CHAPTER V

RESULTS AND INTERPRETATIONS

5.1 Overview

In this chapter the results from different kinds of tests are presented. The additional shear wave velocity profiles from downhole test at Chulalongkorn University and AIT are taken Ashford et al. (1997). Also, an extra result from SCPT at AIT is extracted from Shibuya et al. (2002. Two Vs profiles computed from MASWM are checked with those of mentioned sources. The shear wave velocities profiles determined by seismic downhole test are considered as the principle reference for comparison because they are obtained from the direct measurement at the site. On the other hand, the empirical formula used to convert the number of blows (N values) from SPT (Standard Penetration Test) and the undrained shear strength of Bangkok soft clay from UC test to shear wave velocities are personally based on many assumptions, therefore it is taken into account as the second reference for this evaluation. In addition, we also make verification by comparing the variation the soil classification along depth with the changes of Vs values. The mathematical model for comparison is based on percentage of differences.

5.2 Results from Downhole Test and Boring Reports

The original value of Vs profiles from seismic downhole tests are summarized in table B-1 (Appendix B). Whereas the boring report showing only the undrained shear strength for Bangkok soft clay, number of N value from SPT, and soil classification are summarized in table B-2 (Appendix B). The boring data are sufficient to determine the shear wave velocity by the following empirical formula;

For Bangkok soft clay (Ashford et al., 1997):

$$V_s = 68.7 s_u^{0.475} \tag{5.1}$$

The equation (5.1) was derived from a downhole test data performed at AIT that is considered as the limitation of this formula.

For all types of soil (Imai and Tonouchi, 1982):

$$V_s = 96.926N^{0.314} \quad (5.2)$$

The corresponding units of undrained shear strength (s_u), SPT- N value, and shear wave velocity (V_s) in equation (5.1) and (5.2) are [t/m^2], [blow/ft] and [m/s], respectively. The calculated Vs profiles versus depth are shown in Table B-3 (Appendix B).

5.3 Extra References from Downhole Test and SCPT

After Ashford et al. (1997) the Vs profiles at Chulalongkorn University and AIT are shown in Table 5-1. The Vs profile at AIT by SCPT according to Shibuya et al. (2002) is shown in the same table.

Table 5-1 Shear wave velocity from Downhole test and SCPT

Downhole Test				SCPT	
CU		AIT		AIT	
Depth	**Vs**	**Depth**	**Vs**	**Depth**	**Vs**
(m)	(m/s)	(m)	(m/s)	(m)	(m/s)
0-4.0	60	0-9.0	80	2.5	275
4.0-11.5	95	9.0-18.0	170	3.0	170
11.5-19.0	205	18.0-32.5	260	3.5	100
19.0-29.0	255	32.5-61.0	335	4.0	75
				4.5	75
				5.0	75
				5.5	80
				6.0	85
				6.5	90
				7.0	90
				7.5	100
				8.0	130
				8.5	170
				9.0	185
				9.5	150

5.4 Data Comparison and Interpretation

The shear wave velocity inverted from experimental dispersion curves (figure 4-21 to 4-27) are shown in table A-1 (Appendix A). The Vs profiles are plotted and shown in figure 5-1 to 5-7. The Vs profiles can be extracted until the depth of interest for most of the sites: (Chula, TMD Bangkok, AIT, Kirdkao Observatory, and TMD Kanchanaburi). However, there are some places that the prospecting could not reach the targeted depth. For the sites that the unsatisfactory performance may be caused by:

1. The seismic source is not powerful enough to drive the incident wave to a particular distance.
2. The limited distance between the source and the first geophone. Since the signal of the first channel is much stronger than that of a distance channel, the signal at low frequency (long wavelength) is almost buried by the ones at high frequencies in f-k spectrum.
3. The boundary condition in the field. For example, at Wat Chediluang, we have unintentionally arranged the geophone array closed to a temple. As a result, the data contains a lot of noise due to the reflection from the foundation and obstacle as shown in figure 4-20.

For the downhole test results, the majority of Vs considerably oscillate along the depth. It is suspected that the sampling rate was not sufficient and let to the inconsistency in selecting the arrival time of S-wave.

Figure 5-1 shows five different Vs profiles conducted at Chulalongkorn University: two acquired from MASWM, other two from downhole test performed by Chula research group and Ashford et al. (1997) and another one inverted from boring log report. The first two Vs values are compared one by one with another three as appeared in Table C-1 (Appendix C). The average relative difference (ARD) between the two Vs values from MASW and those from downhole test (Chula research group) are 26% and 14% for $\lambda/2$ and $\lambda/3$, respectively while 30% and 21% compared with Ashford's. By excluding the upper 4m layer, the difference drops to only 28% and 17% from Ashford. The differences between Vs from MASW and boring report are 32% for $\lambda/2$ and 21% for $\lambda/3$. The same evaluation method has been applied to the data obtained from the remaining sites.

