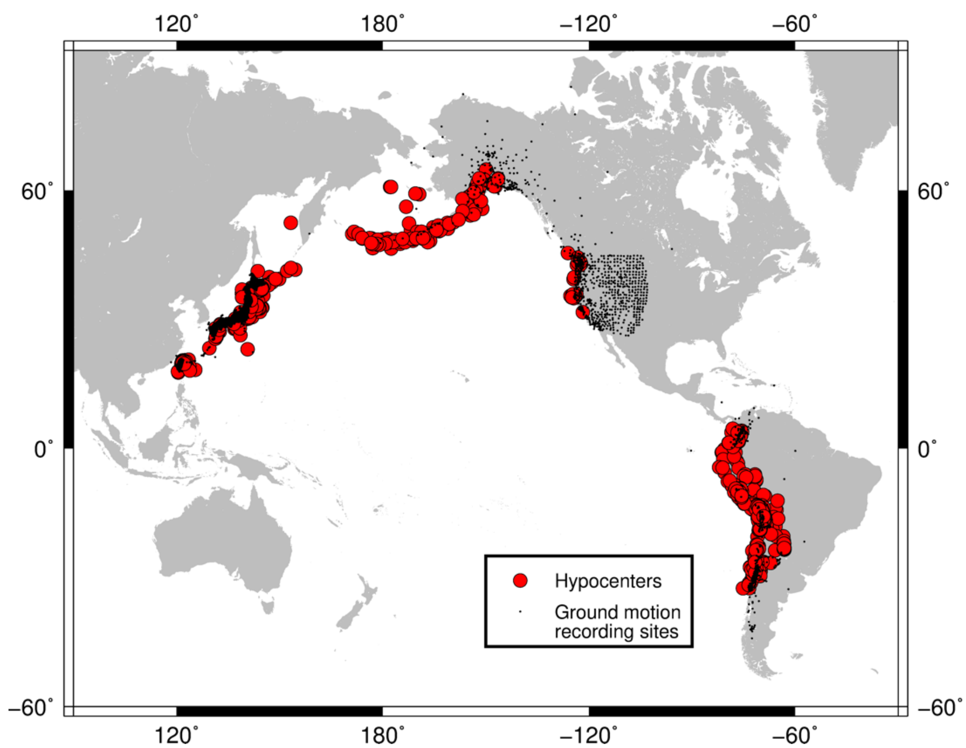

Fig. 1 – Global map showing NGA-Subduction hypocenters and ground motion recording sites.

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.

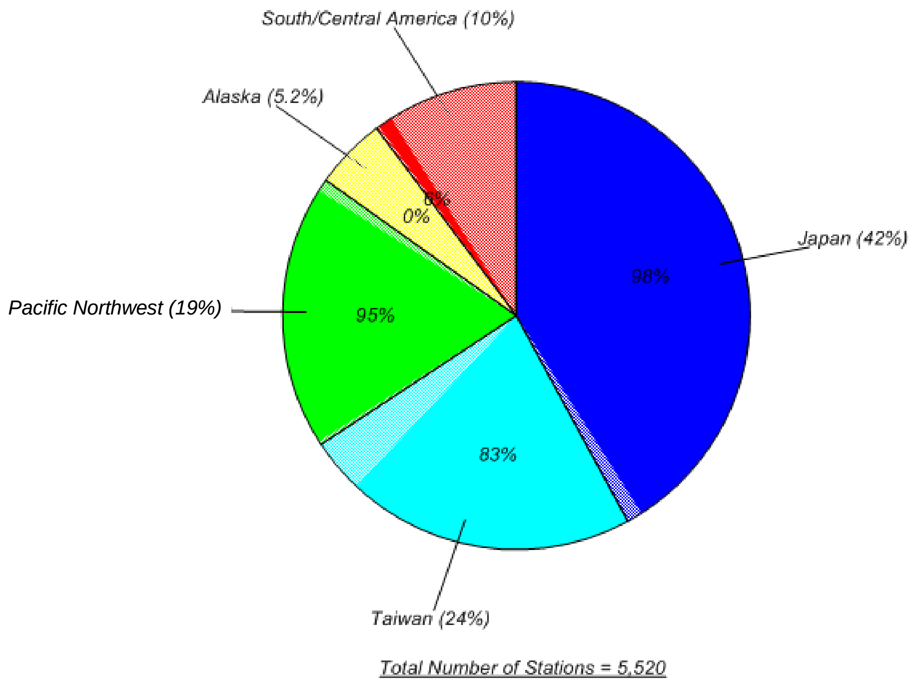

Fig. 2 – Regional distribution of the number of stations in the NGA-Subduction database. Darker color shades correspond to the percentage of sites that have been assigned a V_{S30} value (by measurement or proxy) to date.

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.

