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EVALUATION OF $V_{S,30}$ ESTIMATING MODELS FOR INDONESIA

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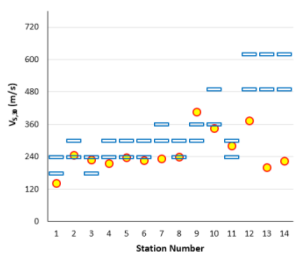
Graphical abstract



Abstract

Series of strong-motion instruments are being installed as part of the seismic hazard reduction program. One of the required information for an instrument station is the geotechnical characteristics, particularly the 30 m deep weighted average of shear wave velocity, $V_{S,30}$. The $V_{S,30}$ values of 25 strong-motion instrument stations in western part of Java Island and western-southern part of Sumatra Island were used to evaluate the topographical information and the geomorphological information based $V_{S,30}$ estimation models. The ratio of the measured $V_{S,30}$ to the estimated $V_{S,30}$ is evaluated, and the simple statistical parameters could not suggest the better model. No apparent geographical and/or geological factors could be identified as the affecting factor as well. Furthermore, the ratio is found to decrease with increasing the estimated values. Based on these observations, several recommendations are proposed, including to develop a new $V_{S,30}$ estimation model, specifically for Indonesia.

Keywords: Seismic hazard, shear wave velocity, Indonesia

Abstrak

Sesiri instrumen gerakan-kuat sedang dipasang sebagai sebahagian daripada program pengurangan bahaya seismik. Salah satu maklumat yang diperlukan untuk stesen instrument adalah ciri-ciri geoteknik, terutamanya halaju wajaran gelombang ricih pada 30 m kedalaman, $V_{S,30}$. Nilai-nilai $V_{S,30}$ dari 25 stesen instrument gerakan-kuat di bahagian barat Pulau Jawa dan bahagian barat daya Pulau Sumatera telah digunakan untuk menilai maklumat topografi dan maklumat geomorfologi berasaskan model anggaran $V_{S,30}$. Nisbah $V_{S,30}$ terukur kepada $V_{S,30}$ anggaran telah dinilai, dan parameter statistik yang mudah tidak boleh mencadangkan model yang lebih baik. Tiada faktor-faktor geografi dan/atau geologi yang jelas dapat dikenal pasti sebagai faktor yang mempengaruhi juga. Tambahan pula, nisbah itu didapati berkurangan dengan peningkatan nilai-nilai yang dianggarkan. Berdasarkan pemerhatian ini, beberapa cadangan telah diberi termasuk untuk membangunkan model anggaran $V_{S,30}$ yang baru, khususnya untuk Indonesia.

Kata kunci: Bahaya seismic, halaju gelombang ricih, Indonesia

1.0 INTRODUCTION

Indonesia is a vast country with land area of approximately 1.8 million km^2, and one of the seismic disaster management challenges is to provide hazard estimates for the entire country. To meet this challenge, the Government of Indonesia has installed up to about 200 seismic strong-motion instruments and is to install additional about 200 instruments in the future. The Agency for Meteorology, Climatology, and Geophysics of Indonesia (BMKG) is responsible for the installation program. To strengthen further the program, some studies [1, 2] have proposed the required minimum number of instrument stations and the distribution plan of the proposed stations.

One of the required information for each strong-motion instrument station is its geotechnical characteristics, typically represented by the 30 m-deep weighted average of shear wave velocity, $V_{S,30}$. The measuring process of $V_{S,30}$ can be conducted using invasive and non-invasive methods. Such $V_{S,30}$ data have been used to develop empirical estimating models [3,4].

This paper presents critical evaluation of two $V_{S,30}$ estimating models. The first model is the topographic slope information-based $V_{S,30}$ estimation model developed by Wald and Allen [3]. The model was developed by correlating 1,401 measured data from active seismic regions [the United States (California and Utah), Taiwan, and Italy] to calculated slopes from global 30 arc sec topographic data. The second model is the geomorphological information based $V_{S,30}$ estimation model developed by Matsuoka *et al*. [4]. The Japan-based model was developed by correlating 1,937 measured data to topographic parameters (slope and elevation) and distance to major geologic features. To evaluate the suitability of these model for Indonesia, the resulting estimates will be compared to the results of field measurements obtained using the non-invasive Multi-Channel Analysis of Surface Waves (MASW) method. This paper also discusses the evaluation results of the $V_{S,30}$ measured using the non-invasive method and that measured using an invasive method.

