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Assessment of Helicopter Flyover Noise for Tonal Components

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Abstract- Tonal noise is produced by bodies rotating at high speeds such as helicopters. Sounds of the same amplitude will produce different responses depending on the tonal content of the sound. Previous studies suggest that tonal noise is more annoying than broadband noise. Nowadays, sound level meters that can detect tonal noise directly are available in the market, but they are very expensive and beyond the reach of most environmental noise researchers. Hence, the need to adopt an analytical method that can be used to analyze and detect the presence of pure tones in helicopter flyover noise. This paper employs the simplified method suggested by the International Organization for Standardization (ISO). An objective study of the total noise environment in Mgbuoshimini Community Nigeria was carried out to determine the presence of tonal components. Results showed that the total noise environment in the Mgbuoshimini community was mostly characterized by broadband noise, with tonal components detected in four locations (Location 7 at 250 Hz, Location 18 at 6.3 kHz, Location 19 at 6.3 kHz, and Location 20 at 6.3 kHz.

Keywords: tonal noise, broadband noise, international organization for standardization, one-third octave bands, mgbuoshimini community.

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Strictly as per the compliance and regulations of:

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Keywords: tonal noise, broadband noise, international organization for standardization, one-third octave bands, mgbuoshimini community.

I. Introduction

Sound is a form of energy and (Suter, 1991) rightly describes it as "the result of pressure changes in a medium (usually air), caused by vibration or turbulence." The human ear captures sound within a specific window of the acoustic spectrum, generally within the 20-20000 Hz range. However, it is most responsive to sounds within the mid-frequencies: 1000-10000 Hz (Mariana Alves-Pereira & Castelo Branco, 2000).

(Cantrell, 1975) defined noise as sound which is disagreeable, discordant, or which interferes with the reception of wanted sounds. There are many sounds in the world, but not all of them pollute the environment and hence are not regarded as noise (Kryter, 1982). Medically speaking, noise is one of the leading causes of environmental stress and low-frequency noise is equally as stressful as high-frequency noise (Cho, Hwang, & Choi, 2011). One of the challenges in studying and managing noise is its subjective nature: one person's noise is another's music. People have widely varying reactions to noise. Individual reactions depend on characteristics of the noise, the noise source, and the individual's attitude to the noise and noise source.

Noise is classified based on its nature into two categories namely: broadband noise and tonal noise. Noise can be said to be tonal if it contains a distinguishable, discrete, continuous note (Greene, Manvell, Scholz, & Enggaard, 2008). Broadband noise has acoustic energy spread out across a wide range of frequencies, whereas a tonal noise has a lot of energy concentrated at certain frequencies – resulting in an audible tone or tones. Tonal noise tends to be more annoying or disturbing and so having the ability to detect and record tones can be very useful.

Noise is usually composed of many frequencies combined (Goelzer, Hansen, & Sehrndt, 2001). To facilitate the comparison of measurements between instruments, frequency analysis bands have been standardized. Thus, the International Organization for Standardization has agreed upon preferred frequency bands for sound measurement and analysis. The widest band used for frequency analysis is the octave band. Occasionally, a little more information about the detailed structure of the noise may be required than the octave band will provide. This can be obtained by selecting narrower bands; for example, one-third octave bands. As the name suggests, these are bands of the frequency of approximately one-third of the width of an octave band.

Nowadays, sound level meters that can detect tonal noise directly are available in the market, but they are very expensive and beyond the reach of most environmental noise researchers. Hence, the need to adopt an analytical method that can be used to analyse and detect the presence of pure tones in helicopter noise. This paper will employ the simplified method suggested by the International Organization for Standardization (ISO). This method tests if the sound pressure level in the one-third octave band of interest exceeds the sound pressure in both adjacent bands by a constant level difference. It is also an extension of previous studies by the current authors (O. Orikpete, Leton, & Momoh, 2020; O. F. Orikpete, Leton, Amah, & Ewim, 2020).

