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Influence of Traffic Vehicles Against Ground Fundamental Frequency Prediction using Ambient Vibration Technique

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Abstract. Ambient vibration (AV) technique is widely used nowadays for ground fundamental frequency prediction. This technique is easy, quick, non-destructive, less operator required and reliable result. The input motions of ambient vibration are originally collected from surrounding natural and artificial excitations. But, careful data acquisition controlled must be implemented to reduce the intrusion of short period noise that could imply the quality of frequency prediction of an investigated site. In this study, investigation on the primary noise intrusion under peak (morning, afternoon and evening) and off peak (early morning) traffic flows (only 8 meter from sensor to road shoulder) against the stability and quality of ground fundamental frequency prediction were carried out. None of specific standard is available for AV data acquisition and processing. Thus, some field and processing parameters recommended by previous studies and guideline were considered. Two units of 1 Hz tri-axial seismometer sensor were closely positioned in front of the main entrance Universiti Tun Hussein Onn Malaysia. 15 minutes of recording length were taken during peak and off peak periods of traffic flows. All passing vehicles were counted and grouped into four classes. Three components of ambient vibration time series recorded in the North-South: NS, East-West: EW and vertical: UD directions were automatically computed into Horizontal to Vertical Spectral Ratio (HVSR), by using open source software of GEOPSY for fundamental ground frequency, F_o determination. Single sharp peak pattern of HVSR curves have been obtained at peak frequencies between 1.33 to 1.38 Hz which classified under soft to dense soil classification. Even identical HVSR curves pattern with close frequencies prediction were obtained under both periods of AV measurement, however the total numbers of stable and quality windows selected for HVSR computation were significantly different but both have satisfied the requirement given by SESAME (2004) guideline. Besides, the second peak frequencies from the early morning HVSR curve was clearly indicated between 8.23 to 8.55 Hz at very low amplitude ($A_o \leq 2$), but it should be neglected according to the similar guideline criteria. In conclusion, the ground fundamental frequency using HVSR method was successfully determined by 1 Hz seismometer instrument with recommended to specific parameters

consideration on field as well as data processing, without disruption from the nearest traffic excitations.

1. Introduction

Ground fundamental frequency by using ambient vibration technique might be questioned in urban site especially when the recording is performed closer to high density of noise intrusion such as vehicles transient. Increasing number of private vehicles and public transportations recently in major cities in Malaysia has creating limited idling time to receive good signal quality of ambient vibration recording. Continuous intrusion due to local source such as traffic flows will eliminate significant number on quality window from the time series, which could imply the reliability of computed Fourier spectra. The noise intrusion becomes worst when the site is situated in middle of city at limited space and distance from the traffic path. Noise sources should be controlled to assure reasonable quality standard for ambient vibration measurements such as close steps, close high speed car or truck traffic, close machinery etc. [2]. Due to these reasons, there are many studies have been discussed about the recommended parameters on field measurement and data processing for quality ambient vibration signal and reliable HVSR results [1,2,3,4,5,6].

Due to high traffic flows at the junctions of UTHM entrance, this area has been selected in this study as shown in figure 1. Simple experimental with 1 Hz tri-axial seismometer instrument, at four periods of traffic volumes with field measurement control, appropriate data acquisition as setup well as processing parameters were carried out to compare and investigate the influence of traffic vibration against the ground fundamental frequency prediction based on ambient vibration testing and HVSR method.

Figure 1. Location of study area.

2. Methodology

2.1. Microtremor Instruments and Connectivity

The ambient vibration instrument comprises three units of Lennartz portable tri-axial seismometer (velocitimeter) of 1 Hz eigenfrequency sensors (S) and 400 V/m/s output voltage, a 24 bit CityShark II digital acquisition system at maximum 4 input sensors, and 1 GB memory flash card data storage (see figure 2). According to [7], ongoing controversy concerns on the use of a 1 Hz seismometer for studying thick sedimentary basins characterized by HVSR peak below 1 Hz and sometimes as low as 0.1 to 0.2 Hz have been reported by [8] when 1 Hz and a broadband seismometer able to give identical estimation from ambient ground motion to frequency greater than 0.15 Hz.

The seismometers are placed, levelled and aligned to the magnetic North direction. All major components of NS (North-South), EW (East-West) and vertical (V) directions recorded signals were stored into the flash card and the ambient vibration signals were manually extracted into external device (portable computer) for data acquisition and processing.

