ATLANTIS PRESS

Advances in Engineering Research, volume 129

6th International Conference on Energy, Environment and Sustainable Development (ICEESD 2017)

Comparison on $V_S(Z)$-$V_S(30)$ models

Linjian Ji[1,a], Zhengru Tao[1,b], Wenqian Li[2] and Xiaxin Tao[3,1]

[1]Key Laboratory of Earthquake Engineering and Engineering Vibration, Institute of Engineering Mechanics, China Earthquake Administration, China

[2]Earthquake Administration of Xinjiang Uygur Autonomous Region, China

[3]Harbin Institute of Technology, China

[a]linjianji@163.com, [b]taozr@iem.ac.cn

Keywords: $V_S(30)$, $V_S(Z)$, time-averaged shear-wave velocity, Pearson correlation coefficient, standard deviations of residuals

Abstract. The time-averaged shear-wave velocity to the depth of 30 m ($V_S(30)$) is the most important site specific parameter in seismic building codes and ground motion prediction equations (GMPEs). So far, there are several models to estimate $V_S(30)$ from average velocities to depths less than 30m $V_S(Z)$. 206 borehole data from the middle-eastern segment of Tianshan Mountain and 20 borehole data from the western segment of southern Tianshan Mountain, with the depth more than 30m, are collected. Five models, which are used to estimate $V_S(30)$ by $V_S(Z)$, are compared by these data. The model of H. Y. Wang et al. is the best for the region on the middle-eastern segment of Tianshan Mountain if $V_S(Z)$ to depth more than 20m. Then, $V_S(Z)$（Z =50 and 90m）are estimated by this model, Pearson correlation coefficient $r \geq 0.9972$ and standard deviations of residuals $\sigma_{RES} \leq 0.0088$. However, the region on the western segment of southern Tianshan Mountain, the model of D. M. Boore et al. is the best, the reason may be the distribution of $V_S(Z)$ is more concentrated and the quantity of data is not sufficient.

Introduction

The time-averaged shear-wave velocity to 30 m ($V_S(30)$) is widely used to judge site classes in seismic building codes[1,2,3], and it is considered as an important variable to estimate site amplification factors in GMPEs[4]. For the sites with shear-wave velocity profiles less than 30m, models need to be developed to estimate $V_S(30)$ [5]. Up to now, models have been established by different datasets. The efficiency of five of those models is analyzed by the data from two regions in China and the regional dependence is discussed in this paper.

Models

D. M. Boore[5] put forward the following equation to estimate $V_S(30)$ by $V_S(Z)$, based on the data from 135 boreholes in California, where the shear-wave velocity profiles reach at least 30 m.

$$\log V_S(30) = a + b\log V_S(Z) \tag{1}$$

where, a and b are regression coefficients.

H. Cadet et al.[6] employ Eq. 1 to calculate $V_S(30)$ for two regions, based on the data from 504 boreholes of the KiK-net sites in Japan and 22 boreholes from Europe, where the shear wave velocity profiles reach at least 30m and pointed out the empirical relations for the two regions are different.

D. Wang et al.[7] propose an equation to derive $V_S(30)$ for comparison with the Next Generation Attenuation models adjusted by the records from Wenchuan Earthquake. $V_S(30)$ can be calculated by Eq. 2.

$$V_S(30) = 30 / [(H_{top} / V_{se}) + (30 - H_{top}) / 500] \tag{2}$$

where, V_{se} is the average shear-wave velocity for soil layers in the top 20m or the thickness of overburden layers H_{top} less than 20m.

D. M. Boore et al.[8] employ Eq. 1 to calculate $V_S(30)$ for different regions, based on the data from 638 KiK-net borehole stations in Japan, 135 boreholes in California, 21 boreholes in Europe, and 228 sites in Turkey. They find that Eq. 1 is unfit to Japanese data, because those values of $V_S(30)$ are systematically higher than other regions . So he developed Eq. 3.

$$\log V_S(30) = c_{0E}\delta_E + c_0 + c_1 \log V_S(Z) + c_2[\log V_S(Z)]^2 \tag{3}$$

where, c_{0E}, c_0, c_1 and c_2 are regression coefficients; $\delta_E=1$ for class E ($V_S(30)<180$m/s) and $\delta_E = 0$ otherwise.

