Comparison of Geophysical Shear-Wave Velocity Methods in Earth and Rock-Fill Dam

Suttisak Soralump[1], Jitrakon Prasomsri[2] and Buncharee Kumma[3]

[1] Associate Professor and [2, 3] Master Student, Dam Safety Research Unit, Geotechnical Engineering Research and Development Center, Civil Engineering Department, Faculty of Engineering, Kasetsart University, Bangkok 10900, Thailand

Email: [1] soralump_s@yahoo.com, [2] jitrakon.mx@hotmail.co.th, [3] maruko_sos@hotmail.com

Abstract

Geophysics survey continues to be most common technique to evaluate shear wave velocity. The shear wave velocity is needed to evaluate the shear stiffness of the dam material, in this study, two surface wave techniques, SASW, MASW were conducted at some dam site in Thailand. Furthermore, cross-hole, down-hole shear wave velocity and empirical equations were also used. By comparing shear wave velocity obtained from two surface wave techniques it is found that the dispersion data was generally in good agreement, and the shear wave velocity profiles were compared with cross-hole and down-hole.

Keywords: Geotechnical, Geophysics, Shear waves, Surface waves, Earth dam, Rock-fill dam

1. Introduction

As for dynamic response analysis of earth and rock-fill dam, the key dynamic soil properties are low-strain shear stiffness and material damping. In fact, the shear stiffness is generally correlated with the surface shear wave velocity, Vs. The generally used field methods for obtaining Vs are cross-hole, down-hole, spectral analysis of surface wave (SASW) and multi-channel analysis of surface wave (MASW). These methods can be provides greater knowledge of the elastic soil properties ([1] Kramer, 1996; [2] Bay and Chaiprakaikeow, 2006; [3] Bay and Chaiprakaikeow, 2009).

In this study the shear wave velocity data testing by low-strain field tests in some earth and rock-fill dam sites are summarized and presented. The results presented herein may be used directly or as a guide in dynamic response analysis for new or the rehabilitation of existing earth and rock-fill dam in Thailand.

2. Dam site characteristics

The studied dams in the present work comprise of 11 dams located in Thailand. The main characteristics of dam site and field testing condition are summarized in the Table 1. The studied dams were divided of four dam types consist of zone with random dam, homogeneous dam, clay core rock-fill dam, and concrete face rock-fill dam. Each dam was tested by different field testing as shown in the table. Most of the dams were carried out by SASW and MASW testing.

Based on the classified dam component that was proposed by [4] Kumma (2010), the data of 37 dam projects in Thailand were used for statistical analysis. Those dams were classified for a dam component according to standard of [5] USBR (1987) and [6] USBR (1988). They are (1) homogeneous zone, (2) core zone, and (3) shell zone. Table 2 is a guideline for general classification of dam material.

Table 1: Compilation of dam data for this study

Dam	Name in this study	Dam type	Province	High m	No. of in situ test			Testing position
					SASW	MASW	Cross-Hole & Down-Hole	
Krasaew	Krasaew	Homogeneous	Suphan Buri	32.5	-	2H*	-	Homogeneous
Sirikit	SRK	with random	Uttaradit	113.6	7C, 5S	-	-	Core and shell
Sirikit Dike 2	SRK Dike 2	Homogeneous	Uttaradit	27	4H	3H	-	Homogeneous
Sirikit Dike 4	SRK Dike 4	Homogeneous	Uttaradit	28.5	2H	1H	-	Homogeneous
Ratchaprapa	RPB	Rock-fill clay core	Surat Thani	94	4C, 3R	-	-	Core and rock-fill
Ratchaprapa Dike 1	RPB Dike 1	Rock-fill clay core	Surat Thani	35	-	7C	-	Core and rock-fill
Ratchaprapa Dike 3	RPB Dike 3	Rock-fill clay core	Surat Thani	11	-	4C	-	Core and rock-fill
Ratchaprapa Dike 4	RPB Dike 4	Rock-fill clay core	Surat Thani	26	-	11C	-	Core and rock-fill
Ratchaprapa Dike 5	RPB Dike 5	Rock-fill clay core	Surat Thani	20	-	7C	-	Core and rock-fill
Srinagarind	SNR	Rock-fill clay core	Kanchanaburi	140	4C, 4R	-	-	Core and rock-fill
Vajiralongkorn	VRK	CFRD	Kanchanaburi	92	3R	-	3R	Rock-fill

Note: H=Homogenous, C= core, S=Shell, R=Rock-fill

Table 2: Classification of dam type based on classification of dam material.