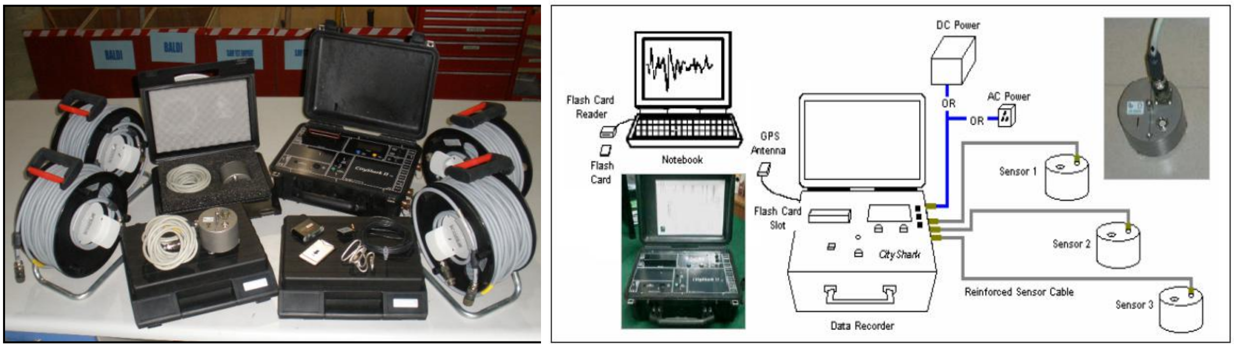

Figure 2. Seismometer instrument and connections

2.2. Fieldwork and Data Logger Parameters

Four ambient vibration measurements were performed in three main peak traffic periods (morning, afternoon and evening) and an off peak traffic period (early morning). The details about the measurement periods and vehicles classification are given in table 1. According to [3], from 36 tests had conducted show that the cars moving closer than 5 meter and turned on engine car at 1 meter from the sensor can influencing the HVSR result. Eight meter distance was considered from the traffic path to ambient vibration station in this study. In additions, the ambient vibration source can be very different from one point to another as well over time [3]. Thus, two units of seismometer sensors were also placed simultaneously at 1.5 meter spacing (see figure 3) for the purpose of results comparison in terms of natural frequency and amplification factor.

Table 1. Selection of peak and off peak traffic periods for ambient vibration measurements, and vehicles classification

Ambient Vibration Recording Periods				**Classification of Vehicles**			
Off Peak Traffic Period (less traffic)	**Peak Traffic Periods (traffic congested)**			**Class 1**	**Class 2**	**Class 3**	**Class 4**
Early Morning 18-01-17 3.41 to 3.56 am	**Morning** 17-01-17 7.55 to 8.10 am	**Afternoon** 17-01-17 12.33 to 12.48 pm	**Evening** 17-01-17 17.10 to 17.25 pm	Motocycles	Cars	SUV, Van, MPV, Small lorries (6 tn and less)	Bus, treller, big lorries (more than 6 tn)

Figure 3. Position of sensor 1 (S1) and sensor (S2).

Meanwhile, [1] has summarized some recommendations parameters on-site and data processing of ambient vibration input motions based on HVSR method [9]. The following field parameters are recommended by [1] and previous studies:

a. The minimum recording length for site between 2 to 1 Hz of natural frequency is recommended between 5 to 10 minutes according to [1].
b. A sampling rate of 50 Hz is sufficient, as the maximum frequency of engineering interest is not higher than 25 Hz, although higher sampling rates do not influence HVSR results [1].
c. According to [10], the gain was adjusted to minimize signal saturation from the three components of ambient vibration time histories. It should also be kept in mind that, whatever the type of sensor used, it is not recommended to use too high of a gain, which would result in excessive signal saturation and severely compromise the result [7].
d. Possibly the main result is that no matter how strongly a tested parameter influences the HVSR amplitude curves, the value of peak frequency is usually not affected with the noticeable exception of the wind [2].

By considering all recommendations as stated above, table 2 summaries the parameters of ambient vibration recording used on CitySharkII data logger, and handheld wind meter was installed during peak and off peak traffic periods in order to monitor the wind velocity.

Table 2. Data logger parameters.