H. Y. Wang et al. [9] take advantage of travel-time averaged shear-wave velocities at two different depths ($V_S(Z_1)$ and $V_S(Z_2)$,and $Z_1 < Z_2 < 30$m) to derive $V_S(30)$ in the same profile. $V_S(30)$ can be calculated by

$$\log V_S(30) = \log V_S(Z_2) + \frac{\log 30 - \log Z_2}{\log Z_2 - \log Z_1}[\log V_S(Z_2) - \log V_S(Z_1)] \tag{4}$$

D. M. Boore[10]obtains a third velocity profile by interpolating two slowness models. We can get one slowness profile with the geometric means of the interpolated travel times[11]. Then, the slowness of the third profile to any depth Z, $S(Z)$, can be a linear combination of those of other two profiles, $S_1(Z)$ and $S_2(Z)$.

$$\bar{S}(Z) = (1-\beta)\bar{S}_1(Z) + \beta \bar{S}_2(Z) \tag{5}$$

When the slowness in Eq. 5 is replaced by average slowness $\bar{S}(Z)$, the coefficient β can be obtained, assuming equals to the desired value of in the target region. The average slowness and the time-average velocity are related by Eq. 6.

$$\bar{V}(Z) = \frac{1}{\bar{S}(Z)} \tag{6}$$

Data

To investigate the efficiency of these five models, Pearson correlation coefficient r and standard deviation of residuals σ_{RES}, between measured values $V_{SM}(30)$ and estimated values $V_{SE}(30)$, are adopted. Two datasets, consisted by 206 boreholes from the middle-eastern segment of Tianshan Mountain (METM) (N41.33° - N44.44°, E80.44° - E88.33°) and 20 boreholes from the western segment of Southern Tianshan Mountain(WSTM)(N38.33° - N41.30°, E73.66° - E78.60°) respectively, are established, in which the depths are more than 30m. The distribution of boreholes is shown in Fig. 1.

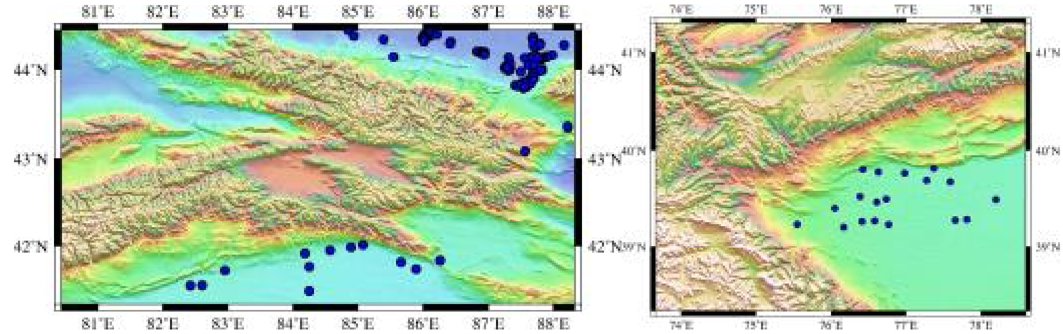

Fig. 1 – The distribution of boreholes in the regions of METM (left) and WSTM (right).

The percentage of borehole numbers in different intervals of time-averaged shear-wave velocity to the depth 5m, 10m, 15m, 20m, 25m and 30m is shown in Fig. 2.

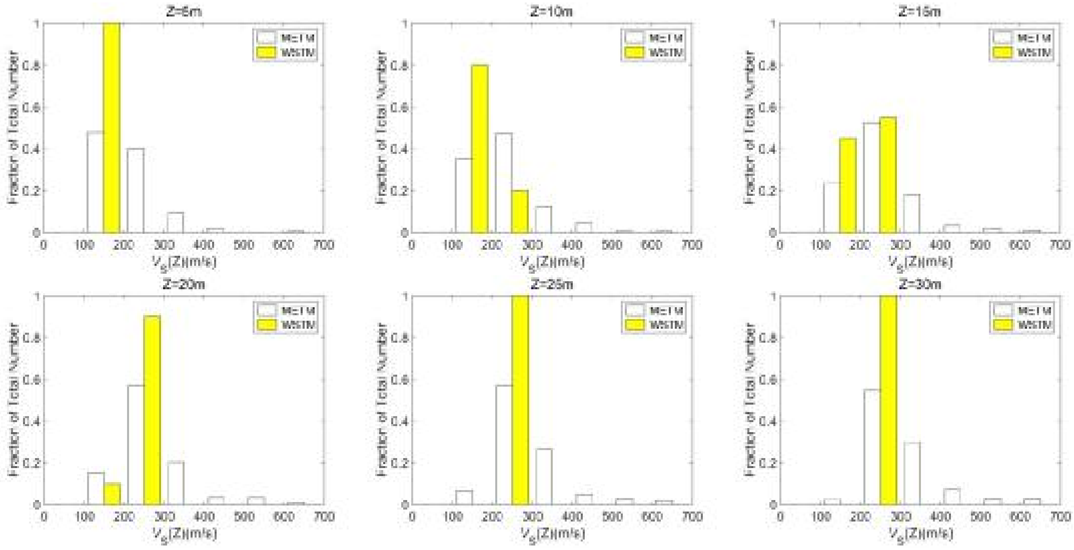

Fig. 2 –The percentage of borehole numbers in different velocity intervals

Results and Discussion

$V_{SE}(30)$ is calculated by empirical relations mentioned above. $V_{SM}(30)$ is calculated by Eq. 7.