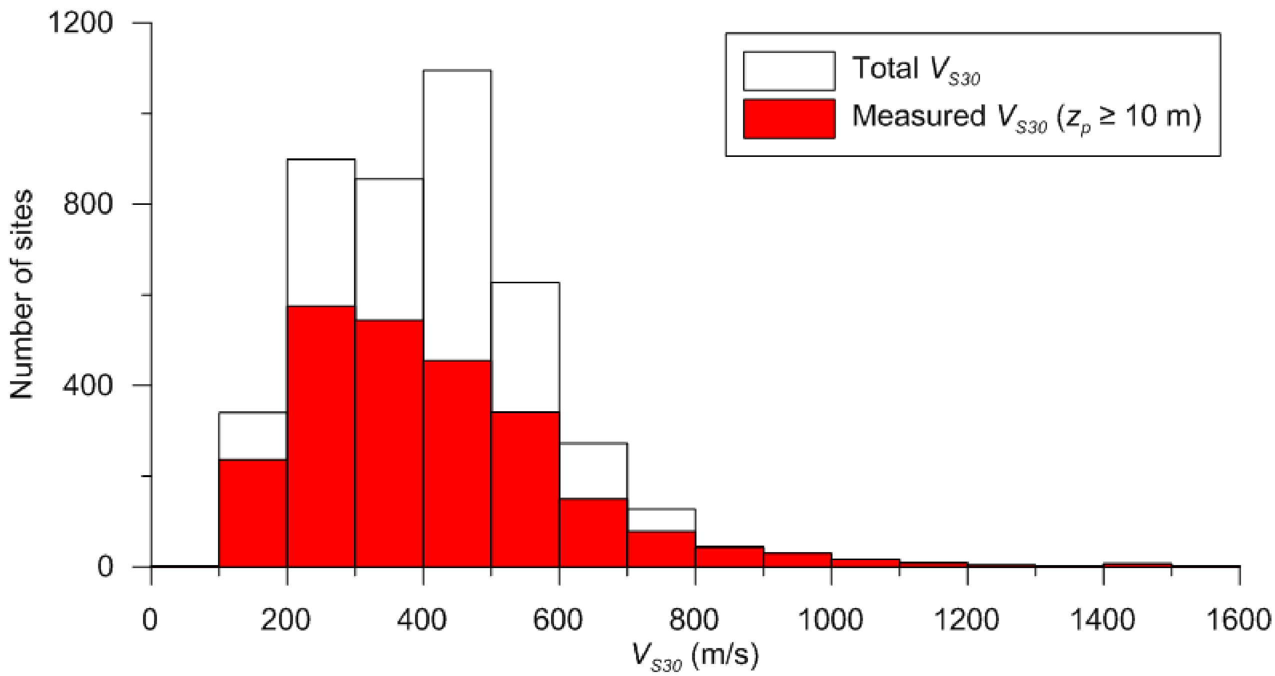

Fig. 3 – Histogram showing V_{S30} values (by measurement or proxy) at all sites in database to date.

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:

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

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.

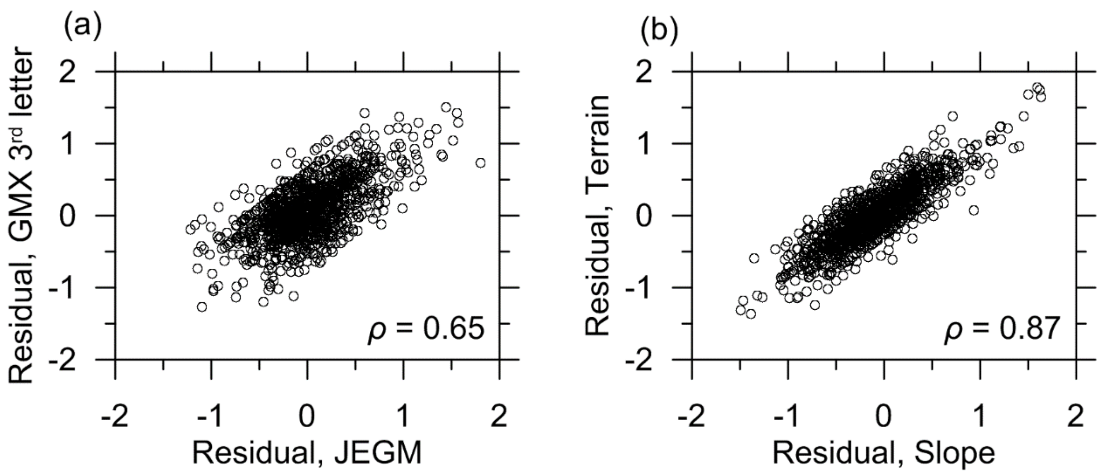

Fig. 4 – Correlations of residuals from proxy-based V_{S30} estimates using data from Japan. (a) example of relatively modest correlation using geotechnical- and geology-based proxies; (b) example of strong correlation using terrain- and slope-based proxies.

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.

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