II. An Empirical Review of the Existing Literature

Over the years, many researchers have studied tonality and noise, and how it affects humans and they are briefly reviewed in this section.

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(Edwards, Broderson, Barbour, McCoy, & Johnson, 1979) conducted a study on behalf of the Federal Aviation Administration (FAA) which involved taking field measurements of helicopter flyover noise over communities along the Gulf Coast of Louisiana and Texas and areas adjacent to selected heliports in the United States using two analyzers. One of the analyzers measured the prevailing environmental noise (including helicopter noise), while the other recorded the prevailing environmental noise (excluding helicopter noise). The study also used a social survey to support quantitative measurements by obtaining 272 questionnaire responses from stakeholders. The outcome of the study revealed an average equivalent continuous noise level of 54.5 dB (A) for helicopter flyover noise, a value which exceeded the background noise by 2.5 dB(A); and 63.1 dB(A) for areas adjacent to heliports, which was 13.3 dB(A) above the heliport background noise. Although the results for the social survey showed that 64% of respondents had no problem with helicopter noise, the actual health implications of helicopter noise on residents living within the study area cannot be fully ascertained without a one-third octave frequency band analysis.

Noise of the same intensity will produce different hearing impairment depending on the frequency. In his book, (Yost, 2001) explained that the actual pressure transformation in the human ear depends on the frequency of the acoustic stimulus; pointing out that the pressure increase between the eardrum and the inner ear is greater than 30 dB in the region of 2.5 kHz and that the ratio decreases at frequencies exceeding 2.5 kHz. He further elaborated that hearing impairment depends on the characteristics of the noise that an individual is exposed to, most particularly, the frequency of the noise. In summary, temporary hearing loss will occur when one is exposed to broadband noise at frequencies between 3 and 6 kHz; whereas exposure to a pure tone at frequencies greater than 6 kHz, is likely to result in more severe hearing loss.

Laboratory studies carried out by (Landström, Lundström, & Byström, 1983) as reported by (Leventhall, Pelmear, & Benton, 2003) revealed that a repeating 42 Hz noise at 70 dB resulted in reduced wakefulness, whereas a repeating 1 kHz noise at 30dB resulted in increased wakefulness.

(Phillips, 1995) observed that the central auditory system of the human body is built on frequency-specific processing channels hence assessment and characterization of an acoustic environment would require both the dB level and the frequency distribution considerations. (Mariana Alves-Pereira & Castelo Branco, 2000) shared the same opinion and reiterated that a holistic study of assessment of noise effects should consist of data of both intensity and frequency spectrum analysis because different organ systems are susceptible to different acoustic frequencies.

(M Alves-Pereira, 1999) also observed that with very few exceptions, environmental noise assessments rarely included a frequency spectra analysis. The study went further to note that scientific investigations into the extra-aural, whole-body, noise-induced pathology issue have been infrequent since the previous decades and that existing data are often regarded as inconclusive.

(Prashanth & Venugopalachar, 2011) investigated the association and contribution of frequency components of industrial noise to auditory and non-auditory effects through a critical review of previous studies published between 1998 and 2009 and found out that most of these noise impact assessment studies were mostly based on inadequate noise intensity. The authors further suggested that for an efficient evaluation of the effects of noise, the frequency spectrum analysis should also be included. They also observed that frequency-related characteristics of noise, for instance intermittent, irregular, tonal, pulse, etc. generated more annoyance than steady noise of the same intensity.

In research by (Helmholtz, 1954) on tone sensation, he stated that the first and most important difference between various sounds experienced by our ear is that between “noises” and “musical tones”, based on this, (Hansen, 2010) went further to examine the various aspects of the tone-noise dichotomy - the magnitude of tonal content and the pitch strength. He discovered that partial loudness was far easier and more intuitive to adjust in a magnitude adjustment experiment than the magnitude of tonal content. (Leatherwood, 1987) addressed the effects of simulated advanced turboprop (ATP) interior noise environments with tonal beats on subjective annoyance. He observed that propeller tones within the simulated (ATP) environments caused an increased annoyance as a result of an increase in overall sound pressure level due to tones.