Type of Parameters	Data Logger Parameters (on site)
• **Recording length**	15 minutes
• **Sampling frequency**	100 Hz
• **Max gain level**	8
• **Wind speed was monitored by portable handheld**	≤ 5 m/s based on [1]

2.3. Processing Tool Parameters and HVSR Method

Ambient vibration wave fields are processed using open-source software of GEOPSY for the peak frequency determination from the squared average of HVSR method. The transforming processes of Fourier amplitude spectra (FAS) involved several steps such as signal corrections, sampling window selections, signal filtering, then finally followed by computational of HVSR curves, spectral curves smoothing, calculation of mean and standard deviation of the HVSR [11]. Computational of Fourier amplitude spectral automatically performed by GEOPSY software against three components of NS, EW and V of the ambient vibration time series then followed by Horizontal to Vertical Spectra Ratio in accordance to equation (1). It is important to highlight, the frequency of the HVSR peak reflects the fundamental frequency of the sediments and the amplitude depends mainly on the impedance contrast with the bedrock but cannot be used as site amplification [12].

$$\text{HVSR} = \sqrt{\frac{H^2{}_{N-S} + H^2{}_{E-W}}{2.V^2}} \quad (1)$$

Where,

H_{N-S} : Fourier amplitude spectra in the North-South direction
H_{E-W} : Fourier amplitude spectra in the East-West direction
V : Fourier amplitude spectra in the vertical direction

Anti-trigger algorithm was recommended by [1] and [2] this function may able to detect transients and try to avoid them. The following recommendations of processing tool parameters from previous guideline and studies are summarized in table 3, and the parameters used in this study are tabulated in table 4.

Table 3. Recommended processing tool parameters by previous studies and guideline.

Type of Parameters	**Ambient Vibration Data Processing**			
	[2]	[7]	[3]	[1]
• **The short term average, "STA"**	Typically around 0.5 to 2.0 s	2 s	2 s	0.5 to 2.0 s
• **The long term average, LTA**	Several tens of seconds	30 s	30 s	Several tens of seconds
• **Ratio STA/ LTA**	Typically between 3 and 5	0.2 and 3	0.01 and 10	1.5 – 2 (Max STA/LTA)
• **Window length**	-	40 s	25 to 40.96 s	≥ 8.25 s
• **Konno & Ohmachi with 40 smoothing constant and 5% Cosine Tapering**	-	√	√	Konno & Ohmachi with with suitable bandwidth smoothing constant

Table 4. GEOPSY parameters applied in FAS and HVSR analyses.

Type of Parameters	**Data Processing on FAS and HVSR analysis**
• **Anti-triggering on raw and filtered signal**	√
• **Window selection parameters for raw signal and filtering signal:**	
✓ **STA**	1.0 s
✓ **LTA**	30.0 s
✓ **Min STA/LTA**	0.20
✓ **Max STA/LTA**	2.50
• **Smoothing type**	Konno & Ohmachi with 40 smoothing constant

• **Cosine tapering**	5%
• **Frequency sampling**	0.5 Hz to 16.0 Hz

The reliability of predicted peak frequency from respective measurements was also verified against three reliability criteria provided by [1] as shown in equation 2 to 4. Besides, the computed HVSR spectrum from both sensors were also compared to increase the stability of the prediction due to none of other geophysical approach, dynamic instrument or numerical analysis was performed on similar site for the purpose of result verification.

i. $F_o > 10 / l_w$ (2)
ii. $n_c = l_w \cdot n_w \cdot F_o > 200$ (3)
iii. $\sigma_A (F) < 2$ for $0.5F_o < F < 2F_o$ if, $F_o > 0.5$Hz (4)
or, $\sigma_A (F) < 3$ for $0.5F_o < F < 2F_o$ if, $F_o < 0.5$Hz

where:

l_w : window length
n_c : number of significant cycles
n_w : number of windows selected for the average HVSR curve
F : current frequency
F_o : HVSR peak frequency
$\sigma_A (F)$: standard deviation of $A_{HVSR} (F)$

3. Results and Discussions

In this section, the statistics of traffic flows during ambient vibration measurement on peak and off peak periods with their HVSR curve results, selected stable and quality windows, average fundamental frequencies and amplitude are discussed. Besides, observation on specific vehicle class and driving attitude affecting ambient vibration signal are also provided as guidance for future fieldwork.