$$V_{SM}(30) = \frac{30}{\sum_{i=1}^{n} \frac{Z_i}{V_{Si}}} \tag{7}$$

where, Z_i and V_{Si} are the thickness and the shear-wave velocity of the i^{th} layer; n is the total number of layers.The case of (5m, 10m), (10m, 15m), (15m, 20m), (20m, 25m) in Eq. 4 are used to represent the result of 10m, 15m, 20m and 25m, respectively. The comparisons for two regions are shown in Fig. 3 and Fig. 4, respectively. And the values are listed in Table 1.

Table 1 –r and σ_{RES} calculated by *D. Wang et al.* [7] for two regions

METM		WSTM	
r	σ_{RES}	r	σ_{RES}
0.9547	0.0101	0.9631	0.0444

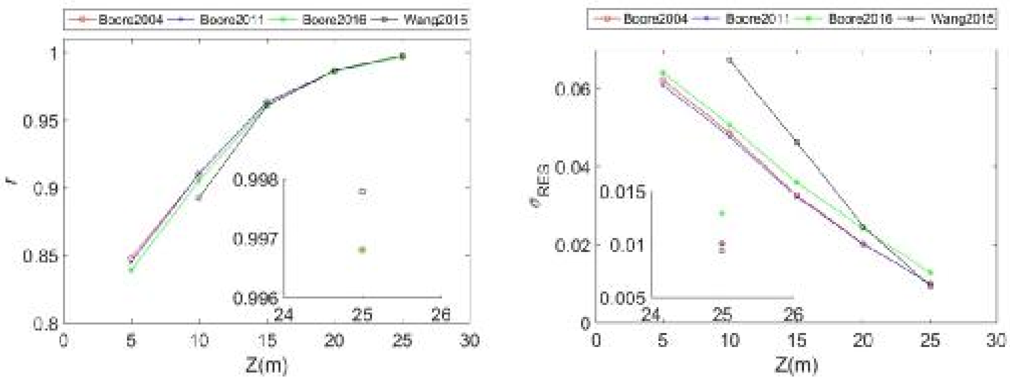

Fig. 3 – r and σ_{RES} for METM

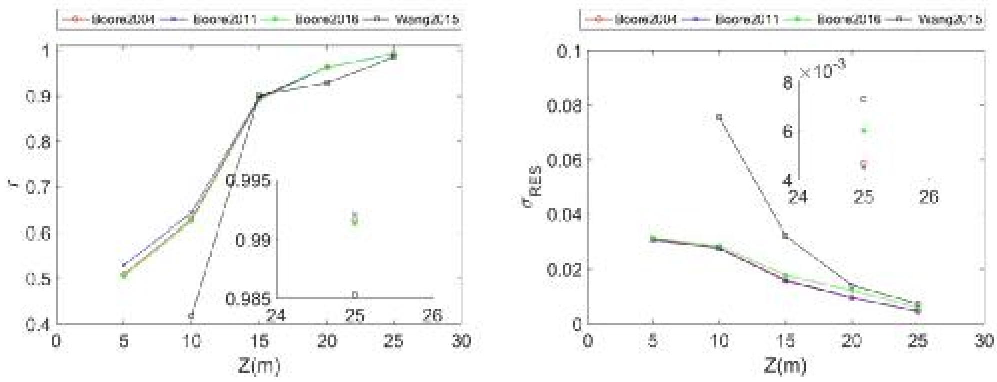

Fig. 4 – r and σ_{RES} for WSTM

From the figures and Table 1, to depth more than 20m, Eq. 4 is the best for METM, however, Eq. 3 is the best for WSTM. And then we select 82 boreholes to the depth 50m , 25 boreholes to 90m from the METM dataset and 3 boreholes to 50m from the WSTM dataset. Because Eq. 3 is proposed as the logarithmic quadratic polynomial model, which means that there is no need to analysis the WSTM dataset with deeper depths. And Eq. 1, Eq. 3 and Eq. 4 are used to calculate shear-wave velocity to deeper depths 50m and 90m, the Pearson correlation coefficients and the standard deviations of residuals almost do not vary with the target depths, which are shown in Table 2 and Table 3. In Eq. 1 and Eq. 3, the average shear wave velocity to the depth of 40m is used to calculate $V_{SE}(50)$, and that of 80m is for $V_{SE}(90)$; in Eq. 4, the velocity of 30m and 40m is used to calculate $V_{SE}(50)$, and that of 70m and 80m is for $V_{SE}(90)$. The results show that Eq. 4 is efficient for deeper depths.