Also, a study by (Suzuki, Kono, & Sone, 1988)on the effect of tonal components on loudness and noisiness of wide-band noise was observed to be less than what was estimated by L_A, LL(Z), PLdB, and PNdB. It was observed that Zwicker's Loudness Level competently evaluates the effect of the test stimuli used. He concluded by stating that conventional positive tone correction is not always required in the evaluation of environmental noise.

In a research by (Angerer, McCurdy, & Erickson, 1991), it was discovered that a model developed using loudness and tonality is a better predictor of an annoyance than either A-weighted sound pressure level (LA) or overall sound pressure level (OASPL). Similarly, in another research by (Vormann, Meis, Mellert, & Schick, 1999) on a new approach for evaluating tonal noise, they discovered that frequency has a distinct effect on tonal-noise perception. (Mirowska, 2001) presented a Polish recommendation for the estimation of low-frequency noise (LFN) in homes as a result of appliances installed within or outside the building. Using the accepted A10 characteristic rating curve for noise spectra measurement in dwellings, he observed that when the sound pressure levels of noise exceeded the A10 curve, low-frequency noise was observed to be annoying. Similarly, (Pawlaczyk-Łuszczyńska, Szymczak, Dudarewicz, & Śliwińska-Kowalska, 2006) researched ways to compute low-frequency noise (LFN) in the working environment to prevent annoyance and its consequences on work performance. All proposed LFN exposure criteria: the assessment method based on the low frequency equivalent continuous A-weighted sound SPL, frequency analysis in 1/3-octave bands and the criterion curves based on the hearing threshold level or A-weighting characteristics was able to predict annoyance experienced from LFN in occupational settings.

Several investigations have also specifically focused on the effects of aircraft noise on human annoyance rating and performance. As discovered by (More & Davies, 2010) from the test conducted on the effect of noise characteristics on people's response to aircraft noise; an increase in annoyance rating was observed when both tonalness and roughness were varied with loudness being kept constant. Loudness was found to be the major contributor to annoyance while tonalness and roughness also influenced the annoyance ratings. In another study (Li, Smith, & Zhang, 2010) made use of a one-quarter-scale A340 main landing gear model to identify and control a source of tonal-noise that had been noted in aircraft landing gear noise during the landing process of an aircraft. Several methods were used to control the tone, the most practical of which was either rotation of the hinged door, so that it was no longer parallel to the leg door, or complete removal of the hinged door. Also, a new signal processing tool for counter-rotating open rotors technology for aircraft propulsion applications was developed by (Sree, 2013). It was verified that the new technique provides almost the same results whether the data segment selection is made with respect to the for ward rotor or aft rotor “1/rev” signal, particularly when the two rotor speeds are about the same.

Also, mechanical buildings and the effect of noises generated from rotating components on humans have been understudied. Most of these studies examined human perception of noise, one of which was the study on differences in task performance and perception under ventilation-type background noise spectra with differing tonality by (Ryherd & Wang, 2008). The result showed that perception trends for tonality, annoyance, and distraction changes based on the frequency and prominence of discrete tones in noise. Furthermore (Ryherd & Wang, 2010) examined the effects of noise on human task performance and perception from mechanical systems in buildings with tonal components using an office-like environment. Higher ratings of loudness followed by roar, rumble, tones, and perception of more low-frequency rumble were noticed to cause higher annoyance and distraction which led to reduced task performance. In a similar study by (Francis, 2014) in an investigation on annoyance thresholds, the background noise level was found out to affect perceptions of annoyance. Also (Lee & Wang, 2014) discovered that loudness and tonality both have a significant influence on noise-induced annoyance and also that maximum allowable tonal components decrease when the background noise level is high. They went further to state that ANSI Loudness Level and Tonal Audibility are the most reliable metrics to reflect human annoyance perception.

