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HVSR recording duration for regolith sites: an experimental approach

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ABSTRACT: The application of the horizontal vertical spectral ratio (HVSR) technique using microtremor measurement to quantify the natural period of sites in urban areas is widely used around the world. However, this technique is still under development in regions with low impedance contrast between the top layer and the underlying bedrock, such as regolith. This paper investigates the recording duration of the aforementioned method for quantifying the site fundamental frequency in regolith environments. An experimental study has been carried out at a regolith site where two days of continuous data acquisition are used to investigate the HVSR technique measurement duration. A series of reliability tests were applied to the HVSR analysis results. The analyses suggest that at least 20 minutes duration is required for more reliable HVSR analysis results at regolith sites.

1 INTRODUCTION

The geophysical community is in agreement that the horizontal vertical spectral ratio (HVSR) technique provides valuable results in seismic hazard assessment in urban areas (Bard, 2002). However, guidelines for the minimum recording duration in a region with low impedance contrast between the top layer and the underlying bedrock, such as regolith sites, is still under development. Therefore, an experimental study has been carried out in accordance with the SESAME European project (Site EffectS assessment using AMbient Excitations) guidelines (SESAME 2004) at such a site in metropolitan Adelaide (Payneham), South Australia. The study aims to measure the fundamental frequency of the site and assess the reliability of various ambient noise measurement durations.

2 HVSR TECHNIQUE

2.1 *Equipment and data acquisition*

The equipment and data acquisition adopted in the present study utilised an LE-3DLite Lennartz seismometer with a Kelunji EchoPro digital data recorder, as shown in Figure 1. In order to reduce extraneous noise generated primarily by the wind, the seismometer was placed on a concrete slab, to provide a firm foundation, and a bucket and brick were used to shield the instrument (Figure 1).

Figure 1. HVSR technique main equipment and data acquisition setup

Horizontal vertical spectral ratio (HVSR) processing was carried out using the Geopsy software (Geopsy Project 2015) developed within the framework of the SESAME Project. This open source software processes the microtremor data in the following steps:

- Select as many as possible most-stationary windows (N) within the recorded data;
- Compute Fourier spectra amplitudes and carry out smoothing for the N most-stationary windows;
- Average of horizontal components for the N most-stationary windows;
- Compute N HVSRs for the N most-stationary windows; and
- Compute the average HVSR and the estimation error.

In the present study, default parameters and auto window selection are employed in the HVSR analysis.

2.2 *Recording duration*

In accordance with the SESAME guidelines (SESAME 2004), the recommended minimum recording duration for the HVSR technique is 30 minutes. However, when the expected fundamental frequency (f_0) is known, the recording duration can be less than that. Details of the SESAME recommendations are given in the Table 1.

Table 1. SESAME Recommendation for recording duration (SESAME 2004)

Minimum expected f_0 (Hz)	Recommended minimum recording duration (minutes)
0.2	30
0.5	20
1	10
2	5
5	3
10	2

2.3 *Reliability of HVSR technique curve*

The SESAME guidelines (SESAME 2004) outline a process by which the reliability of the HVSR curve can be assessed. The following criteria are suggested:

a. Criterion 1: So that the peak is significant, the fundamental frequency, f_0, should be greater than 10 divided by the window length (I_w), which in this study is 40 seconds;
b. Criterion 2: The analysis requires that a large number of windows and cycles is needed. Hence, the number of significant cycles should be greater than 200; and
c. Criterion 3: The level of scatter should be low. Hence, the standard deviation of the amplitude of the HVSR curve, at frequencies between $0.5f_0$ and $2f_0$, should be less than two when $f_0 > 0.5$ Hz, or less than 3 when $f_0 < 0.5$ Hz.

3 METHODOLOGY

The methodology adopted in the present study is outlined as follows:

- Collect continuous microtremor data over a duration of two days;
- Select and arrange the two-day measured ambient noise data into a series of 5, 10, 20, 30 and 60 minute recordings;
- Process each of the 5, 10, 20, 30 and 60 minute record subsets using the HVSR technique, in accordance with the SESAME guidelines (SESAME 2004); and
- Apply the reliability criteria to each of the HVSR results, as outlined in §2.3 above.

