Research Article

V_{s30} Estimate for Southwest China

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Several methods were used to estimate V_{s30} from site profiles with borehole depths of about 20 m for the strong-motion stations located in Southwest China. The methods implemented include extrapolation (constant and gradient), Geomatrix Site Classification correlation with shear-wave velocity, and remote sensing (terrain and topography). The gradient extrapolation is the preferred choice of this study for sites with shear-wave velocity profile data. However, it is noted that the coefficients derived from the California data set are not applicable to sites in Southwest China. Due to the scarcity of borehole profiles data with depth of more than 30 m in Southwest China, 73 Kiknet profiles were used to generate new coefficients for gradient extrapolation. Fortunately, these coefficients provide a reasonable estimate of V_{s30} for sites in Southwest China. This study showed V_{s30} could be estimated by the time-average shear-wave velocity (average slowness) of only 10 meters of depth. Furthermore, a median V_{s30} estimate based upon Geomatrix Classification is derived from the results of the gradient extrapolation using a regional calibration of the Geomatrix Classification with V_{s30} . The results of this study can be applied to assign V_{s30} to the sites without borehole data in Southwest China.

1. Introduction

As ground motion records became more abundant, site amplification had been studied by many researchers. Hayashi et al. [1] proposed the average acceleration response spectra for various subsoil condition in Japan. Seed et al. [2] derived site-dependent spectra from 104 ground motion records obtained from 23 earthquakes, mostly in the western part of US. To meet the application of seismic engineering and measure the site amplification, V_{s30} (time-average shear-wave velocity with depth of 30 meters) was a principal parameter to represent site condition and widely used for site classification. Borchardt [3] studied the relation between F_a and V_{s30} for NEHRP recommended building code provisions. Hartzell et al. [4] derived a correlation between site amplification and V_{s30} from the aftershock records of the 1989 Loma Prieta earthquake. Five NGA ground motion prediction models [5] all used V_{s30} for site classification. Although V_{s30} cannot, of course, capture all of the physics controlling site amplification [6], V_{s30} is widely accepted by seismic engineers for its simplicity and low cost.

The most straightforward way to evaluate V_{s30} for a given site is to measure seismic velocities to a depth of at least 30 meters. For a number of reasons, engineering seismic exploration was always not available for target areas. Then, V_{s30} was estimated from proxies, which may be based on geomorphology [7, 8], geology [9], or geotechnical site categories [10]. Since many seismic explorations would not reach the depth of 30 meters, the empirical relationship between V_{s30} and V_s at shallower depths was derived from borehole data at target areas [11–15]. All these proxies were approximations and had obvious regional limitations. Stewart et al. [16] found the empirical relationship always overestimate V_{s30} for Greece. Boore et al. [12] found that the difference of empirical relationship between Japan and the other places resulted from the difference of site classification of borehole data.

On May 12, 2008, an earthquake with M_w 7.9 occurred in Wenchuan county, Sichuan province, China, which resulted in widespread damage and a great number of casualties. During the Wenchuan earthquake, the National Strong-Motion Observation Network System (NSMONS) of China obtained 1,350 components of strong-motion records from

the main shock, including records from 437 free-field stations in 17 provinces, municipalities, and autonomous regions, 1 topographic array (8 stations) in Sichuan province, and 2 temporary arrays (10 monitoring sites) for structural response at the Kunming mobile observatory [17–19]. After the main shock, 59 mobile instruments were deployed to record ground motion and structural response from strong aftershocks [20]. 15,903 components of digital strong-motion records were obtained from 949 aftershocks, in which 9750 components were recorded by portable instruments [20–22].

In order to use these records from the Wenchuan main shock and aftershocks in the NGA (Next-Generation Attenuation) project of PEER (Pacific Earthquake Engineering Research Center), an estimate of V_{s30} of the recording sites is needed. V_{s30} is a widely used parameter for classifying site condition regarding its ability to amplify seismic shaking. However, in China, the site classification is based on V_{s20} , depth of 20 m, and the thickness of overlying soil over rock according to the Chinese site classification in the seismic design building code. During the construction of strong-motion stations in China, the investigation of the site condition only provides the information on the overlying soil layers of depths less than 20 m, including the thickness and shear-wave velocity of soil layers. In the site investigation, layers with shear-wave velocity greater than 500 m/s are considered bedrock. Therefore, most of the depths of drilling holes are less than 30 m at the strong-motion station sites. As a result, an important issue for the strong-motion stations in China is the use of shear-wave velocity profiles with borehole depth less than 30 m to assign a V_{s30} .