Four Vs profiles at TMD Bangkok are plotted in Figure 5-2. From the graphs we observe that the Vs values computed by λ/3 approach seem to well-fitted with those of other two methods in which it shows only 11% and 14% differences in Vs from downhole and boring log, respectively. Because within these 20m, the results obtained form downhole as well as boring log are not so oscillated, but change smoothly along with Vs profile from λ/3. It shows a good potential of λ/3 method to investigate at the depth of 20m. While, Vs calculated by λ/2 give worse number of 25% for downhole and 27% for boring report (details calculation in Table C-2, Appendix C).

In the case of Vs profiles at AIT (Figure 5-3), there are a number of researchers who have been investigated the soil in this area. Totally, we have six different Vs values: five Vs from the same sources as Chula site and an extra one from SCPT after Shibuya et al. (2002). However, the ARD increase to 37% for λ/2 and 27% for λ/3 comparing to downhole tests performed by Chula group, but only to 16% and 17%, respectively comparing to Ashford's. The downhole offered quite fluctuated Vs profiles from one point of depth to another from which large different gaps were recognized comparing to MASW. Nevertheless, Vs from λ/3 changed consistently with the classified data from Ashford. Shibuya et al. (2002) offered Vs profile only up to 9m depth since SCPT equipment was not able to penetrate into stiff clay layer. Within these depths, the top 3m soil layer have Vs values higher than the usual value determined by other methods, but it shift to the acceptable range for the rest (see Table C-3, Appendix C). The deviation of Vs from MASW and boring reports appears just similar to the site at Chulalongkorn University.

Vs profiles at three sites in the middle part of Thailand increase almost linearly with depth which is well-matched with Teachavorasinskun *et al.* (2004).

The effectiveness of MASWM can be noticed in Figure 5-4 or Table C-4, where merely a few meters depth of borehole can be made. Since Kirdkao Observatory is on the high plateau underlying by bedrock layers, the boring report as well as seismic downhole test were performed only up to these depths. On the contrary, the MASWM was able to explore down to 15m or deeper.

Figure 5-5 illustrates four sets of Vs profiles at TMD Kanchanaburi. There is no significant change from the previous sites, the ARD for the Vs values of MASWM remain 23% for λ/2 and 22% for λ/3 comparing with downhole and 13% and 18% with boring reports for λ/2 and λ/3, respectively (detail calculation in Table C-5, Appendix C). Obviously, Vs profiles from downhole at 6 to 12m depth vary between those from MASWM and show small differences, but for the rest the downhole data seem to move back and forth that make ARD to increase.

The shear wave velocity profiles at Chiang Mai University are shown in figure 5-6. For this site, it is difficult to make comparison since Vs from the three different investigation techniques appear distinctively. However, a brief preview of calculation is shown as a large gap between MASWM and boring log with 85 and 105% ARD for λ/2 and λ/3, respectively. While comparing to the main reference (downhole test) 27% difference for λ/2 and 32% for λ/3 are found (example in Table C-6). Within these numbers only at the top layer from 1 to 6m was indicated good correlation between downhole and λ/3 method.

The four Vs profiles at Wat Chediluang, Chiang Mai province are plotted in Figure 5-7 from computation in Table C-7 (Appendix C). The smallest percentage of error between MASWM and boring report is observed among all the investigated sites with just 15% and 9%, respectively. On the other hand, Vs from downhole test is shown higher than others.

To sum up, a series of shear wave velocity profiles at seven different sites present quite fluctuated results for comparison, yet going to the same circumstance that we can conclude the suitable approach for simplified application of MASWM to subsoil in Thailand. That is λ/3 approach. The shear wave velocity profiles of middle part of Thailand investigated by MASWM show almost a linear increase with depth that was experimentally proved by the previous researchers. Most of Vs from MASWM were found a smooth transition along the depth while those from downhole and boring report are a bit oscillated which makes it difficult to evaluate. It may be improved by using moving average method to smoothen the data.