2.0 NON-INVASIVE VERSUS INVASIVE METHODS FOR $V_{S,30}$

The $V_{S,30}$ results measured using the non-invasive MASW method performed by the seismotectonic group of BMKG are compared independently to those measured using the invasive seismic down hole (SDH) method performed by the Geophysics Laboratory, Universitas Indonesia. For the MASW method, an OYO 24 Channel McSeis-SXW24 seismic refraction equipment was used to measure the wave generated by an active source. For the SDH method, a different OYO McSeis 24-channel portable engineering seismograph and Borehole Pick Model-3315 were used to measure the wave generated by an active source. The measurements were conducted for three strong-motion instrument stations Tj. Priok (JATA, no. 1), UI Depok (JAUI, no. 2), and Tangerang (TNG, no. 8); details of these stations are given in Table 1.

The $V_{S,30}$ results of both methods are summarized in Table 1 as well. The MASW $V_{S,30}$ for JATA was obtained for one direction only, while that for JAUI and TNG was obtained for NS and EW directions. There is a difference between The MASW $V_{S,30}$ and the SDH $V_{S,30}$ for the three stations. The $V_{S,30}$ results from both methods are compared further against results from other studies [5,6] as shown in Figure 1. As demonstrated in Figure 1, the value of $V_{S,30}$ obtained by Moss [5] is slightly lower than the 1:1 line, while the value of $V_{S,30}$ obtained by Comina *et al* [6] is closer to the 1:1 line. In overall, these studies suggest that some degree of measurement uncertainty is to be expected when obtaining $V_{S,30}$ results. Moss [5] suspects that this intra-method uncertainty may be due the fundamental differences in the testing methods; a wave traveling from a source, reflecting off a boundary, and converting into a surface wave before being received as in any MASW tests is different from a wave traveling from a surface source to a subsurface receiver as in any SDH tests.

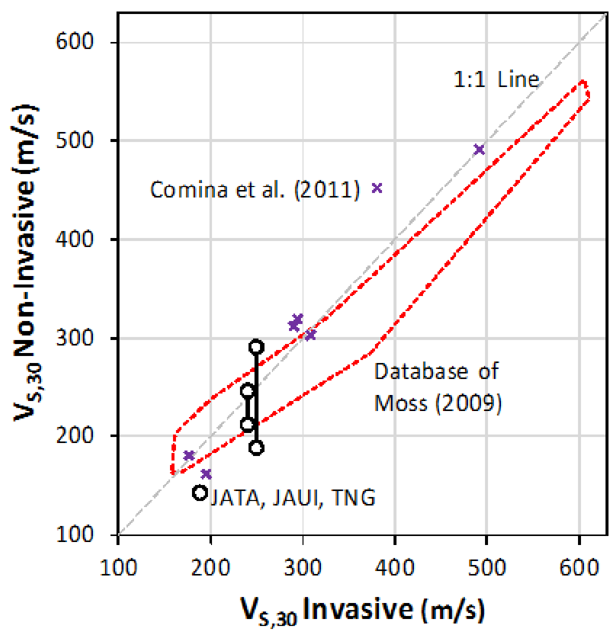


Figure 1 Comparison of $V_{s,30}$ measured using non-invasive and invasive methods

The effect of the measurement uncertainty on the ground surface seismic response uncertainty has been examined in several studies. Foti *et al*. [7] show that, for soil layers with a significant impedance contrast, the effect of this uncertainty is relatively minor. Boaga *et al*. [8] show that the impedance contrast is of importance in the seismic response uncertainty, and that the effect of uncertainty in soil characteristics could be quite significant for soil layers with a relatively low impedance contrast. Furthermore, Roy *et al*. [9] suggest that the combined effect of the frequency content uncertainty and the $V_{S,30}$ uncertainty on the response may be significant.

Table 1 Strong-motion instrument stations with measured and estimated of $V_{S,30}$