In this study, 147 shear-wave velocity profiles measured with borehole technique at the strong-motion station in Southwest China (Sichuan and Gansu provinces) were used. These strong-motion stations are located in the heavily damaged region of the Wenchuan earthquake. The locations of these stations are shown in Figure 1. The Appendix gives the borehole depth, shear-wave velocity at the bottom of borehole, and whether or not the drilling reached bedrock (defined as $V_s > 500$ m/s). There are 6 stations with borehole depth less than 10 m, 32 stations with borehole depth between 10 m and 20 m, and 109 stations with borehole depth larger than 20 m. This study estimates V_{s30} for these 147 stations based on the measured shear-wave velocity profiles to the depth available.

2. Methodology

2.1. Simple Extrapolation. In this method, we assume that the shear-wave velocity from the bottom of the borehole to 30 m is constant at V_s measured at the borehole bottom. The time-average shear-wave velocity (average slowness, [23]), named $V_{s30\text{profile}}$, was computed from the equation

$$V_{s30} = \frac{30}{tt(30)}, \quad (1)$$

where the travel time $tt(30)$ was given by

$$tt(30) = \int_0^{30} \frac{dZ}{V_s(Z)}. \quad (2)$$

$V_s(Z)$ is the shear-wave velocity at depth Z .

TABLE 1: Median V_{s30} and standard deviation for NGA database [10] profiles based on Geomatrix Classification bins.

Geomatrix Classification	Median V_s (m/s)	σ (m/s)	N
A	660	324	74
B	424	211	97
C	338	70	44
D	274	110	306
E	191	61	40

Since $V_{s30\text{profile}}$ is based on the measured velocity profile data, it is taken as the reference value of V_{s30} for comparison with other empirical estimates.

$V_{s30\text{profile}}$ is typically less than the actual V_{s30} in general as V_s generally increase with increasing depth. In cases, where the borehole depth is greater than 20 meters, the difference is generally small.

2.2. Geomatrix Classification Assignment. The PEER NGA database [10] includes 561 sites with borehole data. All the sites were assigned with a Geomatrix Classification according to geological and geographic conditions. The NGA Geomatrix Site Classification criteria are given as follows:

- A, rock: instrument on rock ($V_s > 600$ m/s) or <5 m of soil over rock.
- B, shallow (stiff) soil: instrument on/in soil profile up to 20 m thick overlying rock.
- C, deep narrow soil: instrument on/in soil profile at least 20 m thick overlying rock, in a narrow canyon or valley not more than several km wide.
- D, deep broad soil: instrument on/in soil profile at least 20 m thick overlying rock, in a broad valley.
- E, soft deep soil: instrument on/in deep soil profile with average $V_s < 150$ m/s.

A median V_{s30} and standard deviation have been obtained for each Geomatrix Classification based upon a global database of measured profiles. Table 1 gives the median V_{s30} and standard deviation.

The Geomatrix Classification for the 147 Southwest China sites is 9 A sites, 52 B sites, 83 C sites, and 3 D sites.

Next, we compare the median shear-wave velocity profiles of Southwest China (SWC) with NGA profiles based on Geomatrix Classification. The result is shown in Figure 2. In the depth range of 0 to 5 m, the median V_s of SWC is less than that of NGA profiles on average. The near surface soils in SWC are softer than those in NGA. However, at depths below 5 m, the median V_s of SWC profiles is similar to that of NGA profiles, except for site class B. The site class B profile of SWC has a slightly larger median V_s than NGA.

Since the median shear-wave velocity profiles of SWC sites are similar to those of the NGA sites, we may assign

FIGURE 1: Station distribution around the main shock.

FIGURE 2: Comparison of median V_s between Southwest China (SWC) profiles and NGA profiles.

the median V_{s30} to the sites with the same Geomatrix Classification, ($V_{s30\text{Geomatrix}}$), with a small bias on the high

side. Also, we can assign V_{s30} to sites without V_s profile but with a Geomatrix Classification, again slightly biased high.

2.3. Boore Extrapolation. Boore [11] used a set of 135 borehole profiles with depths greater than or equal to 30 m to estimate a correlation between V_{s30} and $V_s(d)$, which is time-average shear-wave velocity for a profile to depth d . $V_s(d)$ is given by

$$V_s(d) = \frac{d}{tt(d)}, \quad (3)$$

where d is the borehole depth and $tt(d)$ is given by (2).