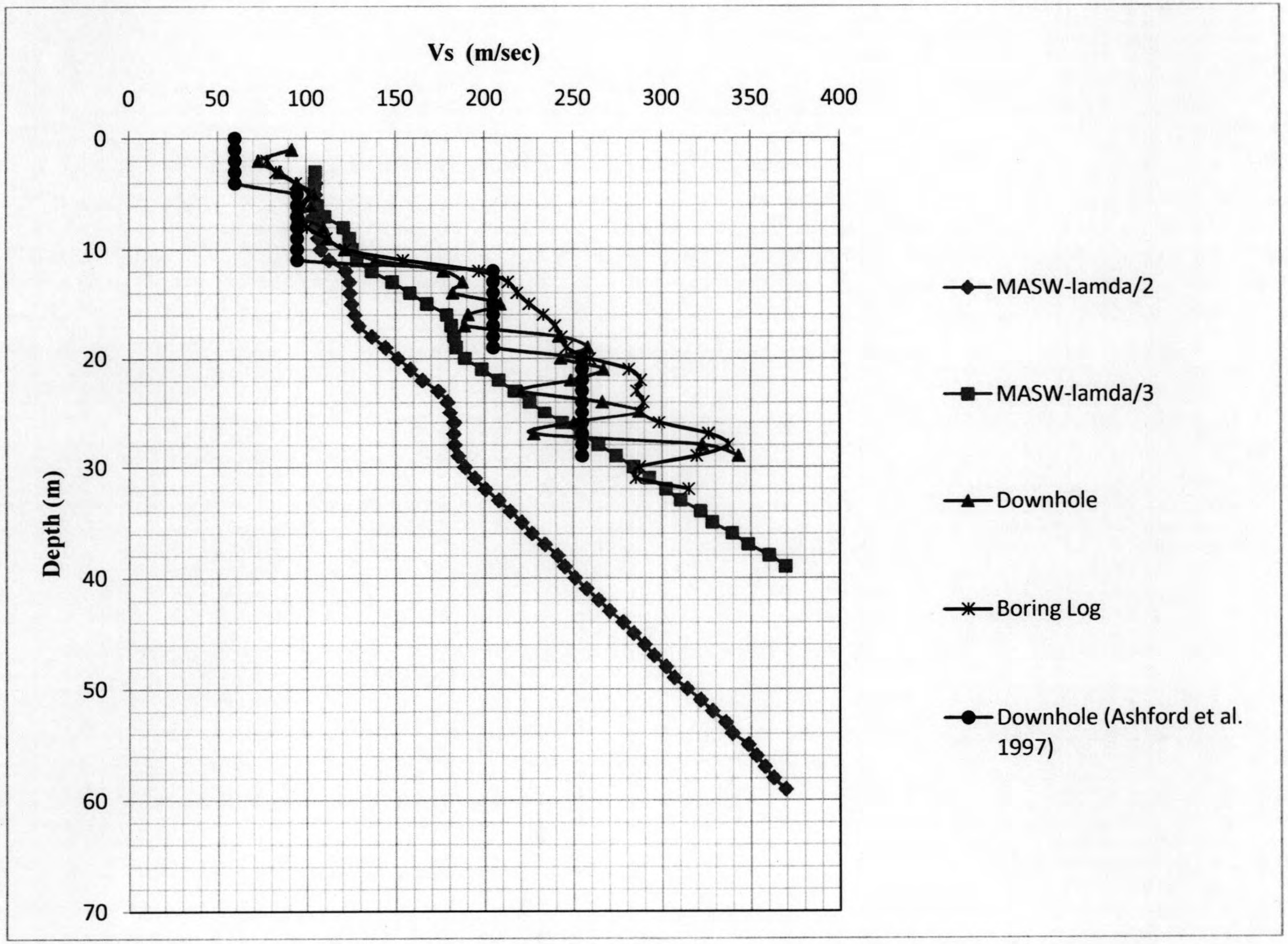

Figure 5-1 Shear wave velocity profiles from various sources of in situ testing at Chula