No	Station	Coordinate		Measured $V_{S,30}$ (m/s)		Estimated $V_{S,30}$ (m/s)	
		South	East	MASW	SDH	Wald & Allen	Matsuoka *et al.*
1	Tj. Priok (JATA)	6.10	106.87	143.2	188.1	180-240	183.7
2	UI Depok (JAUI)	6.40	106.83	246.4	239.8	240-300	343.1
3	Cengkareng (JACE)	6.12	106.65	229.3	-	180-240	260.1
4	AMKG Campus (AMGI)	6.27	106.75	216.5	-	240-300	-
5	Curug (JARU)	6.25	106.55	236.8	-	240-300	217.3
6	Balai Besar II (JABI)	6.23	106.68	227.8	-	240-300	295.9
7	Puspiptek (TASE)	6.35	106.66	219.5-248.2	-	300-360	-
8	Tangerang (TNG)	6.17	106.65	188.9-290.9	249.2	240-300	220.8
9	Serang (SBJI)	6.11	106.13	406.6	-	300-360	225.8
10	Ciguelis (CGJI)	6.61	105.67	345.6	-	360-490	400.0
11	Lebak (BALE)	6.36	106.25	281.6	-	240-300	-
12	Cemara (BACE)	6.88	107.59	367.9-381.5	-	490-620	297.3
13	Lembang (BALE)	6.80	107.62	183.0-217.4	-	490-620	510.5
14	Cisompet	7.56	107.81	222.7-226.9	-	490-620	-
15	Liwa (LWLI)	5.02	104.06	217.8	-	300-360	429.2
16	Kota Agung (KASI)	5.52	104.50	363.3	-	300-360	338.1
17	Kota Bumi (KLI)	4.86	104.86	309.6	-	300-360	332.1
18	Radin Inten (LARE)	5.21	105.17	388.7	-	240-300	183.7
19	Lampung Univ. (BLSI)	5.37	105.25	553.1	-	300-360	292.5
20	Tj. Karang (LATA)	5.47	105.32	262.8	-	360-490	260.1
21	Fatmawati (BEFA)	3.86	102.34	236-247	-	240-300	277.7
22	Pulau Baai (BEPA)	3.87	102.31	187	-	300-360	288.0
23	Kepahiyang (BEKI)	3.07	102.59	266	-	620-760	344.3
24	Bengkulu Univ. (UBSI)	3.76	102.27	192	-	240-300	278.4
25	Muko-Muko (MKBI)	2.45	101.24	309	-	360-490	331.6

3.0 $V_{S,30}$ EVALUATION DATA

3.1 Measured $V_{S,30}$

The $V_{S,30}$ values of 25 strong-motion instrument stations were considered in this paper. The $V_{S,30}$ was measured using the MASW method performed by the seismotectonic group of BMKG using previously described equipment. Eight and three stations are within the Jakarta greater area and in Banten Province, respectively, while three stations are in West Java Province. Six stations were in Lampung Province, while five stations were in Bengkulu Province. Note that Jakarta greater area, Banten Province, and West Java Province are in the western part of Java island, while Lampung Province and Bengkulu Province are in the western-southern part of Sumatra island. The coordinate and measured $V_{S,30}$ value for each station are given in Table 1; the station locations are also shown on Figures 2 to 6 for Jakarta greater area, Banten Province, West Java Province, Lampung Province, and Bengkulu Province, respectively.

3.2 Estimated $V_{S,30}$: Wald and Allen

The topography slope based $V_{S,30}$ generated from digital maps – estimation model proposed by Wald and Allen [3] is implemented in the website maintained by United States Geological Survey (USGS)[10]. The $V_{S,30}$ maps for the Jakarta greater area, Banten Province, and West Java Province are shown as Figures 2to4, respectively. Those for Bengkulu Province and Lampung Province are shown as Figures 5 and 6, respectively. The estimated $V_{S,30}$ ranges were determined based on the colour of the maps and are summarized in Table 1.

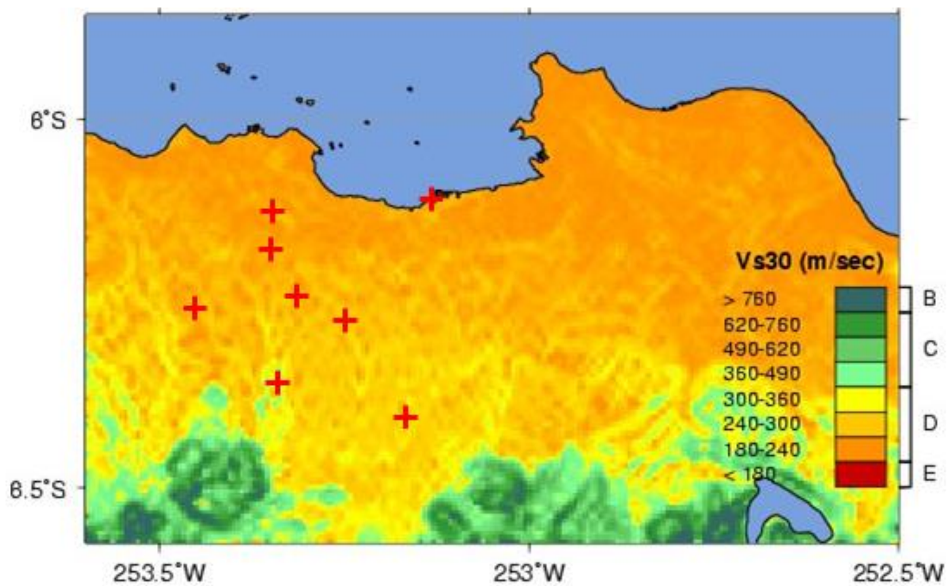


Figure 2 Estimated $V_{S,30}$ map [10] for and instrument stations (+) in Jakarta greater area