Dam component	Soil classification (USCS)
Homogeneous	GC, GM, GM-GC, SC, SM, SC-SM, SM-SC, CL, CL-ML, ML
Core zone	GC, SC, CL
Shell zone	GM, GM-GC, SM, SC-SM, SM-SC, CL-ML, ML

Source: [7] Soralump (2011)

3. Vs from Spectral Analysis of Surface Wave, (SASW) for Earth-Fill Materials

The general idea of SASW testing is to generate surface waves over a broad range of frequencies, and measure the velocity of the waves at various frequencies. From the velocity of high-frequency waves it is determined the shear wave velocity (and shear modulus) of shallow soils, and lower frequency waves give us information about the deeper materials ([2] Bay and Chaiprakaikeow, 2006).

The shear wave velocity profiles of each tested dam component according to Table 2 are presented in Figure 1, including SASW testing result from Sirikit dam, Sirikit dike, Srinagarind dam, Ratchaprapa dam, Ratchaprapa dike and Ratchaprapa saddle dam.

The summary results of core zone component show a general trend of increasing shear wave velocity with increasing effective overburden pressure at 400 kPa, (Figure 1a). Most of shear wave velocities of core zone component are more than 36o m/s this corresponds to a range of stiff clay to soft rock.

At the homogenous zone component, the SASW method provide considerable trend in range of effective overburden pressure of 0 to 100 kPa, below 100 kPa, these trends are a considerable variation in the test results, it possible that a homogenous dam having a potential variation in earth fill materials. The range of shear wave velocities are also corresponds to of stiff clay to soft rock (Figure 1b).

For the shell zone component, shear wave velocities of Sirikit dam is presented (Figure 1c). At this component the shear wave velocities were in relatively good agreement and the range of shear wave velocities are also corresponds to of stiff clay to soft rock. However, for SASW test on shell in another dam site is needed to be compared with these results.

