SVIM: A Program for Seismic Vulnerability Index Determination and HVSR Data Processing

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Abstract. The seismic vulnerability of an area is important to be determined in order to reduce the risk of earthquake disaster. One needs to calculate the values of dominant frequency and amplification from the Horizontal to Vertical Spectral Ratio (HVSR). Currently existing software for HVSR data processing, Geopsy, does not include seismic vulnerability index calculation. Therefore, we introduce a Graphical User Interface (GUI) program for seismic vulnerability index determination and Horizontal to Vertical Spectral Ratio (HVSR) data processing and plotting the results into a map of the study area. The program is called SVIM (Seismic Vulnerability Index of Microtremor). The program has been built using Matlab and successfully tested to 21 microtremor data points acquired in Lamteuba, Aceh Besar, Aceh, Indonesia. We compared our results with those resulted from the calculation by using Geopsy and validated using coefficient correlation. The validation shown that the correlation coefficient of seismic vulnerability index was 96.40%, the correlation coefficient of frequency was 84.19%, and the correlation coefficient of amplification was 95.80%. We conclude the SVIM program can be used for seismic vulnerability index determination and HVSR data processing. The mapping part will be included in the SVIM software so that the users can easily obtain the necessary map.

1. Introduction

The seismic vulnerability index \( K_g \) is important to identify site characteristics of an earthquake prone area. The value of seismic vulnerability index \( K_g \) explains how vulnerable an area is, when an area influenced by ground motion. To get the \( K_g \) value, the parameter of dominant frequency and parameter of amplification factor have to be known. Those parameters are obtained through Horizontal to Vertical Spectral Ratio (HVSR) data processing which was introduced by Nakamura in 1989 [1]. The HVSR data processing make use of ambient noise of microtremor measurements. The ambient noise is recorded by three components seismic sensor consists of two horizontal components (East-West and North-South) and one vertical component (V). This technique can be applied to geophysical prospecting and studies of buildings dynamical behavior [2].

Currently, the existing software for HVSR data processing is Geopsy which does not include the calculation of seismic vulnerability index \( K_g \). Therefore, we introduce Graphical User Interface
(GUI) for seismic vulnerability index \((K_g)\) determination and HVSR data processing which is called SVIM (Seismic Vulnerability Index of Microtremor). We use 21 measurement microtremor data points acquired in Lamteuba, Aceh Besar, Indonesia to test SVIM program. We compared between HVSR results and Geopsy results and calculated the coefficient correlation to validate the results of SVIM program.

2. HVSR
The Horizontal to Vertical Spectral Ratio (HVSR) method is used to estimate dynamics characteristic of ground surface [3]. This method makes use of ambient noise spectrum ratio between two horizontal components and one vertical component. We use equation (1) to calculate the HVSR:

\[
\frac{H}{V} = \sqrt{\frac{N^2 + E^2}{2V^2}}
\]

where \(H\) is horizontal component spectrum, \(V\) is vertical component spectrum, \(N\) is North-South component spectrum (horizontal component) and \(E\) is East-West component spectrum (horizontal component) [4]. There are two output parameters that are obtained from HVSR calculation which are dominant frequency \((F)\) and amplification factor \((A)\). The dominant frequency is detected when the amplification factor is maximum. Both parameters can be used to estimate depth of bedrock of sediment [1]. The HVSR method also can use earthquake data for estimation of dynamic characteristics [3].

3. Konno-Ohmachi Smoothing
The smoothing has to be applied to HVSR spectrum to determine amplification factor. The common smoothing spectrum method is called Konno-Ohmachi smoothing which was introduced by Konno and Ohmachi in 1998 [5]. This smoothing can be calculated by using equation (2)

\[
W_b(f, f_c) = [\sin(\log_{10}(f / f_c)^b)/\log_{10}(f / f_c)^b]^4
\]

where \(b\) is the band-width coefficient, \(f\) is the spectrum frequency, and \(f_c\) is the cut off frequency. According to Konno and Ohmachi (1998), the band-width value \((b)\) has two conditions. The first condition, the smaller band-width value \((b)\) is good to determine linear relation between peaks ratios and velocity contrasts (e.g. \(b\) value smaller than or equal to 10). The second condition, the higher band-width value \((b)\) is good to reduce the elongation of the peak period (e.g. \(b\) value higher than or equal to 20) [5].