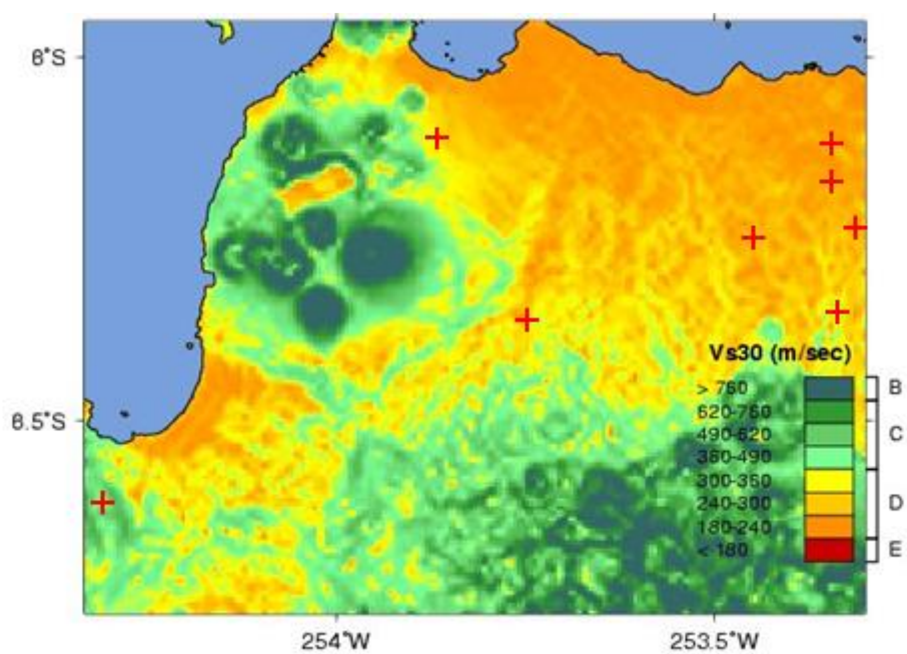


Figure 3 Estimated $V_{S,30}$ map [10] for and instrument stations (+) in Banten Province (modified after [12])

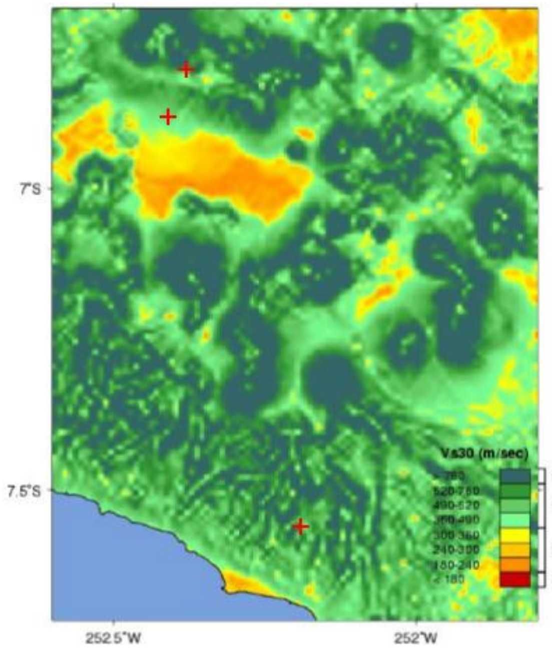


Figure 4 Estimated $V_{S,30}$ map [10] for and instrument stations (+) in West Java Province

