INVESTIGATION OF DYNAMIC CHARACTERISTICS AND VULNERABILITY ASSESSMENT OF SITE AND EXISTING REINFORCED CONCRETE BUILDING

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ABSTRACT

Microtremor measurement is the most popular techniques in estimating the site and building responds as well as subsoil conditions due to non-destructive method, cheap but effective. It is suitable for a region which lacking of ground motions records but higher level of noise for dynamic characteristics investigation of a ground surface layer or structure. This research is carried out in order evaluate dynamic characteristics and resonance effect of low rise existing site and reinforced concrete building by using ambient vibration technique. Two sites have been selected in the study are, namely SMK Kundasang, Sabah (damaged building) and 0.4KM radius of ground surfaces from SK Seri Sabak Uni in Pt. Raja, Johor. Microtremor assessment conducted in SMK Kundasang on 3-storey existing reinforced concrete building and its site has led to the prediction of predominant natural frequencies 2.99 Hz to 3.10 Hz and 5.63 Hz to 5.85 Hz in the transverse direction with 4.85 Hz found in the longitudinal directions of the building. Observation of two modes of building frequencies made on the transverse FAS curves with the latter being attributed to the torsional mode induced by serious structural damage only on the East wing causing non-uniform displacements despite the building being regular and symmetrical in shape. There is only a slight difference between the predominant and fundamental frequencies of the building and ground. In this case, the resonance effect could be the main reason for the structural damage induced by previous earthquakes event. Although there were no microtremor data available prior to the reported damage, physical evidence of structural failures on the first floor level seems to support the occurrence of soil-structure resonance. For the next study area, 75 measurement points were measured for microzoning task. From the data analysis, it was found that the study area is located on soft soil based on natural frequency (Fo) values between 1 to 2 Hz and dominating single peak from most HVSR curves. It has also been determined the values of the seismic vulnerability index for ground (Kg) which ranging from 1 to 131. All microzonation maps have been presented in the contour
layout in 2-D and 3-D model in N-S and E-W directions included for both sensors used. Both sensors 1 and sensor 2 used are quite comparable with some isolated region with different Fo, Ao and Kg values. Similar conclusion could be made within the directions of the North-South and East-West.
ABSTRAK

Pengukuran microtremor adalah teknik yang paling popular dalam menganggarkan tindak balas tapak dan bangunan serta keadaan bawah tanah kerana kaedah ini tidak memusnahkan, murah malah juga berkesan. Ia sesuai dipraktikkan di kawasan yang kekurangan rekod usul tanah tetapi tahap bunyi lebih tinggi untuk penyiasatan ciri-ciri dinamik lapisan permukaan tanah atau struktur. Kajian ini dijalankan bagi menilai ciri-ciri dinamik dan kesan resonans di kawasan rendah yang sedia ada dan bangunan konkrit bertetulang dengan menggunakan teknik getaran ambien. Dua tapak telah dipilih dalam kajian ini adalah, iaitu SMK Kundasang, Sabah (bangunan rosak) dan 0.4km jejari permukaan tanah dari SK Seri Sabak Uni di Pt. Raja, Johor. Penilaian microtremor dijalankan di SMK Kundasang pada bangunan konkrit bertetulang 3 tingkat sedia ada dan tapaknya telah membawa kepada ramalan frekuensi semula jadi utama iaitu 2.99 Hz hingga 3.10 Hz dan 5.63 Hz hingga 5.85 Hz dalam arah melintang dengan 4.85 Hz ditemui dalam arah membujur bangunan. Pemerhatian dua mod frekuensi bangunan yang dibuat arah melintang pada lengkung FAS dengan yang kedua dikaitkan dengan mod kilasan yang menyebabkan kerosakan struktur yang serius hanya pada sayap Timur disebabkan anjakan yang tidak seragam walaupun bangunan itu tetap dan simetri dalam bentuknya. Hanya ada sedikit perbezaan antara frekuensi utama dan asasi dalam bangunan dan tanah. Dalam kes ini, kesan resonans boleh menjadi sebab utama bagi kerosakan struktur disebabkan oleh peristiwa gempa bumi sebelumnya. Walaupun tiada data microtremor disediakan sebelum kerosakan yang dilaporkan, bukti fizikal menunjukkan kegagalan struktur pada tahap tingkat pertama seolah-olah menyokong berlakunya tanah-struktur resonans. Bagi kawasan kajian akan datang, 75 mata pengukuran diukur untuk kerja-kerja microzoning. Daripada analisis data, didapati bahawa kawasan kajian terletak di tanah yang lembut berdasarkan kekerapan semula
jadi (Fo) iaitu antara 1-2 Hz dan mendominasi puncak tunggal dari kebanyakan keluk HVSRS. Nilai indeks kelemahan seismik untuk tanah (Kg) juga telah didapati iaitu bermula dari 1 hingga 131. Semua peta 'microzation' telah dibentangkan dalam susun atur kontur dalam model 2-D dan 3-D di arah NS dan EW untuk kedua-dua sensor yang digunakan. Kedua-dua sensor sensor 1 dan 2 yang digunakan adalah agak setanding dengan beberapa kawasan terpencil dengan nilai Fo, Ao dan Kg yang berbeza. Kesimpulan yang sama boleh dibuat dalam arah Utara-Selatan dan Timur-Barat.
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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Sumatra-Andaman Earthquake of December 2004 (magnitude 9.0) generate tsunami that affected all coasts of the Indian Ocean, killed over 300 000 people and causes loss of property and live hood, 68 peoples died and property losses amounted to about 25 million in Malaysia (Colbourne, 2005).