Boore [11] found that the logarithm of V_{s30} against logarithm of $V_s(d)$ could be fit by a straight line, given by

$$\log(V_{s30}) = a + b \log(V_s(d)). \quad (4)$$

Table 2 gives the regression coefficients and standard deviation for Boore's correlation equation from 135 California profiles.

Since the standard deviation of Boore's estimate is less than 8 percent for stations with borehole depth larger than 10 m, we apply Boore's empirical model, which is generated from California data, to the SWC profiles to estimate V_{s30} ($V_{s30\text{Boore}}^{\text{cal}}$), given by

$$V_{s30\text{Boore}}^{\text{cal}} = 10^{a+b \log(V_s(d))}, \quad (5)$$

TABLE 2: Coefficients of (4) for 135 California profiles [11].

d (m)	a	b	$\sigma_{\ln}$
10	0.0421	1.0292	0.0713
11	0.0221	1.0341	0.0647
12	0.0126	1.0352	0.0594
13	0.0142	1.0318	0.0548
14	0.0123	1.0297	0.0501
15	0.0138	1.0263	0.0459
16	0.0139	1.0237	0.0422
17	0.0196	1.0190	0.0394
18	0.0249	1.0144	0.0364
19	0.0256	1.0117	0.0332
20	0.0254	1.0095	0.0302
21	0.0253	1.0072	0.0270
22	0.0269	1.0044	0.0241
23	0.0222	1.0042	0.0208
24	0.0169	1.0043	0.0177
25	0.0115	1.0045	0.0147
26	0.0066	1.0045	0.0115
27	0.0025	1.0043	0.0084
28	0.0008	1.0031	0.0055
29	0.0004	1.0015	0.0027

where the superscript Cal means that the model is based on California data.

A comparison of $V_{s30Boore}^{cal}$ to $V_{s30profile}$ in the Appendix shows that Boore's estimate for profiles with borehole depth greater than 20 m is very close to $V_{s30profile}$, which has an average bias of 0.006. However, for the 32 profiles with borehole depth between 10 and 20 m, $V_{s30Boore}^{cal}$ has an average bias of 0.139 (positive bias reflects an underprediction) relative to $V_{s30profile}$. The result suggests that the coefficients of Boore's estimate derived from California profiles may not be applicable to SWC profiles.

Boore indicates that V_s of SWC profiles is larger than that of California profiles in the same depth and the velocity gradients of these two regions are different, which results in the underestimate of V_{s30} . Similar to Boore, in order to eliminate the difference of velocity gradients between the regions, we want to derive the coefficients from similar profiles.

Linear and cubic fit to Kiknet profiles were performed to fit $\log(V_{s30})$ against $\log(V_s(d))$. The cubic fit is given by the following equation:

$$\log(V_{s30}) = C_0 + C_1 \log(V_s(d)) + C_2 \log^2(V_s(d)) + C_3 \log^3(V_s(d)). \quad (6)$$

According to (6), V_{s30} can be estimated by

$$V_{sBoore}^3 = 10^{(C_0 + C_1 \log(V_s(d)) + C_2 \log^2(V_s(d)) + C_3 \log^3(V_s(d)))}. \quad (7)$$

Table 3 gives the coefficients and standard deviation of linear and cubic fit based on Boore's correlation equation

applied to 73 Kiknet measured profiles with Geomatrix Classification, and Figure 3 displays the fit.

Figure 3 shows that the goodness of cubic fit is slightly better than linear fit for some stiff sites, especially for depth less than 5 m. When the borehole depth is greater than 10 meters, the difference between these two fits becomes negligible.

Next, we assess whether conditioning a Geomatrix category can improve the V_{s30} estimate. We classify 73 Kiknet sites as 60 rock sites with Geomatrix class A or class B and 13 soil sites with Geomatrix C or D. We use both linear and cubic fit to the rock sites and soil sites separately. Table 4 gives the comparison of the bias and standard deviation between the simple extrapolation, normal fit (all site pooled), and Geo fit (rock and soil bins).

Table 4 shows that the bias and standard deviation decrease with an increase of depth and that of Geo fit, conditioning on Geomatrix categories, provides slightly superior results to that of the normal fit.