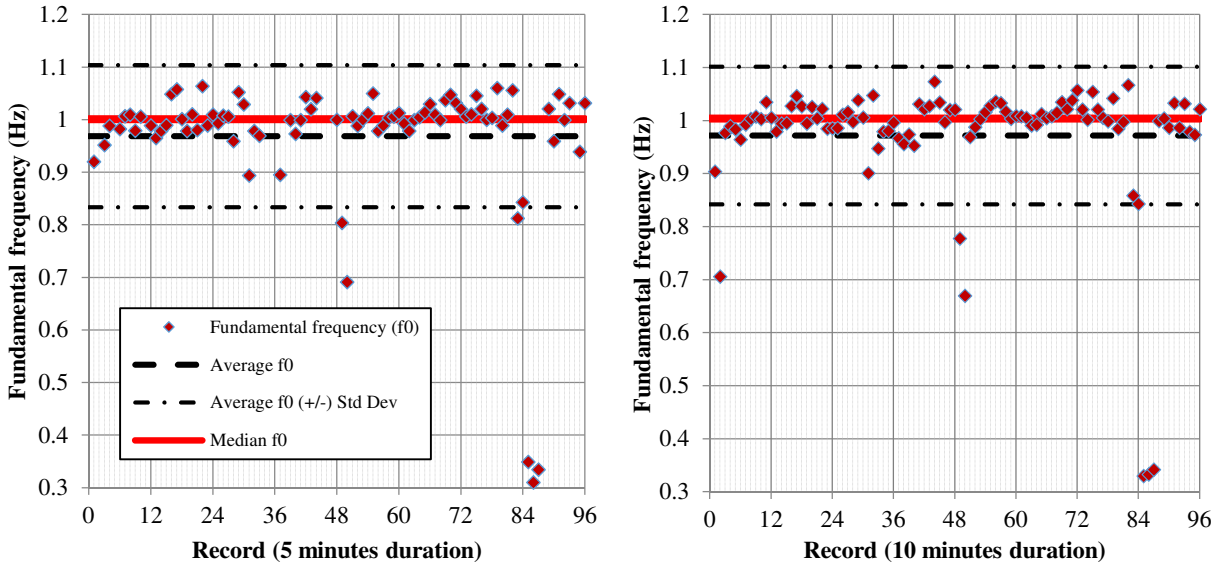
4 RESULTS OF HVSR AND RELIABILITY ANALYSES

4.1 HVSR analysis

A summary of the HVSR results for the 5, 10, 20, 30 and 60 minute subsets is given in Table 2. Detailed plots of the HVSR results are presented in Figures 2 to 4.

Table 2. Summary of all HVSR results

Recording duration (minutes)	Average f_0 (Hz) with the standard deviation	Median f_0 (Hz)
5	0.97±0.14	1.00
10	0.97±0.13	1.00
20	0.98±0.10	1.01
30	0.98±0.01	1.01
60	0.99±0.02	1.01



(a) **(b)**

Figure 2. Results of HVSR technique for (a) 5 and (b) 10 minute recording duration

