Seismic Site Effect along Bukit Tinggi Fault Line from Microtremor Analysis

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Abstract. In the shallow subsurface analysis, the potential hazard is identified and evaluated through the site investigation studies which can be determined either by conducting standard penetration test, cone penetration test, and multichannel analysis of surface wave (MASW). While the three methods stated are widely established and highly reliable, the result produced is sometimes unconvincing and lack of details. In this study, the horizontal to vertical spectral ratio (HVSR) analysis method is proposed instead of the more established methods. HVSR is a technique that based on the spectral analyses of recorded ambient noise in order to estimate the site effect parameters such as fundamental frequency and the amplification factor of local soil. The HVSR method was implemented in Bukit Tinggi, Pahang, Malaysia, which known to experience several small earthquakes between 2007 to 2009. Since the earthquake in central Peninsular Malaysia is uncommon, the tremor has caused panic and requires a thorough investigation of the soil effect in the region. The work conducted is motivated by this after effects with focus on the potential fault line investigation using the spectral ratio method (HVSR). The ambient noise signal measurements were performed at 20 sites along the probable fault line in order to calculate the HVSR. Receiver array arrangement and dimensions are chosen based on the prior information about the earthquake location as experienced by the local resident. At the end of the work, the amplification spectra for the soil column is evaluated at each site location, and the nominal frequency obtained, and maximum amplitudes are contoured showing the corresponding value trends in the region.

1. Introduction

The recent earthquake in Sumatra in addition to local tremor activities had been a major concern to the people in the central region of Peninsular Malaysia. The corresponding damages occurred to the building are viewed as the outcome of local geological condition from ground motion movement. For the area with high and regular seismicity, the ground motion analysis is best conducted through the direct observation. Nevertheless, in view of lack of earthquake activities within Peninsular Malaysia, a different method is required for the site response investigation. In this sense, the implementation of ambient noise analysis which recorded at a three-components weak-motion seismometer is the next best option for acquiring the ground motion prediction in Bukit Tinggi region. The history of the HVSR method began in the early 1970s where a few seismologists investigate the ratio between horizontal to vertical components of a microtremor using the Fourier spectral analysis [1,2,3]. It was suggested that, for a microtremor signal recorded at the ground surface level, the vertical component of the signal is heavily influenced by Rayleigh wave on the sediments, which in turn be used to
remove both source and the Rayleigh wave effects from the horizontal components. In addition, their investigation on the seismic wave propagation had found that the fundamental frequency of soft soils is highly correlated with the vertical component of surface wave motion. Nevertheless, the ideas did not pick up until the explanation by Nakamura (1989) [4] on the spectral ratio technique which explaining the resultant physical background output. Currently, the HVSR microtremor analysis is now widely used to estimate the natural frequency of its soil amplification parameters. Although it is being incorporated almost in all site investigation study around the world, the optimal spectral ratio acquisition, processing and interpretation methodologies are still being debated and require more investigation.

2. Central Peninsular Malaysia Region

Within the central Peninsular Malaysia region, Bukit Tinggi and Kuala Lumpur fault lines are the two paleo-fault lines that are said to be in the process of re-adjustment in order to accommodate the build-up tectonic pressures originating from Indo–Eurasian plates movements [5]. Generally, the resultant faults re-activation can be proven through a comprehensive 3-D velocity tomography with magnetic, gravity and geological data correlation. In the last ten years, seismologist discovered that the reliable subsurface information can also be obtained by correlating two or more seismometers data, which will produce a result as if there had been a real earthquake or seismic activity at the other seismometers [6]. This technique, called seismic interferometry is being developed further by incorporating ambient noise signal to produce the tomography update [7]. Prior 2007 Bukit Tinggi earthquakes, there is little interest and information of the seismic and tectonic activities occurred within Peninsular Malaysia. Over the years, most of the tremors felt in West Coast Malaysia originated from Sumatran strike-slip fault line and Andaman-Sumatra subduction zone, that led to scaling VI of Modified Mercalli Intensity (MMI) scale for the Klang Valley region (Figure 1). However, the aftermath of more than 30 small scale earthquakes in Bukit Tinggi region which caused minor damage to the local housing, there is an urgent need to relook and re-evaluate the seismic site effect of the central Peninsular Malaysia area. As the geological structure of the most affected area is still unknown, in this study, we look into the seismic effect towards the local structure and building, as a result of the earthquake occurrences. It is believed that the 2007-2009 earthquakes from Bukit Tinggi fault line took place as a result of paleo fault line reactivation from compressional stress release, a few years after the mega-earthquake in Sumatran subduction zone. In view of this, several seismological studies are being conducted in the central Peninsular Malaysia region, especially on the trace of ground ruptures [8][9], focal mechanism [9] and 1-D velocity determination for earthquake relocation [10]. However, to deduce a comprehensive seismic hazard analysis, we supplement these researches by investigating the seismic site effect of Bukit Tinggi area through the microtremor analysis.