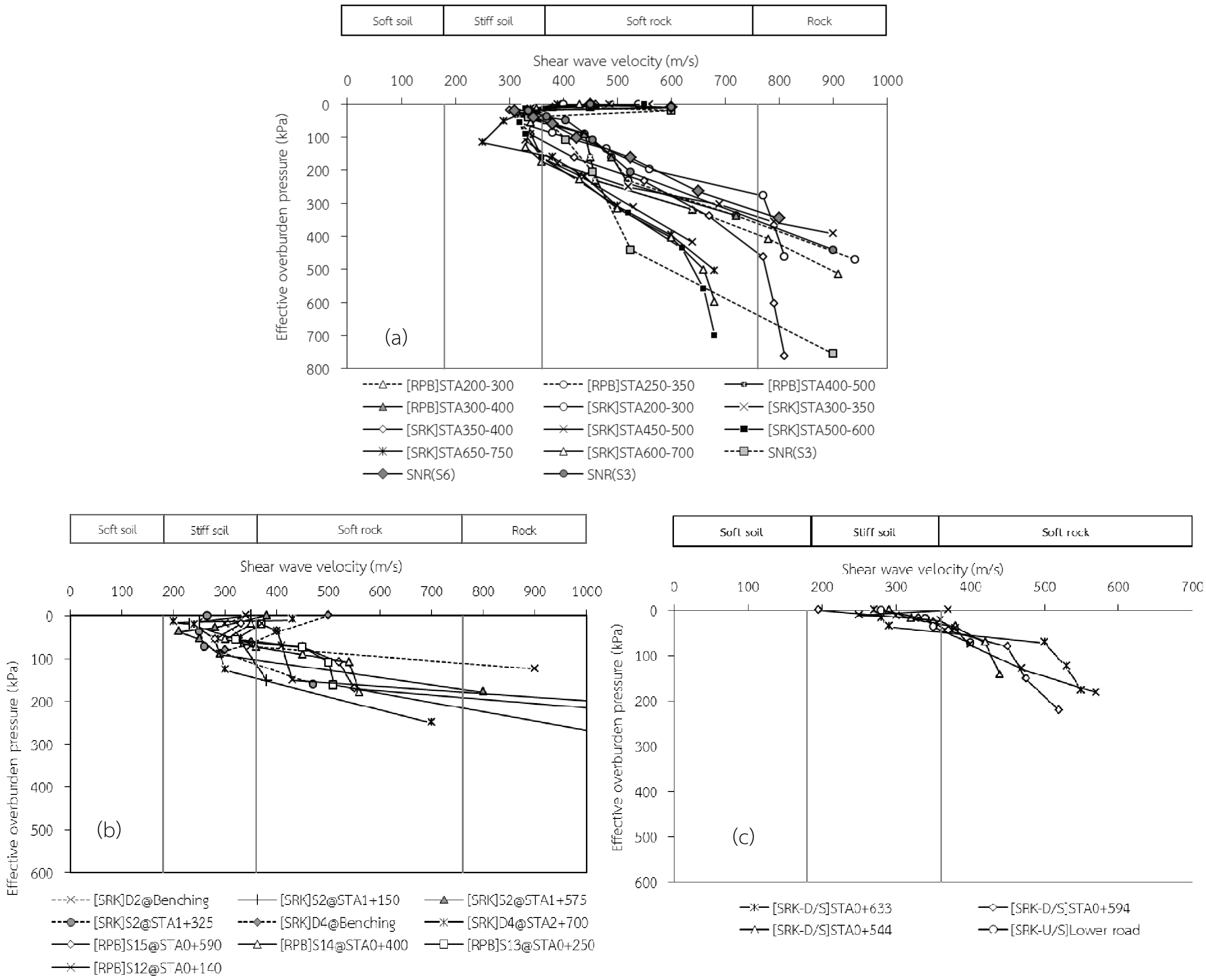

Figure 1 Shear wave velocity profile of SASW tests: a) core zone, b) homogeneous zone and c) shell zone

4. Vs from Multi-channel Analysis of Surface Wave, (MASW) for Earth-Fill Materials

In multi-channel analysis of surface wave, MASW method, multiple numbers (usually twelve or more) of receivers with many-channel seismograph is used. Receivers are planted with equal spacing and either single geophone or a group of multiple geophones can be used as a receiver. Because basic field configuration is very similar to that for body-wave surveying only with slightly different criterion on the optimum data-acquisition configuration ([8] Park et al., 1996), the surface-wave survey can be performed as a by-product of body-wave surveying, making 100 percent of recorded seismic energy useful. Even when a separate surveying with unfavorable configurations for body-wave recording is essential, the recorded body wave fields will not be useless for the surface-wave analysis ([9] Park et al., 1997).

In this study, the MASW is performed on small to medium dam size consist of Ratchaprapa Dike 1, Dike 3, Dike 4 and Dike 5 for core zone component, Sirikit Dike 2 and Dike 4 for homogenous zone component. The results of both components are shown in Figure 2, which also plot with effective overburden pressure. It was found that the core zone component provide a reasonable trend of shear wave velocity profiles in effective overburden pressure to 300 kPa. For the homogenous zone component, it can be seen that the test results of shear wave velocities are slightly variation, it possibly reflecting the potential variation in soil layers of the dam sites.