Many engineered as well as non-engineered structures were severely damaged and collapsed during earthquake. Structures are normally designed to support vertical load and lateral loads due to traffic but none in seismic for conventional buildings. If the ground acceleration is high, the structure may experience very high seismic forces and cause the structural capacity to be exceeded. Worst, when seismic force generated in the structure can be exacerbated by a resonance effect if the fundamental frequency of the structure coincides with the predominant frequency of the site (Koong and Won, 2005).

Microtremor measurement is the most popular techniques in estimating the site responds and subsoil conditions. According to Kanai and Tanaka (1954), a theoretical interpretation and practical engineering application of microtremor to the characterization of soil layers, was introduced to predict the shear wave velocity of the ground and its fundamental frequency. Besides, microtremor is also efficient and
low cost charge in the seismic hazard microzonation study. So, it is useful and applicable to the structured testing without any damage. Recently, microtremor is popular for vulnerability investigation of both ground and structure because it can show the predominant frequency and amplification characteristic (Muccioni et al., 2009).

The main advantages of microtremor are a straightforward estimate of the resonance frequency of sediment without the need to know their thickness and S-velocity structure, simple and low cost measurement (Muccioni et al., 2009). The use of microtremor was later extended to the identification of the main fundamental frequency of the building (Gallipoli et al., 2004). Although the theory and interpretation of microtremor measurement in building are not so elaborated as they are free-field measurement, several studies in the last years showed that the microtremor method is useful for identification of soil-structure resonance (Gosar, 2010).

1.2 Problem Statement

Geotechnical factors often exert one of a major influence on damage patterns and loss of life in earthquake events. For example, the localized pattern of heavy damage during the 1985 Mexico City and the 1989 Loma Prieta earthquake provide illustrations of the importance of understanding the seismic response of deep clay deposits and saturated sand deposits (Bray et al., 1994).

In 1991, an earthquake struck from Mensaban fault in Ranau at a magnitude of 5.1 on a Richter scale, generating tremors in Kundasang region. Structured interview of some local residents drew a consistent observation that one of the parallel adjacent buildings of similar configurations to a 3-storey reinforced concrete buildings of nineteen bays and approximate length of 57 meters connected by open stories of sheltered corridors on each level fractured a few years after the earthquake event due to progressive ground subsidence. Half of the building had to be demolished while the remaining neighboring structure maintained a monitoring system put in place by the local authorities to monitor progressive structural and non-structural deterioration.
It is important to take serious action about site-structure response and interaction in order to provide structural safety of occupants especially at the important public building such as schools. This research is carried out in order to evaluate dynamic characteristics and resonance effect of low rise existing site and reinforced concrete buildings by using ambient vibration technique. Two sites have been selected in the study are, namely SMK Kundasang, Sabah (damaged building) and 0.4KM radius of ground surfaces from SK Seri Sabak Uni in Pt.Raja, Johor.