Table 2 –r and σ_{RES} calculated to the depth 50m for METM

Eq. 1		Eq. 3		Eq. 4	
r	σ_{RES}	r	σ_{RES}	r	σ_{RES}
0.9919	0.1094	0.9919	0.1054	0.9972	0.0088

Table 3 –r and σ_{RES} calculated to the depth 90m for METM

Eq. 1		Eq. 3		Eq. 4	
r	σ_{RES}	r	σ_{RES}	r	σ_{RES}
0.9995	0.0039	0.9995	0.0038	0.9996	0.0035

Conclusions

Five models, estimating $V_S(30)$ by shear-wave velocity to less depth $V_S(Z)$, are compared by datasets from two regions. For both two regions, Eq. 3 is the best, the result from Eq. 1 is close to that from Eq. 3, and Eq. 5 is better than Eq. 4 if $V_S(Z)$ to depth less than 20m is used in the estimation. For METM, if $V_S(Z)$ to depth more than 20 m is used, Eq. 4 is the most efficient, however, the difference, among the results from different models, is not significant; for WSTM, more borehole data to deeper depth are needed. For the depth deeper than 30m, Eq. 4 is the most efficient, compared with Eq. 1 and Eq. 3.

Acknowledgments

This work was financially supported by Scientific Research Fund of Institute of Engineering Mech anics, China Earthquake Administration (Grant No. 2016A04), National Nature Science Foundation of China 51478443, 51178435 and 51678540.

References

[1] R. Dobry, R. D. Borcherdt, C. B. Crouse, I. M. Idriss, W. B. Joyner, G. R. Martin, M. S. Power, E. E. Rinne, and R. B. Seed, in: New site coefficients and site classification system used in recent building seismic code provisions, Earthq. Spectra Vol. 16 (2000), p. 41-67.

[2] Building Seismic Safety Council (BSSC), NEHRP recommended provisions for seismic regulations for new buildings and other structures, 2000 Edition, Part 1: Provisions, prepared by the Building Seismic Safety Council for the Federal Emergency Management Agency (Report FEMA 368), Washington, D.C. (2001)

[3] Eurocode 8, Design of structures for earthquake resistance, part1: General rules, seismic actions and rules for buildings, EN 1998-1, European Committee for Standardization(CEN) (2004)

[4] N. A. Abrahamson, G. Atkinson, D. M. Boore, Y. Bozorgnia, K. Campbell, B.Chiou, I. M. Idriss, W. Silva, and R. Youngs, in: Comparisons of the NGA ground-motion relations, Earthq. Spectra Vol. 24 (2008), p. 45-66

[5] D. M. Boore, in: Estimating $\bar{V}_S(30)$ (or NEHRP site classes) from shallow velocity models (depths <30 m), Bull. Seismol. Soc. Am Vol. 94 (2004), p. 591-597.

[6] D. M. Boore, E. Thompson, and H. Cadet, in: Regional correlations of V_S30 and velocities averaged over depths less than and greater than 30 meters, Bull. Seismol. Soc. Am Vol. 101 (2011), p. 3046-3059.

[7] H. Cadet and A. M. Duval, in: A shear wave velocity study based on the KiK-net borehole data. A shortnote, Seismol. Res. Lett Vol. 80 (2009), p. 440-445

[8] D. Wang, L. L. Xie, N. A. Abrahamson, and S. Y. Li, in: Comparison of Strong Ground Motion from the Wenchuan, China, Earthquake of 12 May 2008 with the Next Generation Attenuation (NGA) Ground-Motion Models. Bull. Seismol. Soc. Am Vol. 100 (2010), p. 2381-2395

[9] H. Y. Wang and S. Y. Wang, in: A New Method for Estimating $V_S(30)$ from a Shallow Shear-Wave Velocity Profile (Depth <30 m), Bull. Seismol. Soc. Am Vol. 105 (2015), p. 1359-1370.

[10]D. M. Boore, in: Short Note Determining Generic Velocity and Density Models for Crustal Amplification Calculations, with an Update of the Boore and Joyner (1997) Generic Site Amplification for $\bar{V}_S(Z)$=760m/s, Bull. Seismol. Soc. Am Vol. 106(2016), p. 316-320.

[11] D. M. Boore and W. B. Joyner, Site Amplifications for Generic Rock Sites, Bull. Seismol. Soc. Am Vol. 87 (1997), p. 327-341.