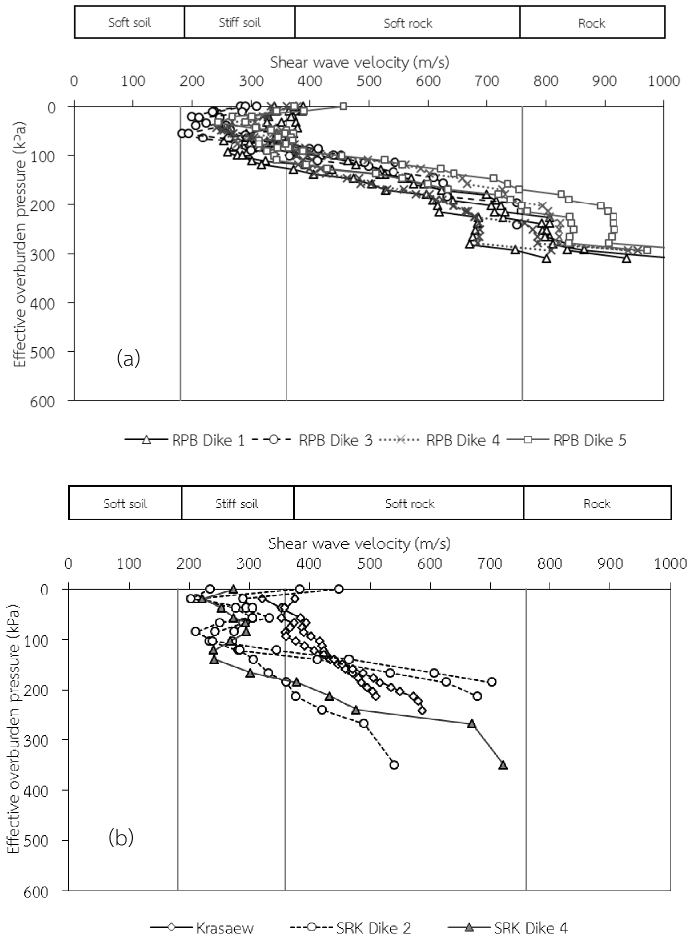

Figure 2 Shear wave velocity profile of MASW tests; a) core zone and b) homogenous zone

5. Comparing Vs from SASW and MASW

The comparison of seismic shear wave velocity profiles with both of surface seismic method is shown in Figure 3. For comparing of surface seismic methods, Sirikit dike 2 and dike 4 must be used. It can be seen that trend of the both of surface seismic method is in good agreement in the upper effective overburden pressure of 200 kPa this reveals the MASW is an efficient method of investigating elastic property for some project of small to medium size homogeneous in Thailand.

6. Vs from Cross-Hole, Down-Hole and SASW tests on Rock fill Material

Seismic cross-hole tests use at least two boreholes to measure wave propagation velocities. The simple cross-hole test arrangement comprise of two boreholes, energy source and receiver. For fixing both the source and the receiver at the same depth in each borehole, the wave propagation velocity of soil between the boreholes at that depth is measured. For testing at various depths, a velocity profile can be obtained. Wave propagation velocities can be determined from differences of arrival time adjacent pairs of boreholes. The arrival time can be determined by using first arrival or first peak of output shear wave ([10] Roesler, 1977).

Seismic down-hole tests can be performed in a single borehole. Impulse source is placed on the ground surface, a single receiver can be moved to different depths, it is fixed against the walls of the borehole, and single triggering receiver is located at the energy source. A high speed recording system is used to connect the receivers therefore data output can be measured as a function of time ([11] Redpath et al., 1982).

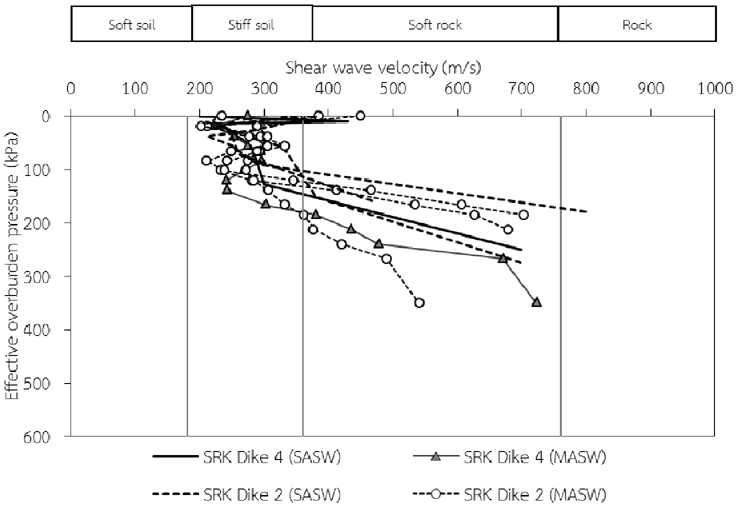

Figure 3 Comparison of shear wave velocity profile by SASW and MASW for homogeneous dam

In this present work, the cross-hole and down-hole were tested on Vajiralongkorn dam (VRK), which is concrete face rock-fill dam (CFRD), located in Kanchanaburi, Thailand. A summary of the cross-hole and down-hole test results is presented in Figure 4. The both test results show a common trend of increasing shear wave velocity with effective overburden pressure to about 200 to 300 kPa, below which the velocities are relatively constant. This shear wave velocity corresponds to a zone of soft rock to rock layers.