We use the normal linear fit, which is defined as $V_{s30Boore}$, to estimate V_{s30} for three reasons. First, it is simple. Second, the bias and standard deviation of the normal linear fit to the 20 m depth bin are only 0.0015 and 0.0912, respectively. The maximum error is just nine percent. At shallow depth, 10 m depth bin, the maximum error is only 20 percent, which is acceptable for many applications. Third, the improvement of Geo fit and cubic fit is not significant and the procedure is more complicated than normal fit due to the large number of coefficients.

2.4. Topographic Slope and Terrain-Based Estimate. The USGS earthquake hazards program developed an approach based on the similarity of geology and topography to provide a first-order assessment of V_{s30} [7]. It is assumed that the slope of topography, or gradient, could be diagnostic of V_{s30} , because more competent (high-velocity) materials are more likely to maintain a steep slope whereas deep basin sediments are deposited primarily in environments with low gradients. Correlation between topographic slope data and regional V_{s30} is built to estimate V_{s30} . We go to <http://earthquake.usgs.gov/hazards/apps/vs30/custom.php> and choose a location boundary including all the 147 Southwest China recording sites; V_{s30} estimate on each grid point is generated. V_{s30} at the closest grid point, whose distance to the target station is less than 0.6 km, is assumed as topographic estimate of V_{s30} , named V_{s30W} .

Yong built a correlation between V_{s30} and California terrain-based units, which are derived from 1 km spatial resolution (SRTM30) digital elevation model. Based on California terrain-based units, Yong made an estimate of V_{s30} for Southwest China, named V_{s30arc} . Considering the difference of terrain between California and Southwest China, Yong makes a small change to V_{s30arc} to provide an alternative estimate of V_{s30} , named V_{s30R} .

3. Comparisons and Conclusion

We have six types of V_{s30} estimates for Southwest China: $V_{s30profile}$, $V_{s30Boore}$, $V_{s30Geomatrix}$, V_{s30arc} , V_{s30R} , and V_{s30W} .

FIGURE 3: The linear fit and cubic fit to the Kiknet data in 4 depth bins, 5, 10, 20, and 28 m.

Since $V_{s30\text{profile}}$ is obtained from the shear-wave velocity profile, we use $V_{s30\text{profile}}$ as a reference V_{s30} to calculate the bias and standard deviation of the five other types of V_{s30} estimates. Table 5 summarizes the results.

Table 5 indicates that two kinds of terrain-based V_{s30} estimates have large bias and standard deviation. We believe this is mainly due to the large difference of terrain slope between Southwest China and California. It is the same with topographic estimate. Because of the difference of geographic and topographic condition between these two regions, the topographic estimate shows more than 40 percent bias and huge standard deviation. The bias of $V_{s30\text{Geomatrix}}$ is small whereas the standard deviation is about 30 percent. This is because there are only five categories in the Geomatrix Classification scheme and there is considerable within-category

variability (Table 1). However, for the sites without profile data, $V_{s30\text{Geomatrix}}$ provides a largely unbiased estimate of V_{s30} .

The bias and standard deviation of $V_{s30\text{Boore}}$ are both small, which verify that Boore's model is a good method to estimate V_{s30} . However, the coefficients must be attained from profiles with similar geological conditions and similar velocity gradient, that is, local or regional calibration. Our results indicate that the geological condition of Sichuan province of China is similar to that of Japan. Hence, we use $V_{s30\text{Boore}}$ to estimate site effect for ground motion prediction equation.

In addition, Table 4 shows that V_{s30} can be estimated by average shear-wave velocity to 10 m depth with a bias of 0.0051 and σ of only 0.1998. Since the NGA models [5] use the natural logarithm of V_{s30} to estimate site effect, 20 percent difference of V_{s30} can make only five percent difference to the

TABLE 3: Coefficients and natural logarithm of the standard deviation for (4) and (6) from Kiknet profiles.