1.3 Objectives

The objectives of this study are:

i. To investigate the dynamic characteristics of soil-structure using field vibration approaches and computer programs.

ii. To estimate the ground vulnerability index based on the established models from previous research.

1.4 Scope of Study

Ambient vibration measurements were carried out at two sites (ground) and a building in order to fulfill both objectives. For the first objective, SMK Kundasang has been chosen. The building predominant frequencies, fo and ground fundamental frequency, Fo were determined by using Lennart Triaxial seismometer sensor with eigenfrequency 1 Hz, 24 bits of CityShark data logger and reinforced geophone cable were used in for the ambient vibration data collection. An open sources computer program of Geopsy was applied in order to transform the ambient vibration wave field signal into Fourier Amplitude Spectral (FAS) and Horizontal to vertical Spectral Ration (HVSR) which has been introduced by Nakamura (1989). Similar field procedure and data processing approach were taken for micro zoning task in Sabak Uni area in Parit Raja for Fo, and empirical vulnerability index (Kg) introduced by Nakamura (2000) to cater for the second objective. Three types of microzonation maps were produced afterward from the processed dynamic
characteristics data of Fo, and amplification factor, Ao, and calculated vulnerability index of Kg values.

1.4.1 Case study 1: SMK Kundasang, Sabah

Dynamic characteristics and site structure resonance were determined from the microtremor measurements. The measurements were conducted on the ground surfaces and building. Two lines of measurement were taken on ground (for each line consists of 3 points) and two sensor alignments (horizontally and vertically) were placed on along the building corridor. From Geopsy software, peak natural frequencies of both FAS and HVSR curves spectral were identify to determine the predominant mode frequencies of building and fundamental resonance frequencies of ground. Further discussions were extended to the expectation of building deformation (mode shape) the result of fo obtained.

1.4.2 Case study 2: Sabak Uni

Ambient vibration measurements were performed at 800 m x 800 m of boundary area with 100 m x 100 m of grid spacing as illustrated. About 81 grid points were identified but only 75 points able to be assessed due to unavoidable physical obstacles such as traffic, drainage, thick bushes etc. Some of the measurement points were required to be shifted from the original grid positions because of similar reasons. The measurement points were identified on site by GPS navigator. Finally, generic mapping tool (GMT) software was used to plot the Fo, Ao and Kg value into two-dimensional and three-dimensional contour graph.

1.5 Significance of Study

At the end of this study simple assessment of dynamic characteristics by using ambient vibration test carried out on sites and building may able to give some indicator in identifying the dynamic behavior and its deficiency based on the characteristic of the Fo, Ao and Kg values obtained.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

If a structure is subjected to vibration at its natural frequency, the displacement of the structure will reach to maximum. Higher the displacement will create greater stresses that developed in the framing members and connection of the structure. Site dynamic characteristic play the important role in establishing in damage assessment, health monitoring or rehabilitation scenario, when destructives testing need not to be carried out either from ground or on building. An ambient vibration testing is a wonderful technique, even easy, quick and accurate in prediction.

2.2 Ambient Vibration Technique

Ambient vibration is a ground vibration caused by natural or artificial sources that can be reflected to the geological conditions. It is also known as microtremor or ambient noise. The noise is the generic term used to denote the ambient vibration of the ground and floor caused by resources such as tide, turbulent wind, the effect of wind and trees or building, industrial machinery, cars, trains, human footprint, oceanic wave, volcanic tremor and more (Warnana et al., 2011).
Warnana et al. (2011) stated that the microtremor HVSR technique was widely used for microzonation and site effect studies but then use of microtremor was extended to the identification of the fundamental frequencies of building and soil-structure resonance. Besides, it may estimate the shear wave velocity (Vs), based on the general relationship of \( F_o = \frac{V_s}{4H} \) when H is the soil thickness, and this \( F_o \) can be determined from HVSR method.