(Lee, Francis, & Wang, 2017) studied the relationship between human perception and noises with tones in the built environment. Correlation analysis with noise metrics and subjective perception ratings suggested that ANSI Loudness Level among the tested loudness metrics corresponded most strongly with annoyance perception. In a review by (Hansen, Verhey, & Weber, 2011) it was reported that high correlation of the magnitude of tonal content and partial loudness indicates that the magnitude of strong tonal components may be assessed by quantifying the partial loudness of the tonal components. (Sottek, 2014) presented a model validation which exploit results of new listening test. It used bandpass-filtered noise signals with varying steep filter slopes and model improvements to adequately indicate the perceived tonality of technical sounds with low sound pressure levels. A research by (White, Bronkhorst, & Meeter, 2017) sought to find out if the continuous rating of aircraft noise above noises from other sources with similar intensity is due to the source identity of the noise. He concluded that annoyance was influenced by both identifiability and the presence of tonal components.

(Oliva, Hongisto, & Haapakangas, 2017) researched on the difference in tonal and non-tonal sounds at overall levels close to typical regulated levels inside residential dwellings. It was observed that penalty depended on the tonal frequency and the tonal audibility. Also, penalty values were different with different overall levels especially at high tonal frequencies. A similar study conducted by (Hongisto, Saarinen, & Oliva, 2019) at overall level 25 dB L_{eq}, which is close to regulated levels in residential dwellings disagrees with penalty values applied in many national regulations, when the overall level is low at 25 dB L_{eq}.

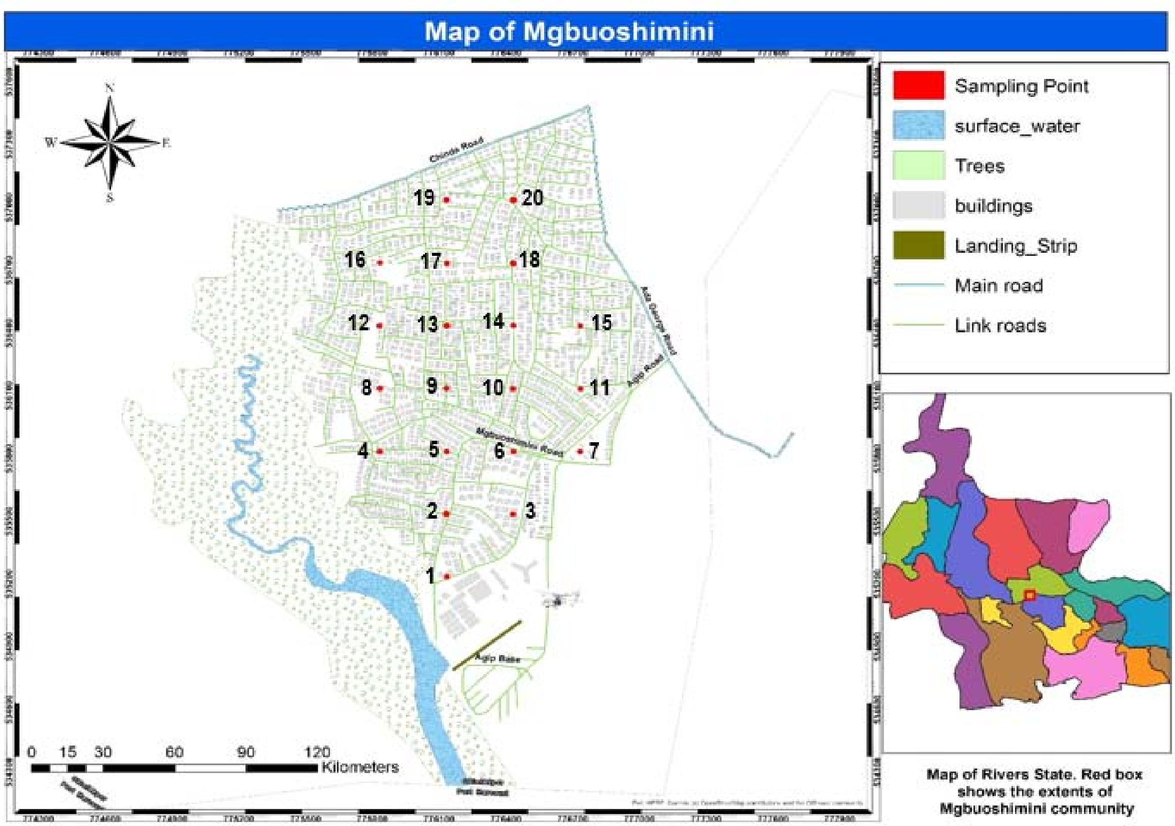
(Lee et al., 2017) investigated the relationship between current noise metrics, annoyance and task performance under assorted tonal noise conditions through subjective testing. The task performance showed that loudness metrics are most highly correlated with annoyance responses while tonality metrics demonstrate relatively less but also significant correlation with annoyance.