4. Seismic Vulnerability Index \((K_g)\)
When an earthquake occurs, the damages of buildings are caused by ground surface response to seismic wave propagation or shakes. The level of damages depends on the intensity, frequency, and duration of earthquakes. The characteristics of ground surface can be identified based on Horizontal to Vertical Spectral Ratio (HVSR) of microtremor which was called as Quasi-Transfer Spectrum (QTS). The characteristics value from ground surface can be calculated by using equation (3) which is called seismic vulnerability index \((K_g)\)

\[
K_g = A^2/F
\]

where the \(A\) is amplification factor and \(F\) is dominant frequency. The seismic vulnerability index \((K_g)\) explains how vulnerable soil or ground surface is deformed when a ground motion occurs (e.g. earthquake)[6].
5. Methods
The SVIM program has been built using equations (1), (2), and (3). We calculate the dominant frequency and amplification factor by using HVSR method to determine the seismic vulnerability index \( K_s \). First, we read three components of microtremor data (two horizontal components that are East-West and North-South and one vertical component) in mseed format. Second, three components of microtremor data were filtered by using band pass filter from frequency range 0.1 to 10 Hz. This frequency range is used for ambient noise [7]. Third, the microtremor data are windowed by using Short Term Average/Long Term Average (STA/LTA) anti-trigger for each component. The STA/LTA anti-trigger is the opposite of STA/LTA trigger for earthquake detection [8]. In this case, the STA/LTA anti-trigger is used to ignore a spike of microtremor data based on the range of threshold values. There are some parameters of STA/LTA anti-trigger have to be configured, consist of the value of STA window was adjusted 1 s, the value of LTA window was adjusted 30 s, the minimum threshold value was adjusted 0.2, the maximum threshold value was adjusted 2.0, and the length window was adjusted 25 s for this research. Fourth, the time series of three components of microtremor data were transformed to frequency spectrum by using Fast Fourier Transform (FFT). Fifth, the two horizontal components of spectrum frequency were merged and calculated the average. Sixth, the two horizontal components of spectrum frequency and the spectrum of vertical component were calculated by using equation (1) to get the HVSR spectrum. Seventh, the spectrum of HVSR was smoothed by using equation (2) where the band-width value \( b \) was adjusted equal to 40 in this research. Therefore, dominant frequency and amplification factor were detected automatically. Eighth, the seismic vulnerability index \( K_s \) was calculated by using equation (3) automatically.

6. Results and Discussion
The Graphical User Interface of SVIM program (figure (1)) has been successfully built. The SVIM program has been tested to determine seismic vulnerability index \( K_s \) and HVSR data processing by using 21 microtremor data points of Lamteuba, Aceh, Indonesia. The SVIM program has several panels such as filter panel, anti-trigger STA/LTA panel for windowing, smoothing panel, output parameters panel, and option panel for button process. The program also has two plot panels such as waveform plot panel and amplification curve panel. Figure 1 shows the interface when the program is opened and figure 2 shows the interface program after the data processing completed.

The results of seismic vulnerability index determination and HVSR data processing using 21 microtremor data points shown in Table 1. The first example of the results of seismic vulnerability index and HVSR data processing using file c0avf180311031836 (hereafter 1836) is shown in Figure 3. The amplification curve resulted by SVIM program is shown in Figure 3(a) and the amplification resulted by Geopsy is shown in figure 3(b) which show the comparable values between that two software. SVIM program use linear scale and Geopsy use logarithmic scale. When the 1836 file was processed using SVIM program, the dominant frequency was 4.49219 Hz, the amplification factor was 0.39973, and the seismic vulnerability index \( K_s \) was 0.03557. The 1836 file was also processed using Geopsy, where the dominant frequency was 4.27264 Hz, the amplification factor was 0.470059, and the seismic vulnerability index \( K_s \) was 0.05171.
Figure 1. The SVIM program is displayed in Graphical User Interface (GUI).

Figure 2. The results from SVIM processing. Seismic vulnerability index was calculated directly by using SVIM program.
Figure 3. The first comparison of 21 microtremor data of amplification (H/V) curve between (a) SVIM program and (b) Geopsy results.

Table 1. The comparison result of the dominant frequency, amplification factor and seismic vulnerability index between SVIM program and Geopsy.