Depth (m)	a	b	C_0	C_1	C_2	C_3	σ_{linear}	σ_{cubic}
5	1.3412	0.5626	1.0320	1.3924	-0.5117	0.0906	0.1174	0.1158
6	1.2498	0.5975	-1.2168	3.8378	-1.3922	0.1955	0.1120	0.1110
7	1.1650	0.6288	-1.1351	3.6074	-1.2640	0.1756	0.1062	0.1055
8	1.1071	0.6492	0.0978	2.1222	-0.6846	0.1022	0.1018	0.1012
9	1.0009	0.6878	-2.0070	4.3394	-1.4621	0.1928	0.0956	0.0952
10	0.9056	0.7223	-3.2943	5.6294	-1.8935	0.2410	0.0896	0.0894
11	0.8111	0.7559	-4.0334	6.2874	-2.0859	0.2595	0.0837	0.0835
12	0.7307	0.7840	-4.0876	6.2020	-2.0116	0.2464	0.0784	0.0782
13	0.6465	0.8132	-4.6981	6.7207	-2.1550	0.2592	0.0732	0.0729
14	0.5709	0.8389	-4.9266	6.8299	-2.1532	0.2550	0.0681	0.0677
15	0.5018	0.8617	-5.3861	7.2075	-2.2547	0.2638	0.0627	0.0622
16	0.4401	0.8816	-5.5568	7.2781	-2.2480	0.2600	0.0579	0.0573
17	0.3824	0.8999	-5.6979	7.3279	-2.2381	0.2563	0.0533	0.0525
18	0.3315	0.9156	-5.6043	7.1366	-2.1460	0.2433	0.0489	0.0480
19	0.2848	0.9296	-4.8807	6.2744	-1.8177	0.2028	0.0445	0.0436
20	0.2440	0.9415	-4.0266	5.2892	-1.4511	0.1583	0.0404	0.0395
21	0.2055	0.9525	-2.9989	4.1264	-1.0243	0.1071	0.0362	0.0353
22	0.1724	0.9616	-1.8671	2.8692	-0.5696	0.0532	0.0323	0.0315
23	0.1424	0.9695	-1.1240	2.0489	-0.2768	0.0191	0.0288	0.0280
24	0.1155	0.9763	-0.5169	1.3890	-0.0458	-0.0073	0.0255	0.0248
25	0.0883	0.9832	-0.1184	0.9585	0.1017	-0.0236	0.0223	0.0217
26	0.0622	0.9897	0.2604	0.5551	0.2377	-0.0383	0.0194	0.0189
27	0.0413	0.9943	0.2788	0.5517	0.2275	-0.0355	0.0163	0.0158
28	0.0216	0.9985	0.2809	0.5694	0.2087	-0.0315	0.0136	0.0133
29	0.0033	1.0023	0.4227	0.4434	0.2391	-0.0331	0.0117	0.0115

TABLE 4: Comparison of bias and standard deviation between the normal fit and Geo fit to Kiknet profiles.

Depth bins	Bias of $\ln(V_{s30})$ Simple extrapolate	Standard deviation Simple extrapolate	Bias of $\ln(V_{s30})$ Linear fit	Standard deviation Linear fit	Bias of $\ln(V_{s30})$ Geolinear fit	Standard deviation Geolinear fit	Bias of $\ln(V_{s30})$ Cubic fit	Standard deviation Cubic fit	Bias of $\ln(V_{s30})$ Geocubic fit	Standard deviation Geocubic fit
5	0.4945	0.3137	0.0074	0.2603	0.0049	0.2428	0.0068	0.2570	0.0028	0.2395
10	0.1670	0.1518	0.0051	0.1998	0.0036	0.1859	0.0068	0.1990	0.0045	0.1855
15	0.0664	0.0790	0.0026	0.1416	0.0014	0.1342	0.0028	0.1411	0.0014	0.1326
20	0.0240	0.0438	0.0015	0.0912	0.0007	0.0868	0.0026	0.0896	-0.0007	0.0827
28	0.0029	0.0249	0.0005	0.0310	0.0003	0.0301	0.0004	0.0303	0.0021	0.0291

Bias = $\ln(V_{s30\text{true}}/V_{s30\text{predict}})$.

TABLE 5: Bias and standard deviation of the five other types of V_{s30} estimates relative to $V_{s30\text{profile}}$.

	$V_{s30\text{Boore}}$	$V_{s30\text{Geomatrix}}$	$V_{s30\text{arc}}$	$V_{s30\text{R}}$	$V_{s30\text{W}}$
Bias (ln)	-0.0704	-0.0656	-0.3189	-0.3451	-0.4434
σ	0.0796	0.2003	0.2769	0.2444	0.4062

TABLE 6: Median $V_{s30\text{Geomatrix}}$ for WCS sites.

Geomatrix Classification	Median V_{s30} (m/s)	σ	N
A	553.40	79.23	9
B	412.29	69.23	52
C	353.73	63.72	83
D	296.83	72.54	3

site effect, which is suitable for ground motion prediction and engineering applications.

Based on $V_{s30\text{Boore}}$ for 145 profiles, we get a median $V_{s30\text{Geomatrix}}$ for the SWC profiles. Table 6 gives $V_{s30\text{Geomatrix}}$

for Geomatrix Classification A, B, C, and D sites, which can be used to assign V_{s30} to SWC sites without profile data.