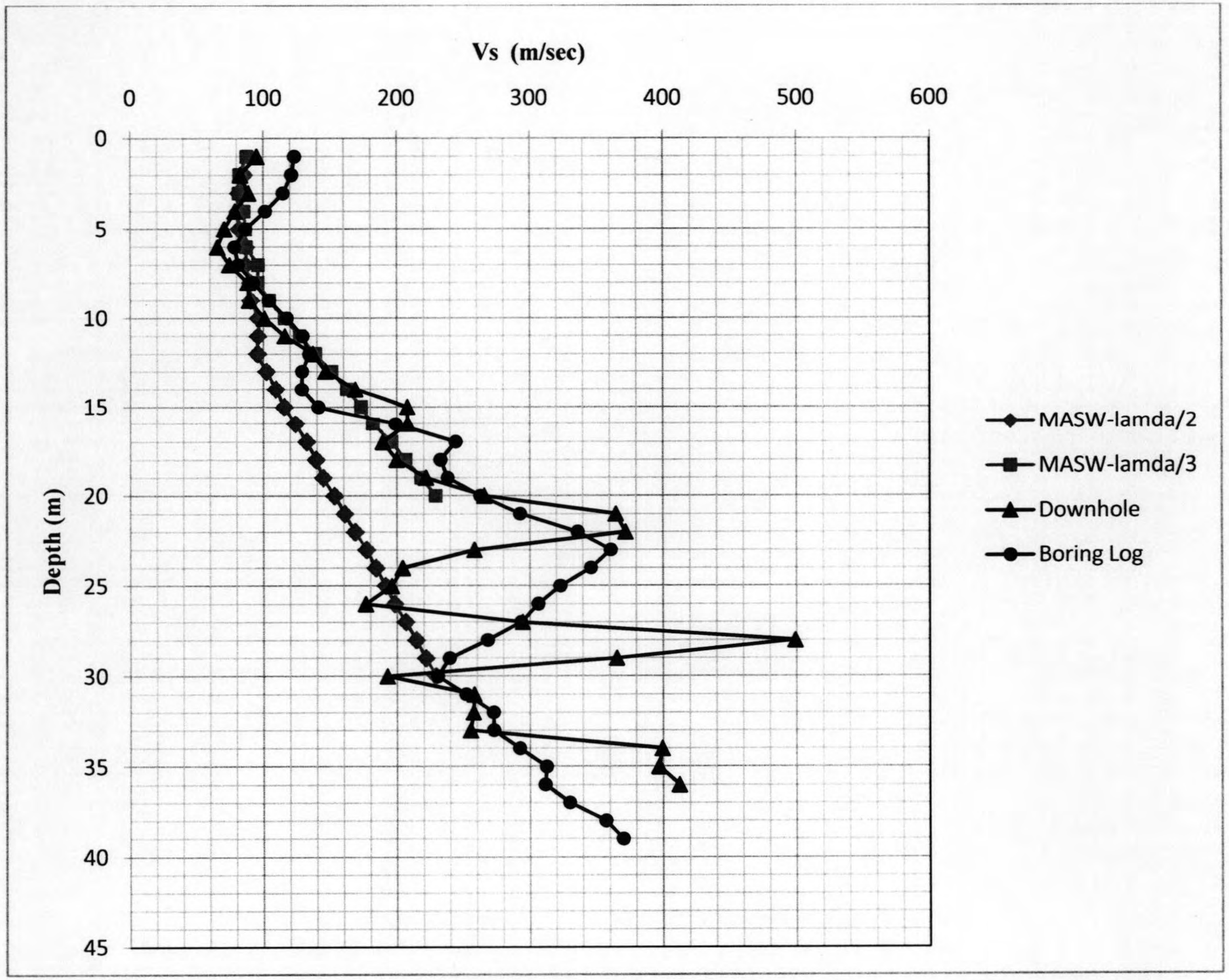

Figure 5-2 **Shear wave velocity profiles from various sources of in situ testing at TMD Bangkok**