| File | SVIM | | | Geopsy | | |
|------|------|------------------|------------------|------------------|------------------|
|      | Dominant Frequency (Hz) | Amplification Factor | Kg | Dominant Frequency (Hz) | Amplification Factor | Kg |
| 1836 | 4.49219 | 0.39973 | 0.03557 | 4.27264 | 0.470059 | 0.05171 |
| 2927 | 1.85547 | 0.59313 | 0.18960 | 1.85292 | 0.680417 | 0.24986 |
| 1420 | 2.68555 | 0.44583 | 0.07401 | 1.99865 | 0.524459 | 0.13762 |
| 5018 | 6.10352 | 1.11742 | 0.20457 | 5.65641 | 1.09648 | 0.21255 |
| 4929 | 9.7168 | 0.26959 | 0.00748 | 4.34258 | 0.398673 | 0.03660 |
| 5853 | 4.39453 | 0.2846 | 0.01843 | 7.06946 | 0.337485 | 0.01611 |
| 4010 | 5.22461 | 0.28362 | 0.01540 | 4.40759 | 0.562528 | 0.07179 |
| 4059 | 4.39453 | 0.35189 | 0.02818 | 4.2873 | 0.637585 | 0.09481 |
| 5058 | 8.30078 | 1.667 | 0.33477 | 8.44106 | 1.76995 | 0.37113 |
| 3636 | 7.61719 | 1.01597 | 0.13551 | 7.38644 | 1.07741 | 0.15715 |
| 3727 | 5.66406 | 0.34078 | 0.02050 | 5.52023 | 0.575192 | 0.05993 |
| 3710 | 4.49219 | 0.36554 | 0.02976 | 4.02013 | 0.547666 | 0.07461 |
| 1020 | 4.49219 | 0.64772 | 0.09339 | 4.44892 | 0.936314 | 0.19706 |
| 0157 | 9.42383 | 0.52956 | 0.02976 | 9.51935 | 0.535112 | 0.03008 |
| 0037 | 2.19727 | 0.93717 | 0.39722 | 2.3339 | 0.839148 | 0.30171 |
| 0821 | 3.17383 | 0.98102 | 0.30323 | 2.92109 | 1.01594 | 0.35334 |
| 0675 | 1.80664 | 1.04548 | 0.60501 | 1.32727 | 1.02244 | 0.78762 |
| 1548 | 2.19727 | 1.14103 | 0.59253 | 2.04367 | 1.08544 | 0.57650 |
| 1427 | 1.85547 | 0.67811 | 0.24783 | 1.90198 | 0.789858 | 0.32801 |
| 3002 | 7.12891 | 0.48998 | 0.03368 | 6.23972 | 0.540737 | 0.04686 |
| 1708 | 5.46875 | 0.39985 | 0.02924 | 5.43022 | 0.598081 | 0.06587 |
The whole comparison results of SVIM program and Geopsy shown in figure 4, red lines are SVIM results and blue lines are Geopsy results. The results between SVIM and Geopsy are close each other. It can be seen that seismic vulnerability index (figure 4(a)), dominant frequency (figure 4(b)), and amplification factor (figure 4(c)) are almost identical between SVIM and Geopsy results. However, refer to dominant frequency comparison shown in figure 4(b) at the fifth measurement point has different dominant frequency result between SVIM program and Geopsy. The dominant frequency of SVIM result is greater than dominant frequency of Geopsy, whereas the settings of parameters were similar during data processing as explained in the method section.

We also validated the results by calculating correlation coefficient between SVIM and Geopsy results. The correlation coefficient of seismic vulnerability index was obtained 0.964 or around 96.40% (figure 4(d)), frequency was 0.842 or around 84.19% (figure 4(e)), and amplification was 0.9580 or around 95.80% (figure 4(f)). If the correlation coefficient is close to one or 100%, the correlation is strong. Three output parameters (seismic vulnerability index, dominant frequency and amplification factor) have strong correlation. We conclude that the SVIM program can be used for seismic vulnerability index determination and HVSR data processing.

![Comparison of Seismic Vulnerability Index (a)](image)

![Correlation of Seismic Vulnerability Index (d)](image)

![Comparison of Dominant Frequency (b)](image)

![Correlation of Dominant Frequency (e)](image)

![Comparison of Amplification Factor (c)](image)

![Correlation of Amplification Factor (f)](image)

Figure 4. Comparison of parameters and correlation results between SVIM program and Geopsy data processing: (a) seismic vulnerability index, (b) dominant frequency, and (c) amplification factor.
7. Conclusion
The Graphical User Interface (GUI) of SVIM program has been built and successfully tested to determine seismic vulnerability index and HVSR data processing to 21 microtremor data points in Lamteuba, Aceh Besar, Aceh, Indonesia. The program is easy to use for seismic vulnerability index determination and HVSR data processing. The comparison results between SVIM program and Geopsy show that SVIM results almost close to Geopsy results based on comparison the seismic vulnerability index, dominant frequency and amplification factor. SVIM results have been validated by calculating coefficient correlation between SVIM results and Geopsy results. The coefficient correlation of seismic vulnerability index was 96.40%, dominant frequency was 84.19%, and amplification factor was 95.80%. We conclude the SVIM program can be used for seismic vulnerability index determination and HVSR data processing.

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References
[1] Nakamura Y. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Railw Tech Res Institute, Q Reports 1989;30.
[2] Mucciarelli M, Gallipoli MR. A critical review of 10 years of Nakamura technique. Boll Geof Teor Appl 2001;42:255–6.
[3] Nakamura Y. On the H/V spectrum. 14th World Conf Earthq Eng 2008:1–10.
[4] Guo Z, Aydin A. A modified HVSR method to evaluate site effect in Northern Mississippi considering ocean wave climate. Eng Geol 2016;200:104–13. doi:10.1016/j.enggeo.2015.12.012.
[5] Konno K, Ohmachi T. Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. Bull Seismol Soc Am 1998;88:228–41.
[6] Nakamura Y. Seismic Vulnerability Indices for Ground and Structures Using Microtremor. World Congr Railw Res 1997:16–9.
[7] Fäh D, Kind F, Giardini D. A theoretical investigation of average H / V ratios Donat Fa. Geophys J Int 2001;145:535–49.
[8] Trnkoczy A. Understanding and parameter setting of STA / LTA trigger algorithm 1 Introduction. 1999.