TABLE 7

Station code	Depth of borehole (m)	V_s at the bottom of borehole (m/s)	Bedrock at borehole bottom	Geomatrix Classification	$V_{s30\text{profile}}$	$V_{s30\text{Geomatrix}}$	$V_{s30\text{Boore}}^{\text{cal}}$	$V_{s30\text{Boore}}^{\text{Kiknet}}$	$V_{s30\text{arc}}$	$V_{s30\text{R}}$	$V_{s30\text{W}}$
51AXD	11.80	878	Yes	B	405	424	280	383	—	—	374
51AXT	12.80	510	Yes	B	331	424	281	376	388	547	362
51AXY	22.00	475	No	C	368	338	371	404	—	—	595
51BTD	22.20	436	No	C	334	338	337	368	547	547	540
51BTT	22.30	403	No	C	273	338	268	296	519	519	525
51BXY	19.80	618	Yes	B	318	424	288	332	519	519	760
51BXZ	18.20	658	Yes	B	379	424	341	394	519	519	760
51CXQ	4.90	321	Yes	A	321	660	—	564	402	402	360
51DCN	22.10	504	No	C	284	338	267	295	547	547	572
51DJA	22.00	453	No	C	287	338	276	304	—	—	332
51DXY	22.00	431	No	C	342	338	347	379	374	374	398
51DYB	15.20	539	Yes	B	374	424	345	418	388	388	355
51GYS	12.20	517	Yes	B	345	424	290	385	519	519	557
51GYZ	20.10	1207	Yes	B	388	424	326	366	519	519	465
51GZT	22.00	350	No	C	244	338	240	266	519	519	415
51GZX	22.00	325	No	C	337	338	373	406	402	519	431
51HDD	9.00	639	Yes	A	502	660	—	547	—	—	602
51HDQ	13.00	689	Yes	B	414	424	336	423	—	—	747
51HDX	14.50	651	Yes	B	362	424	297	376	—	—	719
51HLB	12.00	659	Yes	B	370	424	278	373	—	—	760
51HLD	9.00	579	Yes	B	431	424	—	471	—	—	760
51HLF	21.50	311	No	C	290	338	311	346	—	—	760
51HLW	12.00	564	Yes	B	403	424	355	449	—	—	760
51HLY	13.50	802	Yes	B	417	424	324	411	—	—	479
51HSD	21.00	496	No	C	340	338	331	367	519	519	760
51HSL	21.00	227	No	C	266	338	316	351	519	402	760
51HYJ	22.30	515	No	C	449	338	470	507	547	519	497
51HYQ	22.40	392	No	C	322	338	331	362	519	519	760
51HYU	20.30	677	Yes	A	441	660	424	469	—	—	271
51HYW	22.50	521	No	C	401	338	407	442	519	519	760
51HYY	19.40	515	Yes	B	414	424	426	475	519	519	760
51JLN	22.00	547	No	C	415	338	416	451	519	519	583
51JLT	15.30	520	Yes	B	311	424	267	337	547	547	760
51JYC	15.00	1070	Yes	B	466	424	357	430	497	388	311
51JYD	10.20	603	Yes	A	435	660	367	475	328	388	184
51JYH	22.00	633	Yes	B	320	424	296	326	547	547	760
51JYW	20.00	887	Yes	B	459	424	415	459	—	—	376
51JZB	22.00	465	No	C	328	338	323	354	519	519	760
51JZG	22.00	451	No	C	304	338	296	326	519	519	760
51JZW	22.00	607	No	C	428	338	422	457	519	519	760
51JZY	22.00	485	No	C	321	338	312	342	519	519	760
51KDG	22.00	330	No	C	269	338	275	303	519	519	536
51LBD	13.20	503	Yes	B	345	424	304	391	519	519	484
51LBH	13.20	503	Yes	B	345	424	304	391	519	519	559
51LDD	22.00	400	No	C	336	338	346	378	519	519	760
51LDJ	22.00	450	Yes	C	313	338	308	338	519	519	760

TABLE 7: Continued.