In this dam site also was carried out by SASW test for evaluated Vs. The comparison of the cross-hole, down-hole and SASW tests are shown on Figure 5. The results show that the three methods provide relatively good agreement in the upper 600 kPa. Below 6oo kPa the cross-hole measured shear wave velocities are relatively lower than that results of down-hole and SASW tests, there is a considerable variation in the test methods, it is possible that reflecting the variation in rock-fill.

7. Conclusions

1. Since all of the dam in Thailand have to be built under the same standard, therefore the variation of Vs obtained from the field testing of each dam component seems to be small. Figure 6 concludes the recommendation for Vs function range of each dam component for using in dynamic response analysis of the dam in Thailand.

2. the MASW is an efficient method of investigating elastic property for some project of small to medium size of earth and rock-fill dam in Thailand, they have limited necessity to perform seismic surface wave tests for evaluate V_s

8. Acknowledgements

The authors would like to thank Geotechnical Engineering Research and Development Center and Civil Engineering Department (GERD), Kasetsart University for useful suggestion, Electricity Generating Authority of Thailand (EGAT) and Royal Irrigation Department, Thailand for useful information.

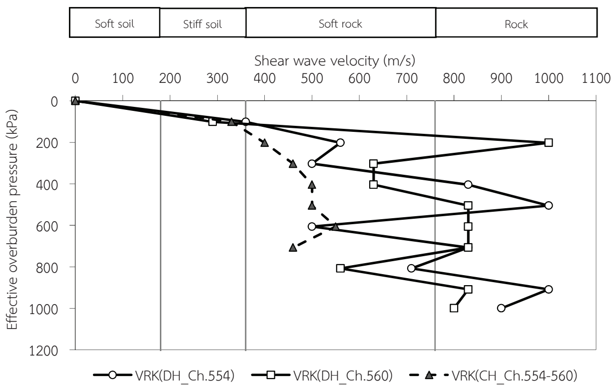

Figure 4 Comparison of shear wave velocity profile of cross-hole test and down-hole test of rock-fill material

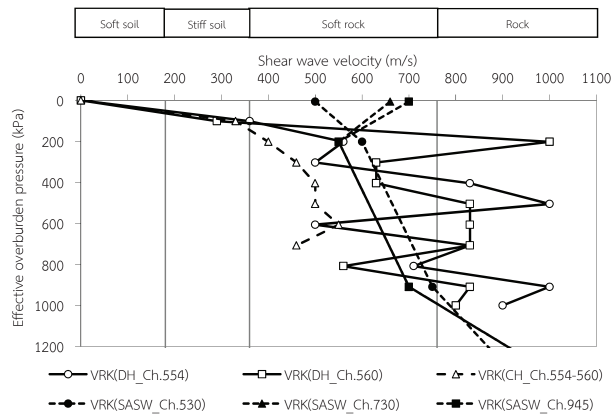

Figure 5 Comparison of shear wave velocity profile of cross-hole test, down-hole test and SASW of rock-fill material