Congested traffic was recorded during peak traffic periods as surveyed in table 5. Comparison were made between the highest numbers of vehicles in the evening (975 vehicles) against the smallest numbers of vehicles in the early morning (only shows 29 vehicles) which has increased up to 34 times. Class 2 are the most dominating vehicle among all classes, followed by Class 1, Class 3 and Class 4.

Automatic window selection protocol with anti-triggering and filtering features set in GEOPSY software have successfully removed almost 50% of noisy windows (see Table 5) among peak traffic periods compared to more stable and quality windows during off peak period. The selected stable and quality windows were also illustrated in figure 4 (a) to (d), before transforming them into Fourier amplitude spectra and HVSR curves. From the afternoon measurement, the numbers of stable and quality windows shows the least selected due to high numbers of heavy trucks (class 4) intercepting and engaged to severe noise intrusion. From the observation have been made during early morning, speeding cars (class 2 and 3) intercepting the ambient vibration measurement station has mostly creating noisy windows. It must be emphasized under circumstances of heavy trucks and speeding vehicles, adequate sensor distance and recording length are necessary for the sake of good ambient vibration signal acquisition and enough quality windows for reliable HVSR analysis.

Table 5. Number of vehicles, selected quality windows and average peak frequencies.

Recording periods		Distribution of traffic volume					Total window selected, (n_w)		Frequency, F_o (Hz)		Average F_o (Hz)
		Class 1	Class 2	Class 3	Class 4	Total no. of traffic	S1	S2	S1	S2	
Peak	**Morning** 17-01-17 from 7.55 am	145	406	78	42	671	37	39	1.38	1.38	1.38
Peak	**Afternoon** 17-01-17 from 12.33 pm	96	381	117	64	658	28	30	1.33	1.38	1.36
Peak	**Evening** 17-01-17 from 17.10 pm	197	582	146	50	975	36	37	1.33	1.38	1.36
Off Peak	**Early Morning** 18-01-17 from 3.41 am	4	16	9	0	29	79	82	1.33	1.38	1.36

Reliability criteria recommended by [1] from all traffic periods were successfully fulfilled. A single sharp peak of HVSR curves were achieved from the ambient vibration measurement during peak and off peak traffic periods as given in figure 4. The first mode frequencies (or resonant frequency is occurred at the maximum amplitude) were ranging between 1.33 to 1.38 Hz. These resonant frequencies have shown no significant deviation of F_o values as well as on HVSR curve shape, under both heavy traffic and less traffic flows. But, only a small bump within 8.23 to 8.52 Hz has been appeared (see figure 4 (d)) in the early morning measurement but only noticeable at very low amplitude, $A_o \leq 2$.

The HVSR amplitudes were slightly fluctuating among all traffic periods as well as between both sensors. According to [13] based on [14], the classic merged of spectral ratio is stable in time but unstable in amplitude for a site. In addition, according to [2] the peak of HVSR curves should therefore coincide with the fundamental soil frequency but there should not exist any link between HVSR peak amplitude and actual ground amplification.