Station code	Depth of borehole (m)	V_s at the bottom of borehole (m/s)	Bedrock at borehole bottom	Geomatrix Classification	$V_{s30\text{profile}}$	$V_{s30\text{Geomatrix}}$	$V_{s30\text{Boore}}^{\text{cal}}$	$V_{s30\text{Boore}}^{\text{Kiknet}}$	$V_{s30\text{arc}}$	$V_{s30\text{R}}$	$V_{s30\text{W}}$
51LDL	22.00	365	No	C	308	338	318	349	519	519	760
51LDS	22.00	360	No	C	352	338	380	414	519	519	760
51LHT	20.50	375	No	C	327	338	346	387	519	519	732
51LSF	9.80	1130	Yes	B	605	424	—	517	547	388	760
51LSH	9.80	1660	Yes	B	858	424	—	649	328	547	682
51LSJ	10.70	876	Yes	A	598	660	498	587	374	393	363
51LXM	21.00	359	No	C	287	338	292	326	519	519	760
51LXS	20.20	452	No	C	311	338	302	341	519	519	760
51LXT	21.00	424	No	C	317	338	316	351	519	519	760
51LXY	20.20	257	No	C	269	338	308	347	—	—	760
51MCL	20.50	1050	Yes	B	460	424	409	453	519	519	568
51MED	16.00	941	Yes	B	489	424	408	475	519	519	760
51MES	12.00	482	Yes	B	389	424	380	473	—	—	760
51MEZ	20.10	474	Yes	B	363	424	364	406	519	519	760
51MNA	22.00	529	No	C	492	338	525	563	519	519	760
51MNC	22.00	516	No	C	438	338	453	490	519	547	760
51MNH	22.00	527	No	C	349	338	339	371	547	547	404
51MNJ	22.00	410	No	C	388	338	415	450	388	547	448
51MNL	22.00	500	No	C	323	338	312	343	519	388	419
51MNM	22.00	456	No	C	342	338	342	374	547	547	496
51MNZ	22.00	526	No	C	374	338	370	403	519	519	760
51MXD	21.00	358	No	C	268	338	267	299	519	519	760
51MXN	21.00	494	No	C	387	338	391	430	519	519	760
51MYL	22.00	375	No	C	310	338	319	349	—	—	324
51MYS	22.00	415	Yes	B	300	424	297	327	388	547	474
51NNH	22.00	432	No	C	267	338	256	283	—	—	760
51NNL	22.00	369	No	C	302	338	309	339	519	519	760
51NNS	22.00	280	No	C	267	338	287	316	519	519	760
51PGD	22.00	380	No	C	265	338	260	287	—	—	688
51PGL	22.00	413	No	C	331	338	337	368	519	519	760
51PGQ	22.00	557	No	C	284	338	263	290	519	519	760
51PJD	22.00	433	No	C	350	338	357	389	402	497	267
51PJW	22.00	440	No	C	312	338	308	338	363	374	216
51PWM	25.00	753	Yes	B	373	424	357	376	519	519	589
51PZF	22.00	700	Yes	A	573	660	588	628	—	—	760
51PZT	22.00	750	Yes	A	448	660	427	463	—	—	760
51PZW	22.00	800	Yes	B	411	424	381	415	—	—	453
51QCD	20.00	893	Yes	B	394	424	345	386	—	—	611
51QLY	22.00	747	Yes	B	486	424	472	508	547	519	527
51SFB	20.00	548	Yes	B	355	424	338	379	519	519	476
51SMC	22.00	340	No	C	309	338	326	357	519	519	760
51SMK	22.00	405	No	C	363	338	382	416	519	519	760
51SML	22.00	395	Yes	C	336	338	348	380	519	519	760
51SMM	22.00	320	No	C	279	338	291	320	519	519	760
51SMW	22.00	405	No	C	281	338	276	305	519	519	760
51SMX	22.00	400	No	C	310	338	312	343	519	519	760

TABLE 7: Continued.