HVSR was introduced by Nakamura (1989). It can be performed only by one station to identify the dynamic characteristics of the ground or building. However, bigger number of operating stations, higher reliability of the prediction made. This technique is very attractive since it gives ease of data collection and it can be applied in the area of low or even no seismicity. Nakamura assumes that the H/V ratio reflects the amplification of ground motion.

Although the theory and interpretation of the microtremor technique in buildings are not as elaborated as they are free-field measurements, several studies in last years showed that microtremor method is useful for the identification of soil-structure resonance (Gosar, 2010).

### 2.3 Natural Frequency

According to U.S Geological Survey (USGS), the natural frequency is a frequency at which a particular object or system vibrates when pushed by a single force or impulse, and not influenced by other external forces or by damping. If holds a slinky by one end and let it hang down and then give it one push up from the bottom, the rate of up-and-down motion is its natural frequency. The natural frequency of a second-order system is the frequency of oscillation of the system without damping.

Generally, for structure, the shorter a building is the higher its natural frequency and the taller the building, the lower the natural frequency (MCEER, 2009). Tall buildings have a low natural resonance and respond to low frequency while short buildings have high resonance and respond to higher frequencies. The smaller building is more affected or shaken by high frequency waves (short and frequent) while large structures or high buildings are more affected by low-frequency or slow shaking (IRIS, 2010). Taller buildings have lower natural frequencies than
short building, meaning that if a broad spectrum of seismic wave frequencies is released, building with different resonant frequencies will sway differently.

In determining the natural frequencies of the building, the most suitable method proposed by Gosar (2010) which is the Fourier Amplitude Spectral (FAS) that is a standard method. To check the reliability of FAS and HVSR to estimate the natural frequencies of the buildings take on different floors of the building. The best method shown from result of analyses, there are good correspondence in frequency which mean the frequency of each floor is the same and there are amplification or amplitude of peaks fundamental frequencies which increase with an increase in high. Moreover, the best method is can determine the exact and clear values of frequency (Warnana et al., 2011). This is especially dangerous if soil-amplification is significantly strong, in which the free field HVSR may contaminate building natural frequency, finally false possible resonance identified (Warnana et al., 2011).

2.4 Horizontal to Vertical Spectral Ratio

Horizontal to vertical spectra ratio technique (HVSR) is popular for vulnerability investigation of both ground and structures because the HVSR can show the predominant frequency and the amplification characteristics (Mucciarelli et al., 2009). The HVSR technique has been widely used in assessing the response of the ground to microtremors and the inference of site amplification to seismic strong ground motion. In the recent years, many researchers have successfully extended the usage of HVSR to study the response of a civil structure for example the reinforced concrete building to ambient noise. This method has proven to be useful for tall and complicated buildings (Luo et al., 2008). The main advantages of the HVSR method are able to estimate of the resonance frequency of sediments without knowing the geological and S-velocity structure of the underground, simple, low-cost measurements (Gosar et al., 2010).

2.5 Floor Amplitude Spectral

In Gosar (2010) stated that the theory and interpretation of ambient vibration inside the building using the microtremor technique for building are not so structured and
straightforward as they are for free-field, when measuring inside a given building in a densely populated area, one of the main difficulties is to detect and eliminate the effects of the fundamental frequencies of nearby free-field and other buildings in the vicinity. The building response is the ratio of the spectra of the horizontal to record to the spectra of the corresponding basement record. In the addition, when the instrument is not positioned in the mass center, the torsional frequency can mask the results (Warnana et al., 2011). As a conclusion, the analysis result from the measurement was analysis using the FAS method to get the exact value of the fundamental frequency of the building.