Figure 1: Modified Mercalli Intensity scale for Peninsular Malaysia. The shaded rectangle indicates the study area of Bukit Tinggi, Malaysia.
3. Microtremor Data Acquisition

The importance of seismic site effect can be explained in terms of the earthquake wave which propagates and causes the soil and ground amplification, while these properties are controlled by the frequency contents of ground motions. Ground amplification analysis is carried out through a 10 km long lines with 500 m interval of microtremor data acquisition using a weak-motion seismometer. The 20-points data subsequently provide the dominant earth period and the dynamical behaviour of the local soil and rock properties in the Bukit Tinggi region. Among many microtremor analysis, we incorporate Nakamura’s horizontal-to-vertical spectral ratio (HVSR), which give important information in the soil amplification factor and its natural frequency [11]. These properties have the capacity to influence ground motions and consequently give important information on the potential damage caused by future seismic activity. The 20 data points with 1-hour long duration interval of ambient noise data were recorded at Kampung Janda Baik, Bukit Tinggi in between 24th January 2018 to 28 January 2018 (Figure 2). To avoid the influence from the monochromatic signal such as the passing-by car, electromagnetic waves noise and strong topographic features, each of the selected point were carefully selected (minimum 5 m away from the road and electrical poles) and monitored (data recording during peak hours of 7am-10am and 4pm-7pm were avoided).

Figure 2: The location map of the study area in Bukit Tinggi, where the 1-hour duration of ambient noise recording was conducted (in the yellow star).

4. H/V Spectral Ratio (HVSR) Analysis

The basic theory of H/V spectral ratio method is to compute the fundamental frequency, $f_0$ and soil amplification ratio, $A_0$, of soil sediments. Nevertheless, it was pointed out by Pilz et al. (2010) [12] that only $f_0$ provide reliable estimation while H/V amplitude ratio is highly ambiguous. In addition, the
recent study shows that the HVSR curve also resembles the Rayleigh waves ellipticity, which in turn can be extended for 1-D S-wave velocity determination. Therefore, extensive work was carried out through this project to govern the reliability of the estimated resonance frequency. The recorded ambient noise is processed and analysed using GEOPSY software (http://www.geopsy.org). Prior to conducting the spectral ratio analysis, a band pass filter between 0.5 Hz to 20 Hz is applied to remove the unwanted signal. The frequency range was selected as per recommendation by SESAME European Research Project [13], which stated the expected fundamental frequency range, $f_0$ through the HVSR implementation shall fall in between 0.1 to 20 Hz, depending on the microtremor data record [14]. The 1-hour duration data (Figure 3) is then subdivided into shorter time window lengths of 25s. Each of the time windows is transformed into frequency spectrum for HVSR analysis. In the frequency domain, the ratio between horizontal and vertical components was analysed in determining the resonance frequency of the area, as shown by the highest amplitude obtained (Figure 3). While the work conducted is only for 20 locations in Bukit Tinggi, we found that the resonance frequency in Bukit Tinggi region is in between 3-6 Hz (Figure 4). This implies that the area is vulnerable if a local, high magnitude earthquake occurred as local earthquake exhibits similar frequency response. In addition, a regional but enormous earthquake (>9.5 Mw) that originate in Sumatra might also cause soil amplification in the area based on the HVSR analysis.

![Figure 3: The recorded waveform at two locations as specified in Figure 2. Location A and B are part of 20 points with recorded ambient noise data in Bukit Tinggi.](image-url)
Figure 4: Horizontal-to-vertical spectral for two locations (A and B) indicate in Figure 2. In the spectral ratio, the resonance frequencies are found at 3 Hz (location A) and 6 Hz (location B).

5. Conclusion

Based on our initial target to investigate the potential of using the HVSR method for seismic site effect in Bukit Tinggi region, we had achieved through the 20-points location data acquisition along the Bukit Tinggi fault line. With the duration of 1-hour interval of recording time, the ambient noise recorded to fulfil the criteria for HVSR analysis implementation. The HVSR method used to prioritise the qualitative observations, particularly in the abrupt change of fundamental frequencies or peak amplitudes that may be attributed to soil effect for the particular region. It can be deduced from the ratio obtained that the soil resonance frequency in Bukit Tinggi is in between 3 Hz to 6 Hz. Nevertheless, further theoretical investigations are needed to verify the findings of the present work.

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