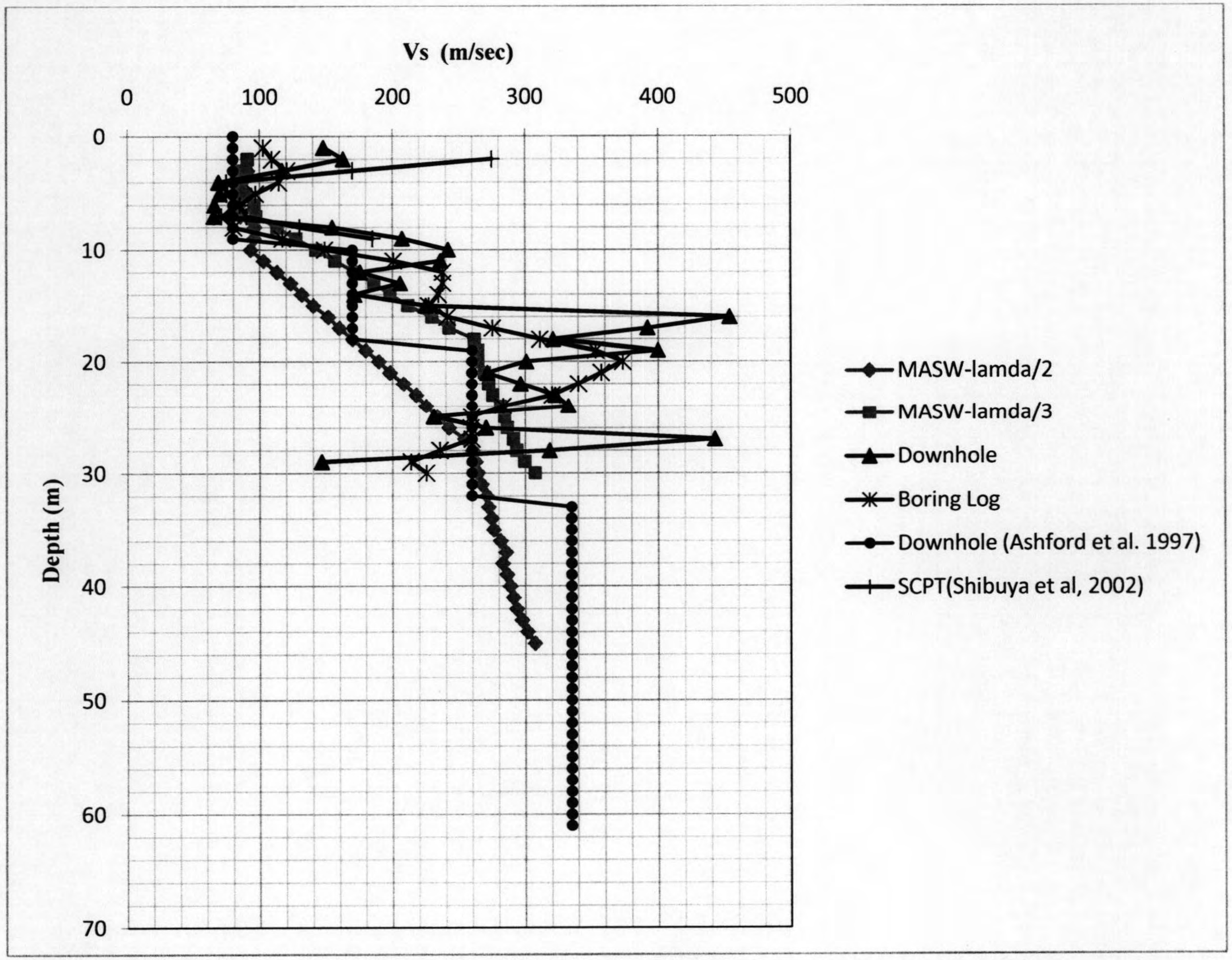

Figure 5-3 **Shear wave velocity profiles from various sources of in situ testing at AIT**