2.6 Site-Structure Resonance

Resonance is a tendency of a system to oscillate with larger amplitude at some frequency than the other. Resonance is in maximum when the frequency of the ground motion oscillation is equal to the one natural frequency of the structures (Gioncu and Mazzolani, 2011).

There are many factors affecting the value of natural frequency, one of the factors is the bedrock location. According to Waas (2004) the flexibility of the pile foundation contributed to the natural frequency of the building is mainly due to bending of the vertical piles when subjected to a horizontal base shear force of the structure. The rocking stiffness of the pile foundation, even in shorter direction, is relatively large and therefore has only a small influence on the fundamental period of the building.

When the frequency contents of the ground motion, are coincided with the building's natural frequency, the building and the ground motion tend to resonance with one another. When the earthquake ground motion occurs beneath the building and strong enough, it sets the building in motion, starting with the building foundation, and transfers the motion throughout the rest of the building in a very complex way. These motions in turn induce forces which can produce damage (MCEER, 2009). This means the location of the bedrock also influence the result of the natural frequency of the building.

An important factor in predicting earthquake damage is the relation between the building predominant frequency and the ground fundamental frequency. If the
building frequencies are close to a nearby natural frequency of the material on which it is built, or if it equals some whole number multiple of the material’s natural frequencies, the seismic motion will create a resonance with the building could that can greatly increase the stress in the building (Warnana et al., 2011). Jovasnoka (2013) give the example of damage from resonance situations illustrated, among many others, in the cases of Caracas (1976), Mexico City (1985), Leninakan (1988), Loma Prieta (1989), Izmit (1999), Colima (Mexico)(2003) and Al Hoceima (Morocco)(2004) and in Europe the cases of Adra (1993), Umbria - Marche (1997), Azores and Mula.

If we consider the soil condition of the case study are the soil is sandy clayed soil. From previous studies at Loma Prieta, California at 17th October 1989 earthquake shows that earthquake damage tends to be large on soft soil compare to stiffer ground. In the great earthquake on September 1985 in Mexico City hundreds of tall buildings located on the tick clay layer in the center of the city compare to hard ground. Suspected for this case study this building will occur high damage because of the geological data the area is clay soils. After all the analysis have been done, we can conclude the school building have a possible for resonance effect. This is because the natural frequency estimated for the building in the range 2.99 Hz to 3.10 Hz and the ground natural frequency in the range 4.85 Hz.
CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology of this research is divided into two sites, namely SMK Kundasang and Sabak Uni. Similar ambient vibration (AV) operation and processing procedures of FAS and HVSR were applied on both study area. The following discussions have been specifically discussed on the methodology of respective site.

3.2 Microzonation Study at Sabak Unit, Pt. Raja, Bt. Pahat, Johor

Generally, the methodology can be divided into three phases; pre measurement, measurement day and post measurement as in Figure 3.1. Local site effects evaluation of natural frequency, Fo and amplification factor, Ao of Sabak Unit area, has been presented in microzonation maps from ambient noise measurements carried out using Lennartz 1 Hz tri-axial seismometer sensors. Fo and Ao are the key components in seismic hazard analysis, resonance effect assessment of existing site, characterization of sediment layers, prediction of shear wave velocity through cheaper and quicker microtremor technique. 75 points of ambient noise records are analyzed using Horizontal-to-vertical spectral ratio (HVSR) method. The reliability and clarity of the significant peaks of mean HVSR curves are checked against the criterions recommended in the SESAME (2004) guideline. Predicted Fo,
Ao and Kg values were plotted into three dimensional contour graphs by using Generic Mapping Tool software.
Figure 3.1: Methodology Flowchart
3.2.1 Pre-Measurement

3.2.1.1 Desk Study

Desk study is an initial step which refers to the collection process of site information before the fieldwork able to be started. SESAME (2004) was used as the main guideline on ground measurement, which related to preparation of the fieldwork, HVSR processing parameters and interpretation of HVSR curves that automatically computed by Geopsy.