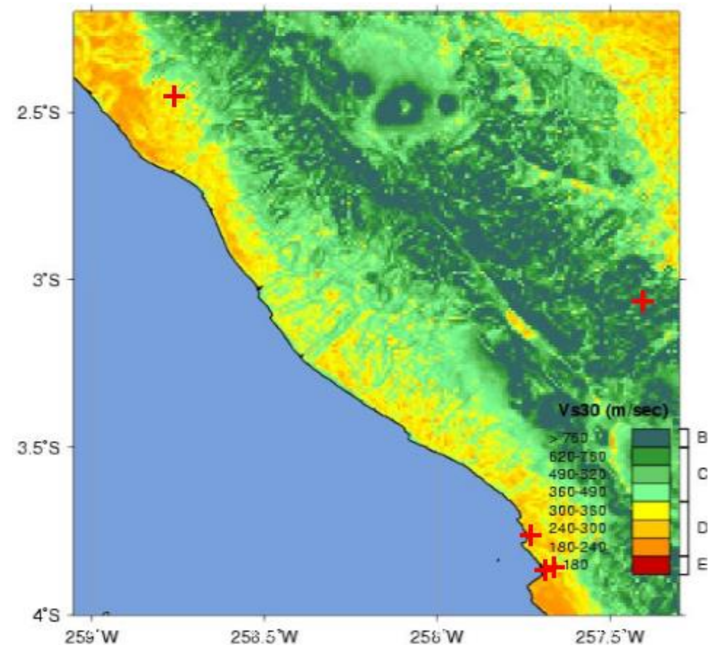


Figure 5 Estimated $V_{S,30}$ map [10] for and instrument stations (+) in Bengkulu Province

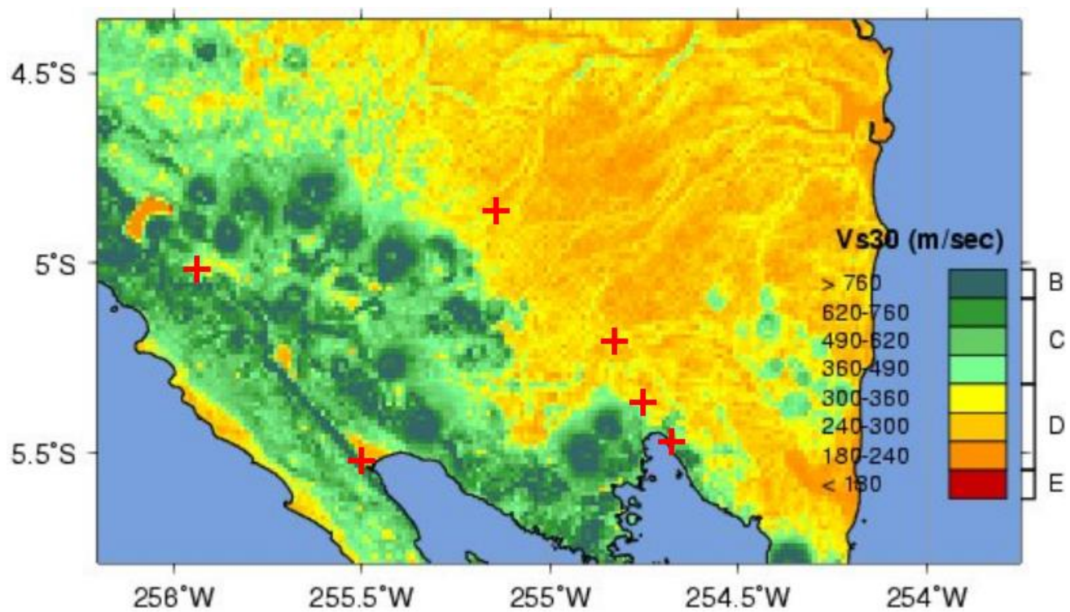


Figure 6 Estimated $V_{S,30}$ map [10] for and instrument stations (+) in Lampung Province (modified after [12])

3.3 Estimated $V_{S,30}$: Matsuoka *et al*.

The geomorphologic information based estimation model proposed by Matsuoka *et al*. [4] was adopted by Rudyanto [11] to estimate $V_{S,30}$ for a number of strong-motion instrument stations. It is noted that the model is based on the Japanese geomorphology system, and some adjustments needed to be considered in applying the method for the Indonesian context. Twenty-one estimates of 25 stations considered are available in the report of Rudyanto [11], as given in Table 1.

4.0 DISCUSSION ON $V_{S,30}$ ESTIMATING MODELS

The topographic slope based $V_{S,30}$ estimation model proposed by Wald and Allen [3] and generated from USGS[10] is evaluated against the measured $V_{S,30}$using the MASW method. Furthermore, the geomorphologic information based $V_{S,30}$ estimation model proposed by Matsuoka *et al*. [4] as reported by Rudyanto [11] is evaluated against the measured values as well.

The estimated $V_{S,30}$ ranges obtained from USGS [10] are compared to the respective measured ones in Figure 7 for the Jakarta greater area, Banten Province and West Java Province, and in Figure 8 for Lampung Province and Bengkulu Province. From measured $V_{S,30}$ values of 25 station locations, only five measured values are within the respective estimated $V_{S,30}$ ranges. The other estimated ranges do not cover the respective measured values; sixteen ranges are higher than the respective measured values, while four ranges are lower. For the considered stations, the $V_{S,30}$ estimates tend to over predict the field $V_{S,30}$ values.