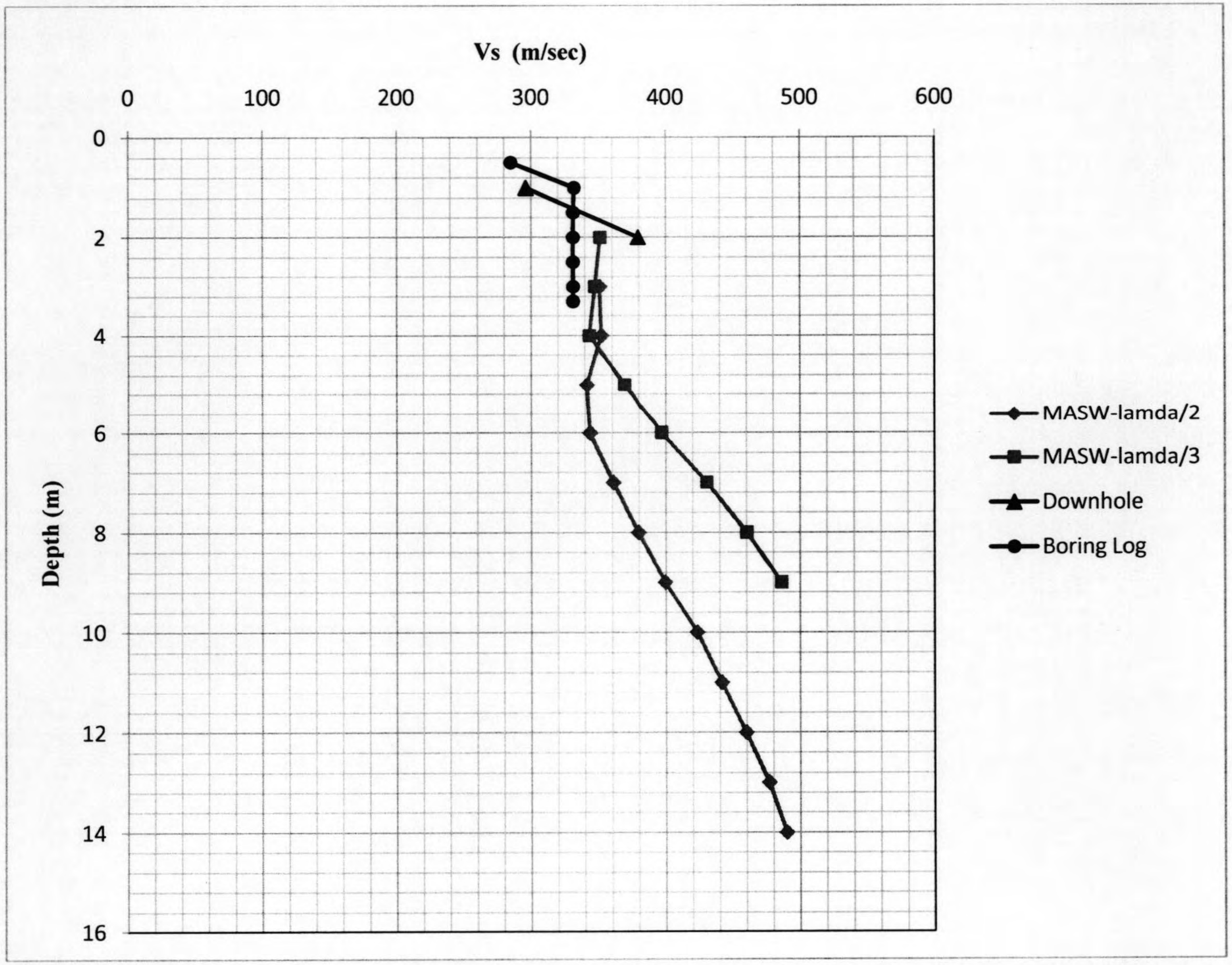

Figure 5-4 **Shear wave velocity profiles from various sources of in situ testing at Kirdkao Observatory, Kanchanaburi**