A study by (Hajczak, Sanders, & Druault, 2019) focused on the boundary element method (BEM) with a simple harmonic point source model used to characterize the resonance between the two facing cylindrical cavities in the wheels of a generic nose landing gear LAGOON, where a flow independent of tonal noise emission had been reported experimentally. It was observed that the facing cavities present much sharper resonances than the single cavity, and that the presence of the main strut only increased the amplification of the axisymmetric mode.

Recently, (Radosz, 2018) observed that noise with medium and high frequencies of tonal components were regarded as more annoying in an experiment carried out on the relationship between human perception and noise with tonal components in a working environment. (Torjussen, 2019) observed that the Aures tonality method outperforms the EPNL tone correction approach when assessing the subjective response to aircraft noise during take-off with the presence of multiple complex tones. A research by (Wallner, Hutter, & Moshammer, 2019) showed that a scientific approach within a complex environmental noise problem could foster an agreement about noise protection measures.

III. Study Area

Mgbuoshimini is a community located in Obio Akpor Local Government Area (LGA) of Rivers State. It lies on Latitude 4° 48' 30N and Longitude 6° 58' 22E. It is surrounded by Nkbuodahia, Rumu-Olumene and Azumini communities to the West, Orowokwo-Woji, Rumueme and Rumuepirikom to the North, Diobu and Elechi to the East and Amatagwolo and Eremogbogoro communities to the South. The map for Mgbuoshimini is presented in Figure 1 using the geographical information system (GIS). The heliport in the community is located at the Nigerian Agip Oil Company base, and used for offshore transportation of personnel and equipment with over six thousand flights (6 000) per year.



Source: Department of geography and regional planning, University of Port Harcourt

Figure 1: Map of Mgbuoshimini community

IV. Materials and Method

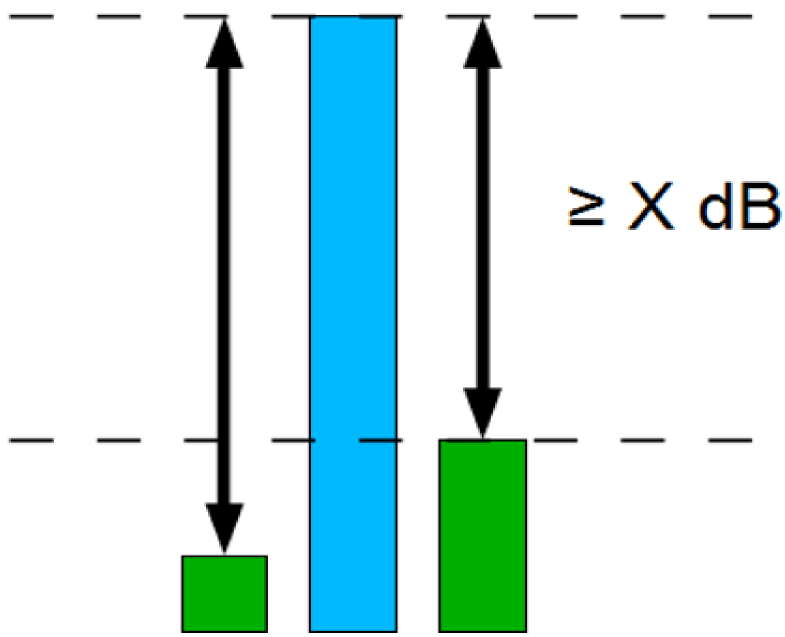
a) *Instrumentation and description of measurement procedure*