3.2.1.2 Preliminary Works

There are three main parts in the preliminary work, such as determination of site boundary, contour and accessibility planning to the measurement points planned and site visit. Figure 3.2 shows the location of the study area where SK Seri Sabak Uni was the center point within 800 m x 800 m of grid area.

![Figure 3.2: Plan view of study area (source: Google Earth)](image)

The study boundary covered 100 m x 100 m grid spacing within 0.4 km radius from the center point of SK Seri Sabak Uni. The grid points were divided
approximately from the Google Earth application, accordingly to the grid spacing applied. 81 points measurements (see Figure 3.4) were identified with its specific coordinates of longitude and latitude as shown in Figure 3.3. Most of the measurement points were located in the palm grove, and some of them close to the main road. Finally, site visit was performed in order to check the accessibility of 81 grid coordinates for ambient vibrations measurement and safety, without severe obstacles or danger to be faced later.

![Coordinates of Grid Points](image1)

Figure 3.3: Coordinates of Grid Points (source: Google Earth)

![81 Grid Points](image2)

Figure 3.4: 81 Grid Points (Google Earth)
3.2.2 Measurement Day

3.2.2.1 Measurement

During the measurement, the ambient vibrations were collected by using seismometer equipment. Ambient vibration or microtremor was a background noise caused by man-made noise, generally high frequency, generated by local surface such as industry and traffic, and natural low-frequency noise by tides, winds and others. GPS equipment (see Figure 3.5) was used to navigate the locations of every grid points directly to the location.

![Figure 3.5: Seismometer and GPS Equipment](image)

After a grid point has been navigated, the data logger need to be setting up based on 100 Hz of frequency sampling and optimum gain level. Two sensors were used simultaneously in order to calibrate the HVSR result from each other. The connection between sensors and data logger used was sketched as in Figure 3.6.
All sensors were connected by reinforced cable to the data logger. In order to make sure the sensor was leveled, an adjustment must be made through the adjustable screws that attached at the bottom part of sensors. The bubble must be in the middle of the provided circle shown in Figure 3.7 (a). In the benchmarking direction, all sensors were aligned to the True North direction that guided by the magnetic compass, as shown by the arrow the sticker on top of sensor as given in Figure 3.7 (b).

The recommendation of the recording duration for ambient vibration can be referred to SESAME (2004) guideline. 10 minutes of recording length was used in
this study at minimum expected Fo was bigger than 1 Hz. Table 3.1 shows the recommendation of recording duration given by SESAME (2004).

<table>
<thead>
<tr>
<th>Type of parameter</th>
<th>Main recommendations</th>
<th>Minimum expected $f_0$ [Hz]</th>
<th>Recommended minimum recording duration [min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recording duration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.2</td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

All information related to the condition of measurement points such as date, times of measurement, weather, coordinates, recording duration, gain, number of measurements, file index, vehicle and wind condition were recorded in the field sheet as references in stage of post-measurement. The field sheet example was shown in Figure 3.8.
3.2.3 Post-Measurement

3.2.3.1 Data Processing

In this stage, all ambient noise signals from 3 main components of North-South, East-West and Vertical were transferred into a computer via Readcity software. Then, the ambient noise signals are processed by Geopsy software in order to compute the signals into HVSR curves for fundamental ground frequency, Fo and amplification factor, Ao of each measurement point.

Figure 3.9 shows the sample of ambient noise vibration signals in three mentioned components extracted from Geopsy software. The signals were divided automatically into 10 sec consistent windowing for Fourier amplitude spectral
conversion followed by HVSR computation. Automatic window selection module had been introduced to enable the processing of large amounts of data. The main objective is to keep the stationary parts of ambient vibrations, and to avoid the transients often associated with specific sources (footsteps, close traffic). The window selection module was shown in Figure 3.10.

Figure 3.9: Sample of Ambient Vibration Signal Data

Figure 3.10: Windowing Process by Geopsy (source: SESAME, 2004)
Several parameters were applied in HVSR analysis, and they were:

1) Baseline correction and band-pass filtering to retain the frequencies in the range from 0.5 to 50 Hz.