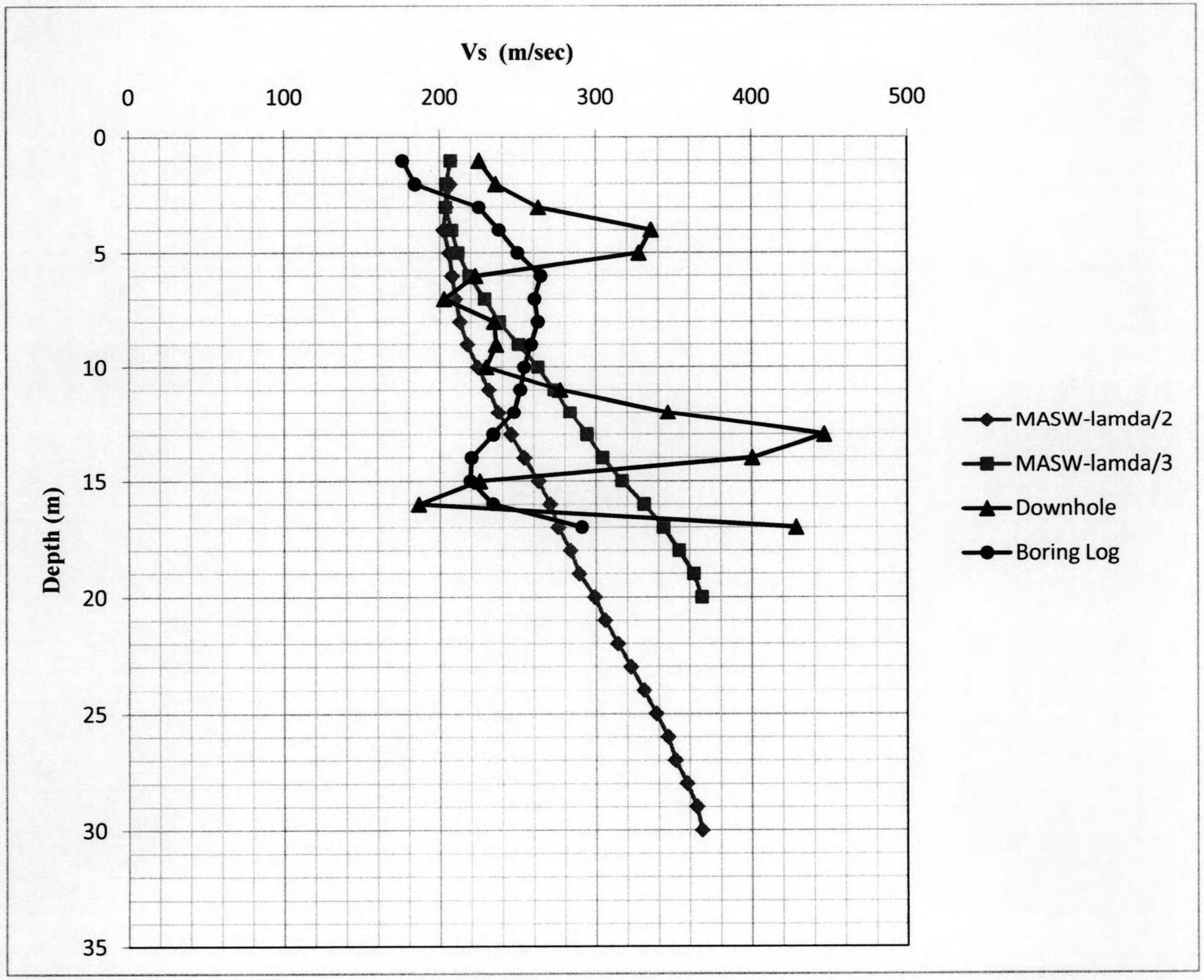

Figure 5-5 **Shear wave velocity profiles from various sources of in situ testing at TMD Kanchanburi**

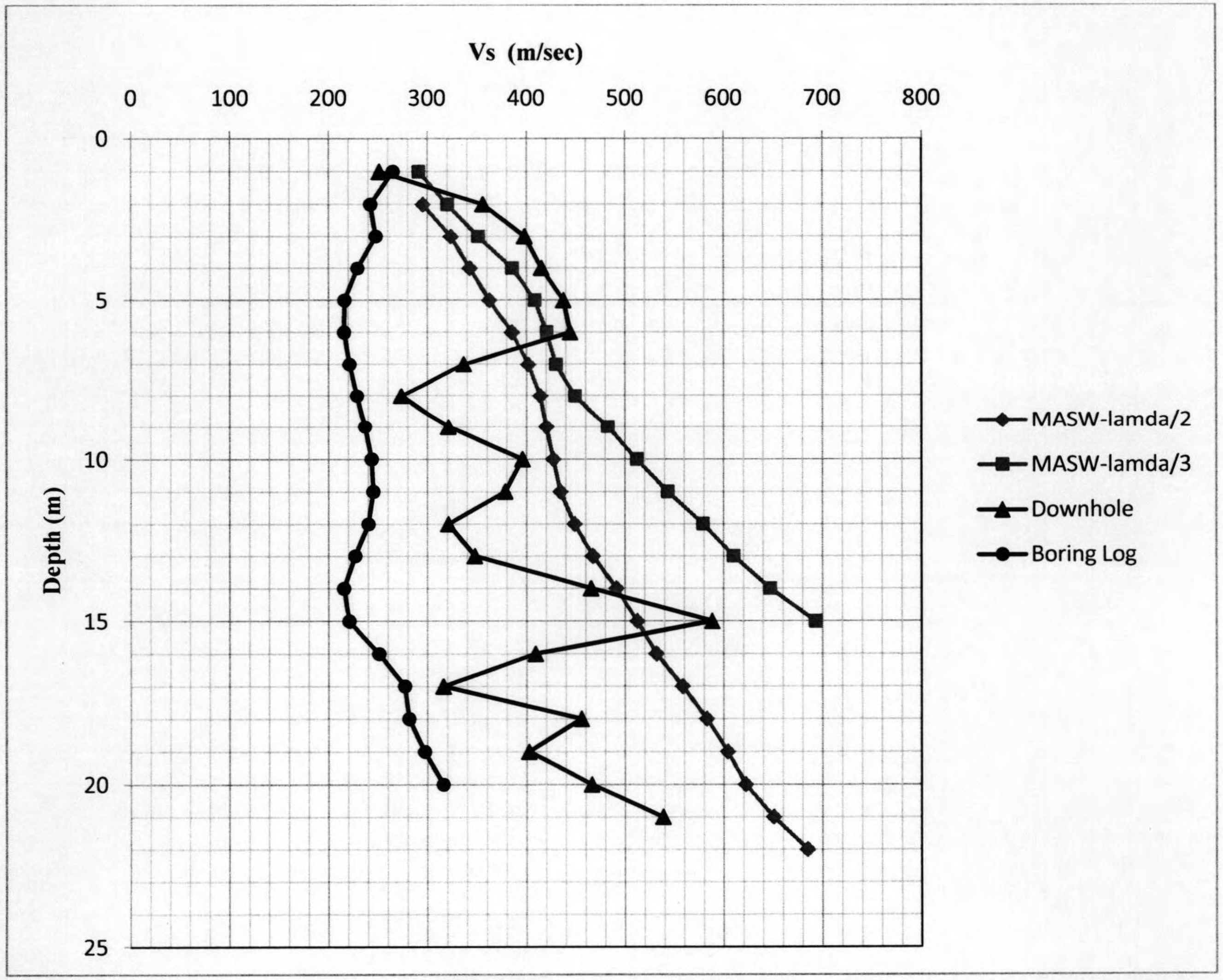

Figure 5-6 **Shear wave velocity profiles from various sources of in situ testing at Chiang Mai University, Chiang Mai**