The ratio of the measured $V_{S,30}$ to the median value of the estimated range for each station was also evaluated. The minimum and maximum ratios are 0.361 and 1.676, respectively, with an average ratio of 0.842. It is noted that, ideally, the ratio is one for all $V_{S,30}$ estimates. The statistics of the ratio is summarized in Table 2, while the histogram of the ratio is shown as Figure 9. The model proposed by Wald and Allen [3] significantly over predicts the $V_{S,30}$ estimates for four locations, namely Lembang and Cisompet stations in West Java Province (Figure 8, nos. 13 and 14) and Kepahiyang and Pulau Baai stations in Bengkulu Province (Figure 10, nos. 22 and 23); the ratio of the measured to estimated median values is less than or about 0.5. These stations, except Pulau Baai station, are located in highland areas. No other apparent geographical and/or geological features can be identified as the common factor for these significant ratio differences (Figures 7 and 8.).

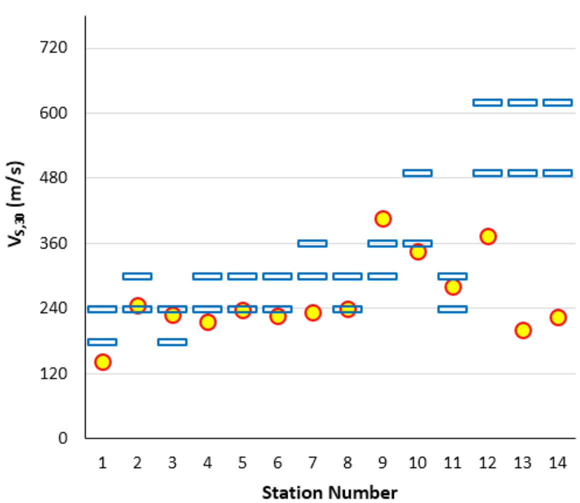


Figure 7 Comparison of measured value (O) and Wald-Allen estimated range (--) for Jakarta greater area, Banten Province, and West Java Province

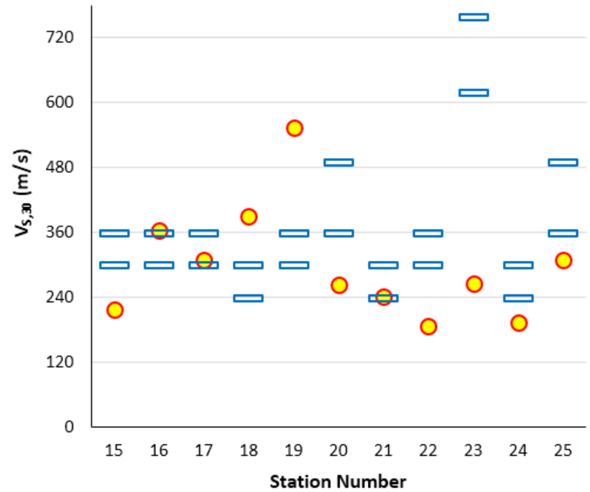


Figure 8 Comparison of measured value (O) and Wald-Allen estimated range (--) for Lampung Province and Bengkulu Province

Table 2 Comparison statistics

Statistical Parameters	Measured / Estimated (Median) (Wald & Allen)[3]	Measured / Estimated (Matsuoka *et al.*) [4]
No. Stations	25	21
Mean	0.842	1.004
Std. Deviation	0.309	0.441
Minimum	0.361	0.392
Maximum	1.676	2.116

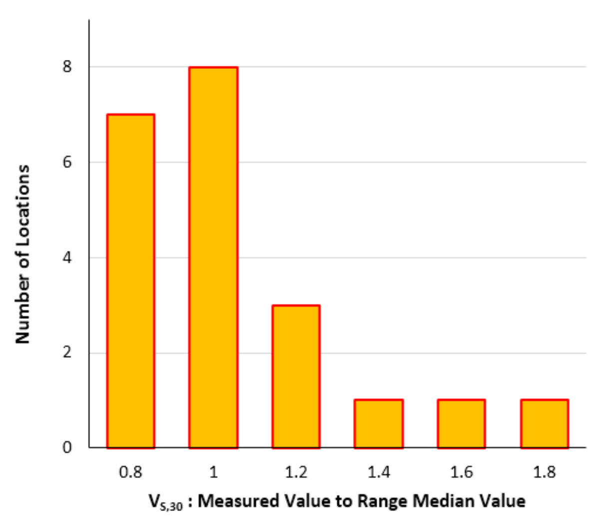


Figure 9 Histogram of ratio of measured value to estimated range median value (Wald and Allen [3] model)