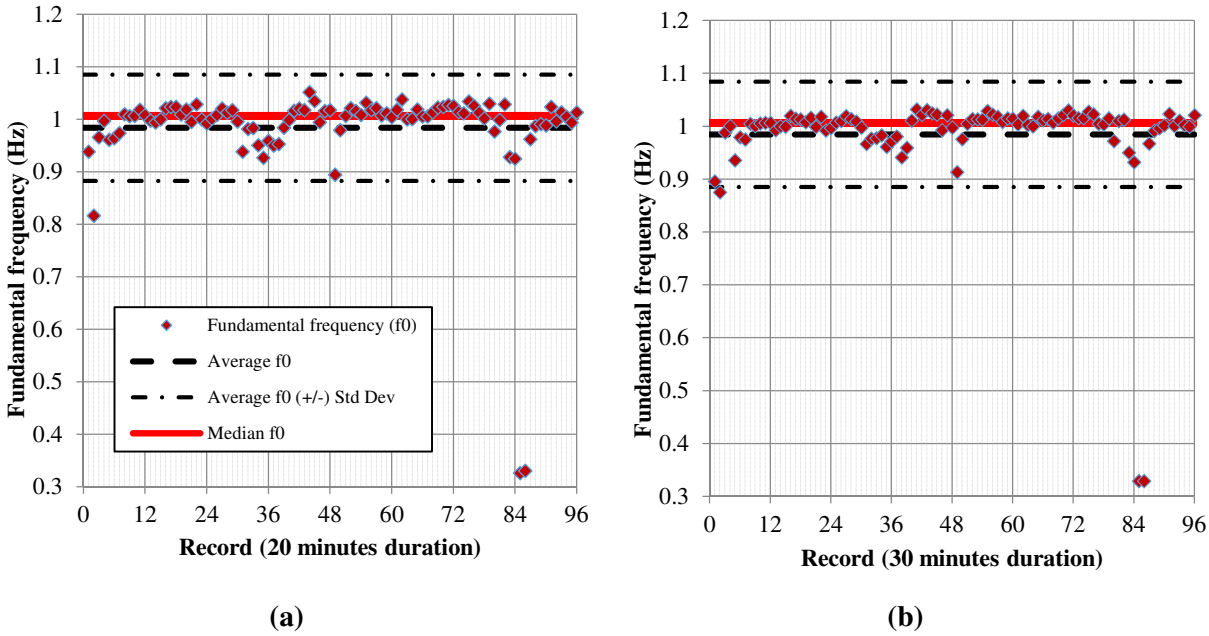


Figure 3. Results of HVSR technique for (a) 20 and (b) 30 minute recording duration

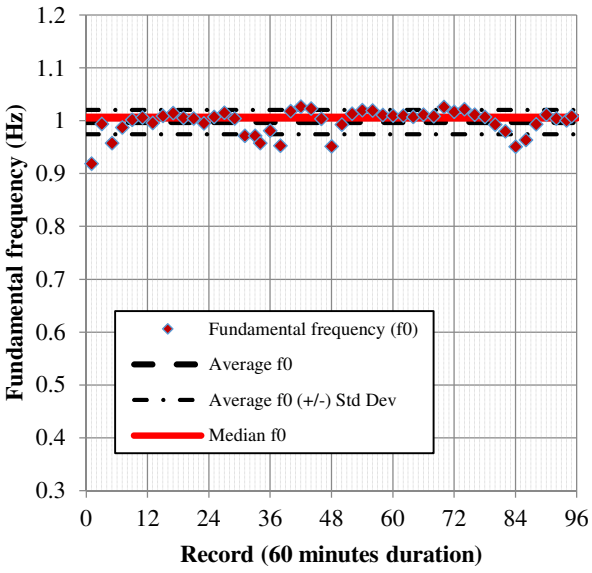


Figure 4. Results of HVSR technique for 60 minute recording duration

4.2 **Reliability analysis**

In accordance with the SESAME guidelines (SESAME 2004) the three reliability criteria have been applied to the HVSR results and these are summarised in Table 2. The reliability analysis results show that the 5 and 10 minute records produce only 14% and 64% records respectively pass the three criteria. Good results, however, are obtained for the 20, 30 and 60 minute duration records. These produce 86% to 89% of the records which pass the criteria.