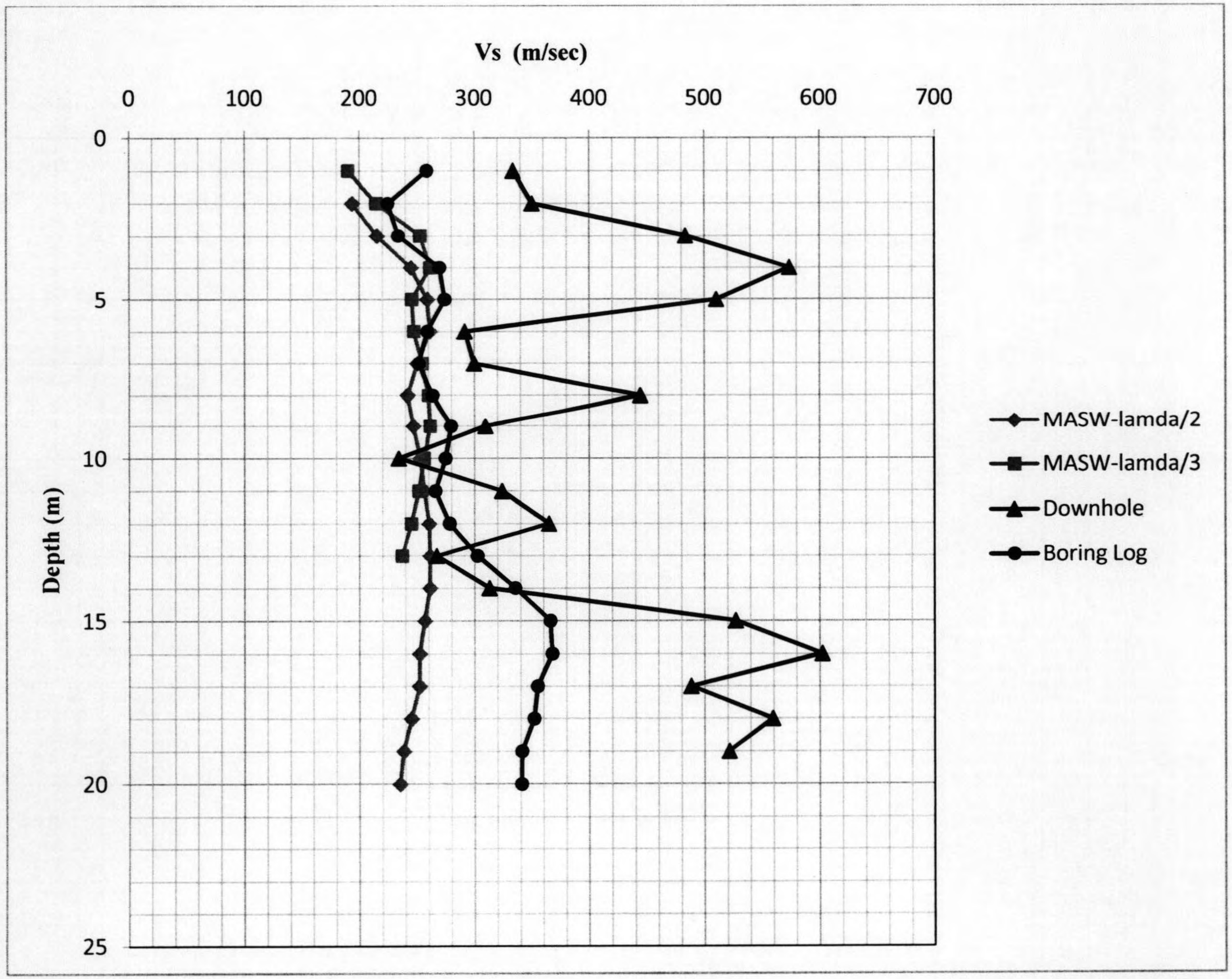

Figure 5-7 **Shear wave velocity profiles from various sources of in situ testing at Wat Chediluang, Chiang Mai**