2) Windows of 10 sec length were automatically selected using an anti-STA/LTA trigger algorithm and tapered with a 5\% cosine function before the computation of spectra.

3) Fourier spectra were calculated for each noise component and smoothed using Konno-Omachi window having a smoothing constant b-value of 40.

4) The resulting spectral amplitudes of horizontal components were geometrically average and divided by the vertical spectra to calculate the H/V function.

5) Directional energy, where 00 degrees (00°) for North-South and 90 degrees (90°) for East-West.

A sample of HVSR curves shown in Figure 3.11 was obtained from HVSR analysis computed by Geopsy software. Each significant peak of mean HVSR curve was automatically picked up by the software for fundamental frequency and amplification factor determination.

![Figure 3.11: Sample of HVSR Curves (source: Geopsy software)](image)

**3.2.3.2 Criteria for Reliability**

The first requirement, before any extraction of information and any interpretation, concerns the reliability of the H/V curve. Reliability implies stability, i.e., the fact that the actual H/V curve obtained with the selected recordings be representative of H/V curves that could be obtained with other ambient vibration recordings.
Based on SESAME (2004), three reliability reliable and at least five out of six clarity criteria must be fulfilled for a clear HVSR peak. Table 3.2 shows those criteria mentioned in SESAME (2004). It is recommended to reprocess the recordings with some other processing parameters or repeating the fieldwork, if the criteria still unable to be satisfied.

<table>
<thead>
<tr>
<th>Criteria for a reliable HV curve</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) ( f_0 &gt; 10 ) and ( n_0 &gt; 100 )</td>
</tr>
<tr>
<td>ii) ( \text{var}(f_0) &gt; 200 )</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Criteria for a clear HV peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) (</td>
</tr>
<tr>
<td>ii) (</td>
</tr>
<tr>
<td>iii) (</td>
</tr>
</tbody>
</table>

Table 3.2: Reliability and Clarity Criteria (SESAME, 2004)

<table>
<thead>
<tr>
<th>Threshold Values for ( \sigma_f ) and ( f_{0} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency range [Hz]</td>
</tr>
<tr>
<td>( \Delta f ) [Hz]</td>
</tr>
<tr>
<td>( \sigma_f ) for ( f_{0} ) [Hz]</td>
</tr>
<tr>
<td>( \log_{10} \sigma_f ) for ( 1000 f_{0} ) [Hz]</td>
</tr>
</tbody>
</table>

3.2.3.3 Microzonation Maps

The final stage in the post-measurement is a process of developing microzonation contour graph or map. Microzonation maps in this study were developed based on the significant values of the Fo, Ao and seismic vulnerability index, Kg, obtained. Kg can be calculated according to Nakamura (1997) as following expression. A sample of two-dimensional (plane) and three-dimensional (space) microzonation maps illustration is given by Figure 3.12 and 3.13.

\[
Kg = A_o / F_o
\]  
(3.1)
3.3 Site-Structure AV Measurement at SMK Kundasang, Sabah

SMK Kundasang was constructed in 1984 and became formal two years later. It is located on a flattened sloping ridge at 1250 m above the sea level, flanked by two basins. From the interview conducted, in 1991 an earthquake struck from Mensaban fault in Ranau at a magnitude of 5.1 on a Richter scale, generating tremors in Kundasang region and causing severe damage to some structures, roads (see Figure 3.14) and infrastructures including those within the compound of SMK Kundasang.
A microtremor study was conducted to measure the dynamic characteristics of a seriously damaged 3-storey existing school building and its site using tri-axial 1 Hz seismometer sensors. Horizontal-to-vertical spectral ratios (HVSР) and Fourier amplitude spectra (FAS) of microtremor measurement on the ground and structure were used to predict modal parameters of natural frequencies in the longitudinal (EW) and transverse (NS) directions.

3.3.1 Methodology flow chart: SMK Kundasang

Three phases were similarly applied in this study area such illustrated in flowchart Figure 3.15. It consists of pre-measurement, measurement day and post measurement.
Figure 3.15: Flow chart of methodology
REFERENCES