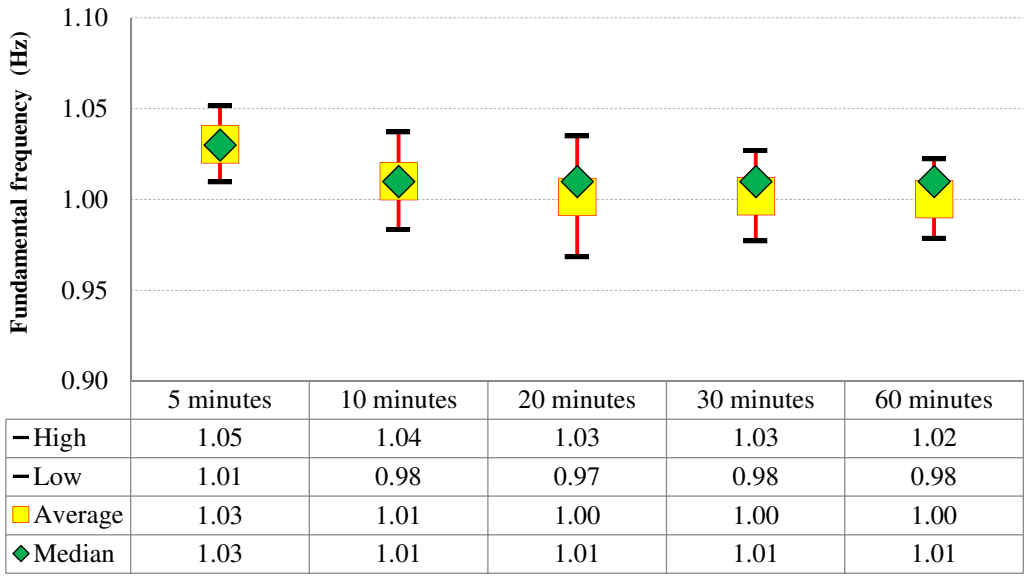
Analysis of the reliable records show that all the durations yield estimates of f_0 = 1 Hz with a maximum standard deviation of ±0.03. Furthermore, the median f_0 of the reliable records is about 1.0 Hz as well. Detailed results are given in Table 3 and Figure 5.

Table 2. Summary of reliability test of HVSR results

Recording duration (minutes)	Criterion 1		Criterion 2		Criterion 3		Remarks
	Pass	Fail	Pass	Fail	Pass	Fail	
5	84	12	14	82	68	28	12 records do not produce a f_0. 13 of 96 records pass the reliability criteria (14%).
10	96	0	70	26	78	18	62 of 96 records pass the reliability criteria (64%).
20	96	0	93	3	84	12	83 of 96 records pass the reliability criteria (86%).
30	96	0	95	1	86	10	86 of 96 records pass the reliability criteria (89%).
60	96	0	96	0	91	5	44 of 49 records pass the reliability criteria (89%).

Table 3. Average and median f_0 for reliable records

Recording duration (minutes)	Average f_0 for only the reliable measurement with the standard deviation (Hz)	Median f_0 for only the reliable measurement (Hz)	Remarks
5	1.03±0.02	1.03	14% pass
10	1.01±0.03	1.01	64% pass
20	1.00±0.03	1.01	86% pass
30	1.00±0.02	1.01	89% pass
60	1.00±0.02	1.01	89% pass



	5 minutes	10 minutes	20 minutes	30 minutes	60 minutes
High	1.05	1.04	1.03	1.03	1.02
Low	1.01	0.98	0.97	0.98	0.98
Average	1.03	1.01	1.00	1.00	1.00
Median	1.03	1.01	1.01	1.01	1.01

Figure 5. Plot of average and median f_0 for reliable records for all record durations

5 CONCLUSIONS

The HVSR technique has been applied to data obtained from a regolith site in metropolitan Adelaide. Two days of continuous ambient noise data were used to examine the reliability of the HVSR technique over a range of measurement durations. The analyses consistently yielded a site frequency, f_0, of

1 Hz and, based on 96 recordings, the results demonstrated that a duration of 20, 30 and 60 minutes duration provided more reliable HVSR results than records obtained over a 5 and 10 minute duration. This conclusion is in contrast with the guidelines provided by the SESAME Project, which recommend a recording duration of 10 minutes.

6 REFERENCES

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