Station code	Depth of borehole (m)	V_s at the bottom of borehole (m/s)	Bedrock at borehole bottom	Geomatrix Classification	$V_{s30\text{profile}}$	$V_{s30\text{Geomatrix}}$	$V_{s30\text{Boore}}^{\text{cal}}$	$V_{s30\text{Boore}}^{\text{Kiknet}}$	$V_{s30\text{arc}}$	$V_{s30\text{R}}$	$V_{s30\text{W}}$
51SPA	21.00	473	Yes	C	342	338	338	374	519	519	527
51TQL	22.00	1066	Yes	B	529	424	489	526	519	519	760
51WCW	20.10	485	Yes	C	357	338	353	395	—	—	760
51XCC	22.00	351	No	D	277	274	280	309	363	388	224
51XCH	22.00	522	No	C	386	338	385	418	547	547	518
51XCL	22.00	504	No	C	324	338	313	343	547	547	348
51XCT	22.00	510	Yes	B	389	424	390	424	—	—	449
51XCY	21.00	358	Yes	C	249	338	243	274	547	547	606
51XDG	22.00	507	No	C	353	338	347	379	519	519	573
51XDM	22.00	700	No	C	405	338	384	417	519	547	760
51XJB	21.00	430	No	C	327	338	328	364	—	—	760
51XJD	21.00	498	No	C	343	338	334	370	519	519	760
51XXC	22.00	431	No	D	336	274	340	372	459	459	726
51YAD	22.00	721	Yes	B	245	424	216	240	—	—	253
51YAL	22.00	1168	Yes	B	544	424	497	535	519	519	372
51YAM	22.00	877	Yes	A	577	660	561	600	547	388	760
51YAS	22.00	694	Yes	B	422	424	403	437	519	547	760
51YBA	22.00	760	Yes	B	475	424	456	493	—	—	589
51YBG	15.10	1302	Yes	A	739	660	631	693	—	—	516
51YBH	22.00	566	Yes	B	358	424	345	377	—	—	376
51YXX	22.00	364	No	C	304	338	313	343	547	547	630
51YXZ	22.00	444	No	C	348	338	352	385	547	547	757
51YYJ	22.00	555	Yes	B	384	424	376	410	—	—	760
51YYM	22.00	550	No	C	347	338	334	365	388	547	282
51YYW	22.50	420	No	C	248	338	238	264	388	459	430
51ZJJ	22.30	523	Yes	B	354	424	348	380	519	519	760
51ZJQ	20.80	520	Yes	B	346	424	338	379	519	547	524
62ANY	30.00	562	No	C	425	338	425	425	—	—	519
62BAS	23.00	530	Yes	C	307	338	293	318	519	519	687
62DAT	13.50	532	Yes	B	432	424	438	522	388	388	348
62ERT	13.00	528	Yes	B	371	424	330	417	246	519	333
62GLA	30.00	523	Yes	C	229	338	229	229	402	402	368
62GXT	24.00	510	Yes	C	256	338	243	262	402	519	403
62HEP	30.00	290	No	C	238	338	238	238	547	519	605
62HEZ	20.00	540	Yes	B	338	424	318	358	—	—	589
62HJI	28.00	506	Yes	C	372	338	373	381	—	—	563
62JAI	30.00	540	No	C	282	338	282	282	388	519	269
62JCH	22.00	550	No	C	477	338	498	535	—	—	306
62KLE	16.00	562	Yes	B	351	424	311	376	519	519	339
62LJB	25.00	540	No	C	358	338	354	373	328	547	304
62MXT	22.00	638	Yes	C	301	338	275	303	402	547	378
62PAN	30.00	530	Yes	C	343	338	343	343	519	388	548
62PJY	30.00	284	No	C	249	338	249	249	—	—	320
62QCH	28.00	510	No	C	362	338	362	370	374	345	322
62SHW	22.00	510	No	C	384	338	385	419	519	519	760
62TCH	16.00	790	Yes	B	402	424	332	397	519	519	698

TABLE 7: Continued.

Station code	Depth of borehole (m)	V_s at the bottom of borehole (m/s)	Bedrock at borehole bottom	Geomatrix Classification	$V_{s30\text{profile}}$	$V_{s30\text{Geomatrix}}$	$V_{s30\text{Boore}}^{\text{cal}}$	$V_{s30\text{Boore}}^{\text{Kiknet}}$	$V_{s30\text{arc}}$	$V_{s30\text{R}}$	$V_{s30\text{W}}$
62TSH	22.00	540	Yes	C	408	338	409	443	547	547	574
62WUD	28.00	262	No	D	221	274	223	228	519	519	522
62XGU	24.00	548	Yes	C	298	338	285	306	519	547	325
62XHS	26.00	530	Yes	B	341	424	337	351	—	—	642
62XIC	30.00	506	No	C	284	338	284	284	388	374	356
62YGX	20.00	525	Yes	B	311	424	288	327	—	—	544
62YLG	12.00	810	Yes	B	517	424	423	513	—	—	666
62ZNI	9.00	730	Yes	B	387	424	—	363	519	402	760
62ZPU	20.00	516	Yes	B	406	424	411	456	547	519	475

Appendix

See Table 7.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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