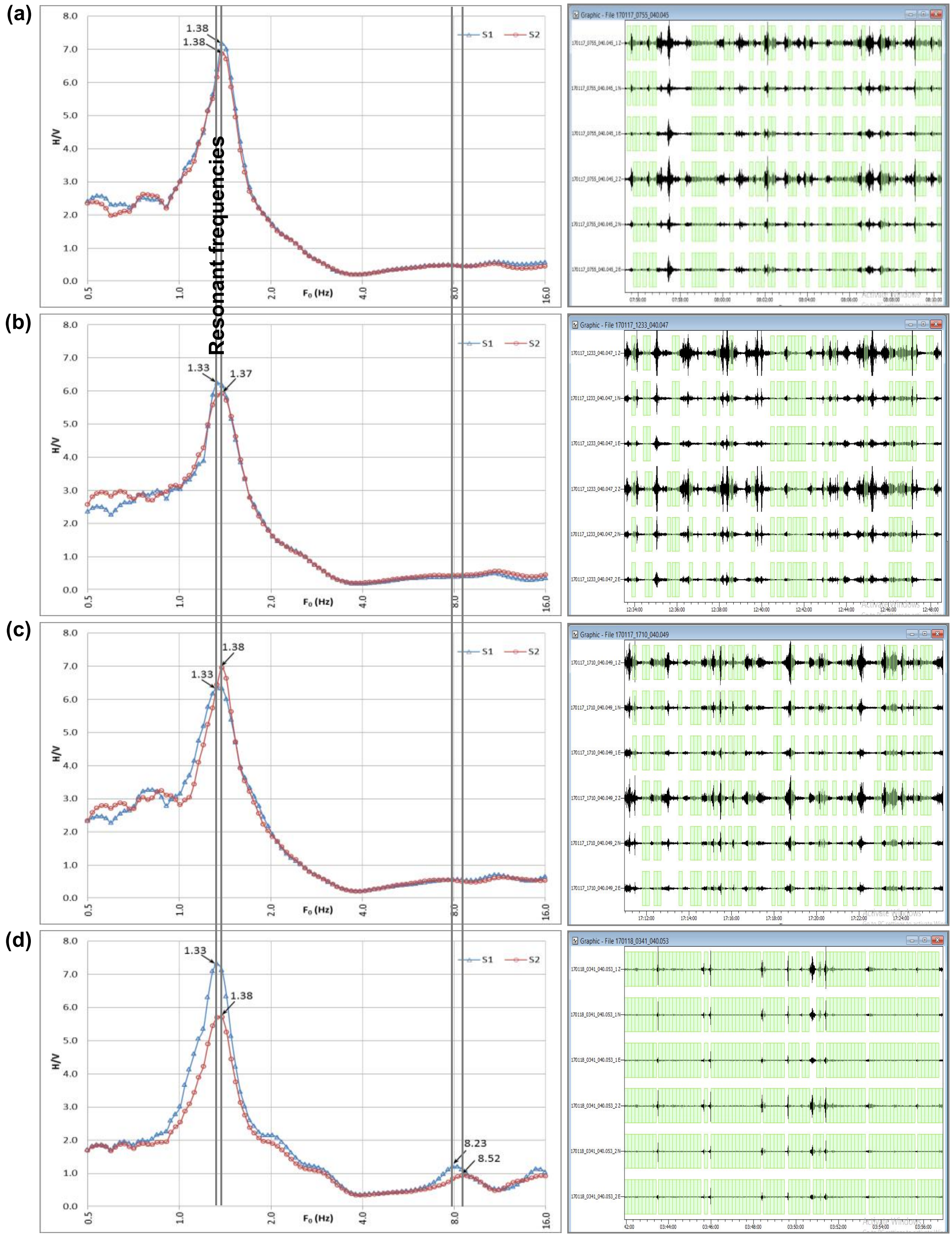

Figure 4. HVSR curves computed from ambient vibration signal captured by S1 and S2 from (a) morning, (b) afternoon, (c) evening and (d) early morning recording periods.

HVSR technique can give reliable results on site characterization when the impedance contrast between surface layer and bedrock is high [13]. The average frequencies obtained from table 5 between 1.36 to 1.38 Hz (0.73 to 0.74 sec, when the natural period is inversely calculated to natural frequency) has classified the site to approach under soft soil classification as given in table 6 according to [15]. Closer finding reported by [16] via Multichannel Analysis of Surface Wave (MASW) method conducted approximately 100 meter away to study area indicating the existence of sub-surface profile under firm to very soft classification below 30 meters depth of investigation.

Table 6. Ground classification for seismic design [15].

Ground classification	Site period, T_o (s)	Description
G0	-	Hard rock
G1	-	Bedrock
G2	0.25 and shorter	Diluvium
G3	0.25 to 0.5	Dense soil
G4	0.5 to 0.75	Dense to soft soil
G5	0.75 to 1.0	Soft soil
G6	1.0 to 1.5	Very soft soil
G7	1.5 and longer	Extremely soft soil

Conclusions

Determination of ground fundamental frequency in front of UTHM entrance successfully carried out even though under severe traffic noise influence. The selection of right instrument, fieldworks and processing tool parameters as recommended by previous guideline and studies able to disseminate the gap between both peaks and off peak traffic periods. Future investigations will be planned to study the crucial effects at closer distance to traffic path, different type of soil classifications, and minimum recording length that could modify the prediction of ground fundamental frequencies.

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