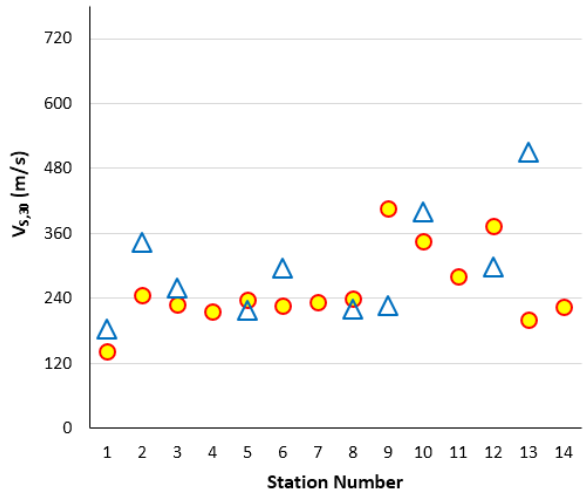


Figure 10 Comparison of measured value (O)and Matsuoka *et al*. estimated value (Δ) for Jakarta greater area, Banten Province, and West Java Province

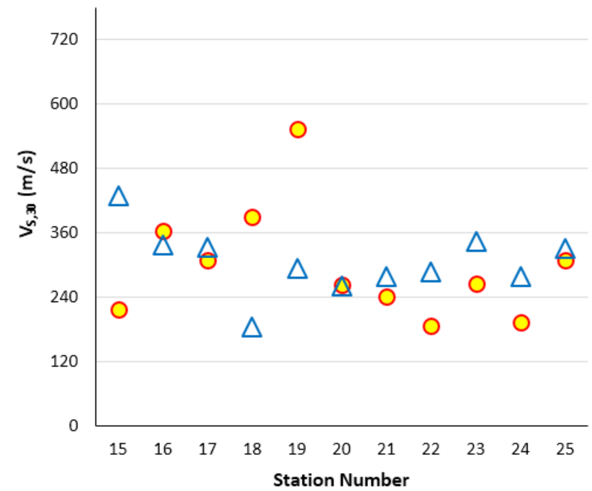


Figure 11 Comparison of measured value (O) and Matsuoka *et al*. estimated value (Δ) for Lampung Province and Bengkulu Province

The estimated $V_{S,30}$ ranges obtained from Rudyanto [11] are compared to the respective measured ones in Figure 10 for the Jakarta greater area, Banten Province and West Java Province, and in Figure 11 for Lampung Province and Bengkulu Province. From $V_{S,30}$ from 21 station locations, eight measured values are greater than the respective estimated $V_{S,30}$ values, while 13 measured values are less than the estimated ones.

The ratio of the measured $V_{S,30}$ to the estimated value for each station was also evaluated. The minimum and maximum ratios are 0.392 and 2.116, respectively, with an average ratio of 1.004. The statistics of the ratio is summarized in Table 2, while the histogram of the ratio is shown as Figure 12. The model proposed by Matsuoka *et al*. [4] significantly over predicts (the ratio of the measured to median values less than or about 0.5) the $V_{S,30}$ estimates for two locations, namely Lembang station in West Java Province (Figure 8, no. 13) and Liwa station in Lampung Province (Figure 10, no. 15). This model significantly under predicts (the ratio of the measured to median values greater than or about 2.0) the $V_{S,30}$estimates for three locations, namely Serang station in Banten Province (Figure 8, no. 9) and Radin Inten and Lampung University stations in Lampung Province (Figure 10, nos. 18 and 19). No apparent geographical and/or geological features can be identified as the common factor for these significant ratio differences (Figures 10 and 11.).

The ratio mean value of the Wald and Allan model is poorer than that of the Matsuoka *et al*. model. However, as given in Table 2, the standard deviation of the first model is better than the second model. Therefore, based on these simple statistical parameters, it is still difficult to conclude whether the first model is better than the second model.