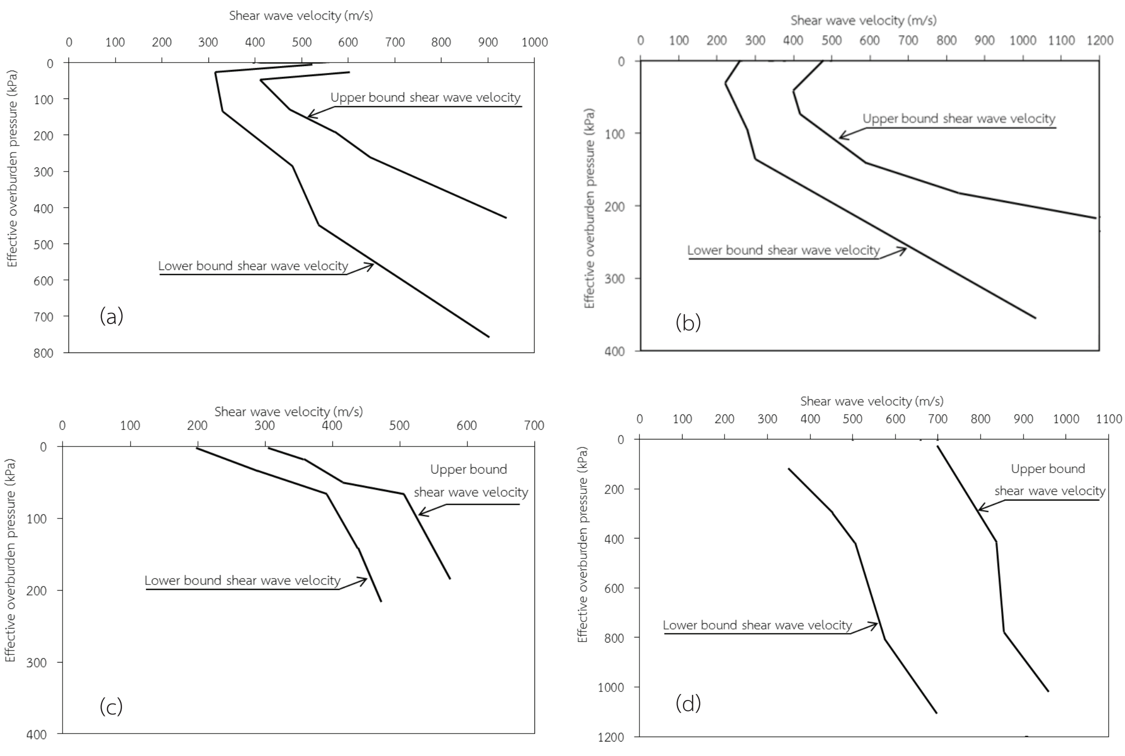

Figure 6 Recommendation for V_s function range of each dam component: (a) core zone, (b) homogeneous zone, (c) shell zone and (d) rock-fill materials

References

[1] Kramer, S.L.. Geotechnical earthquake engineering. Prentice-Hall International Series in Civil Engineering and Engineering Mechanics, N.J. 1996, pp. 203-208.

[2] Bay, J.A. and Chaiprakaikeow, S. Spectral Analysis of Surface Wave (SASW) Testing of Srinakarind (SNR) and Vajiralongkorn (VRK) Dams, Utah State University, Utah, 2006.

[3] Bay, J.A., and S. Chaiprakaikeow. Spectral Analysis of Surface Wave (SASW) Testing of Sirikit and Rajjaprabha Dams. Utah State University, Utah, 2009.

[4] Kumma, B. The Influence of Dam Components and Their Properties of Small and Medium Earth Dams in Thailand on Their Stability during Earthquake. M.A. Thesis, Kasetsart University, 2010.

[5] USBR. Design of small dams. 3 ed, Washington DC, 1987.

[6] USBR. Earth manual Part 1. United States Government Printing Office, Denver, Colorado, 1998.

[7] Solalump, S. Dam safety engineering. 1 ed, Kasetsart University, Thailand, 2011.

[8] Park, C. B., Miller, R. D., and Xia, J. Multi-channel analysis of surface waves (MASW): Submitted for publication in Geophysics. 1996.

[9] Park, C. B., Miller, R. D., and Xia, J. Multi-Channel Analysis of Surface Waves (MASW) "A summary report of technical aspects, experimental results, and perspective". 1997.

[10] Roesler, S.K. Correlation methods in soil dynamics. In Proceedings, DMSR77, Karlsruhe, Germany, Vol. 1, pp.309-334., 1977.

[11] Redpath, B.B., Edward, R.B., Hale, R.J., and Kintzer, F.Z. Development of field techniques to measure damping values for near surface rocks and soils, Report URS/John A. Blume and Associates, San Francisco, pp. 120, 1982.