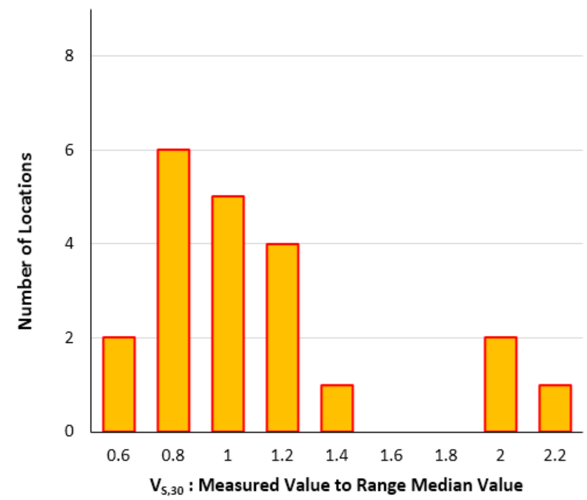


Figure 12 Histogram of ratio of measured value to estimated range median value (Matsuoka *et al*. model [4])

The ratio of the measured $V_{S,30}$ to the estimated value for each model is further evaluated against the respective estimated value as shown in Figure 13. It is noted again that, ideally, the ratio is one for all $V_{S,30}$ estimates. The ratio data trend for the Wald and Allen model is similar to the ratio data trend of the Matsuoka *et al*. model. For lower estimated values, the ratio is relatively high, indicating underprediction of the estimated values. However, for higher estimated values, the ratio is relatively low, indicating over prediction of the estimated values. The range of ratio values for low estimated values is significantly wider compared to the range for high estimated values. The wide range of ratio values indicates that the uncertainty of the estimates is rather significant.

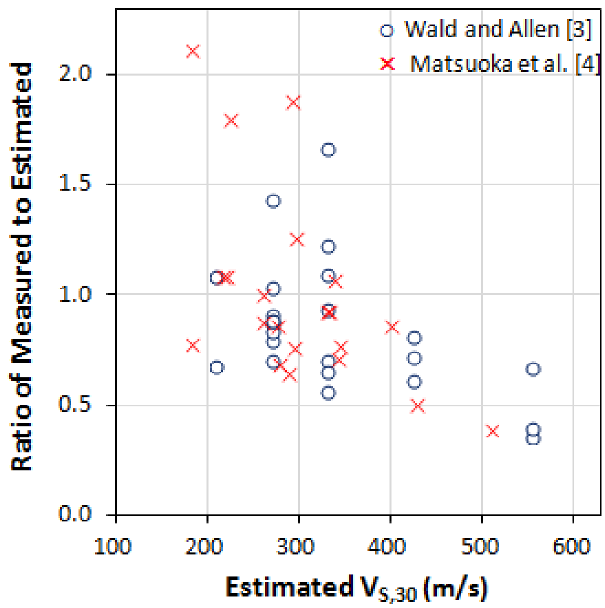


Figure 13 Relation between ratio of measured $V_{s,30}$ to estimated $V_{s,30}$

In general, The topographic slope information based $V_{S,30}$ estimation model proposed by Wald and Allen [3] and the geomorphologic information based $V_{S,30}$ estimation model proposed by Matsuoka *et al*. [4] should be further evaluated against Indonesia database to understand better the accuracy level of the resulting estimates. The present study only considers measured data from the western part of Java Island and the western-southern part of Sumatra Island; a model evaluation for other parts of Indonesia is warranted. Alternatively, new estimating models may be developed specifically for Indonesia. In the development of the new models, the basic concepts in both models could be adopted, and geographical and/or geological effects may also be considered.

5.0 CONCLUSIONS

This paper discusses two related issues. The first issue is the reliability of the $V_{S,30}$ values measured using the non-invasive Multi-Channel Analysis of Surface Waves (MASW) method. Three measured MASW $V_{S,30}$ values were compared to the $V_{S,30}$ values measured using the invasive seismic down hole method. The two tests, conducted by two independent teams, gave reasonably similar $V_{S,30}$ estimates.

For the second issue, the MASW$V_{S,30}$ measured values of 25 strong-motion instrument stations in the western part of Java island and western-southern part of Sumatra island were used to evaluate the suitability of the topographical slope information based $V_{S,30}$ estimation model and also the geomorphological information based $V_{S,30}$ estimation model for Indonesia. The parameter used in the analysis was the ratio of measured $V_{S,30}$ to estimated $V_{S,30}$. The simple statistical parameters of the ratio could not suggest which model gives better estimates. No apparent geographical and/or geological factors could be identified as the affecting factor as well. Furthermore, the ratio was evaluated against the estimated values for both models. Both models have similar trends of decreasing ratio with increasing estimated values. The range of ratio values for low estimated $V_{S,30}$ values is significantly wider compared to the range for high estimated values. The wide range of ratio values indicates that the uncertainty of the estimates is rather significant. Based on these observations, several recommendations are proposed, particularly the development of a new $V_{S,30}$ estimation model specifically for Indonesia.

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