Measurements were obtained between August 2019 and March 2020. The study area was divided into 20 different locations as shown in Figure 1. Measurements were taken from 7 am to 5 pm at each location using two integrating sound analyzers; one measured the sound level including the contribution from helicopters and the other the sound level excluding that from helicopters (this was switched to IDLE mode any time a helicopter was audible). Location coordinates were obtained using a handheld Global Positioning System (GPS) device.

b) *Tonal Noise Detection Method*

(ISO, 2003) provides objective one-third octave band assessment procedure (shown in Figure 2) to be used to verify the presence of audible tones if their presence is in dispute. This method is based on one-third octave analysis. The one-third octave spectrum is searched for peaks and the search criterion is the level difference between a peak and its adjacent bands. When this difference reaches a certain frequency dependent level a tone is found. The standard defines different levels of threshold depending upon the frequency of the one-third octave band and these are:

25Hz to 125Hz:	15 dB
160Hz to 400Hz:	8 dB
500Hz to 10kHz:	6 dB



Source: (Morillas, González, & Gozalo, 2016)

Figure 2: Method for detecting tonal noise from one-third octave frequency band

V. Results and Discussion

Figures 3 to 22 shows the background noise profile for the 20 locations. Based on the stated criteria (ISO 1996-2), it can be seen that in the figures, there is no tonal noise present for background noise for all twenty locations.

Table 1: Equivalent Continuous Noise Levels at various frequencies for Background Noise (Excluding Helicopter Noise)

Location	L_{eq}	12.5Hz	16Hz	20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz
1	76.59	10.32	9.58	12.33	21.46	26.77	42.86	43.77	37.46	42.55	49.76	52.54	50.99	53.25	54.67	54.70	56.45
2	71.49	12.5	10.30	8.58	18.30	31.52	34.41	40.37	41.47	48.34	45.13	48.66	52.28	51.58	52.35	55.27	57.10
3	70.95	4.25	5.29	6.92	13.26	22.99	27.26	30.92	38.02	43.95	44.27	47.60	48.45	50.09	51.48	54.01	57.36
4	64.65	4.51	3.20	10.76	19.85	28.62	34.81	40.04	40.03	38.61	41.03	43.81	43.28	45.27	46.99	47.42	48.29
5	66.36	6.18	8.92	7.71	12.83	16.42	19.50	26.46	40.34	45.69	39.71	37.54	39.65	46.31	48.44	49.12	51.84
6	71.94	4.50	7.87	26.70	23.44	28.59	35.09	35.13	40.25	41.08	44.92	47.84	53.55	57.67	59.70	59.04	61.13
7	50.46	2.75	1.46	4.02	5.18	8.59	11.47	15.04	14.94	17.17	24.86	29.16	28.12	33.41	38.09	36.18	41.60
8	65.41	4.05	3.66	11.14	19.50	29.30	35.44	40.69	40.80	39.32	41.92	44.49	43.89	45.99	47.76	48.22	48.50
9	66.07	6.33	9.05	7.85	13.03	16.80	19.84	26.61	40.44	46.59	40.39	37.60	39.73	46.92	48.32	47.60	50.16
10	72.20	4.79	7.81	26.63	23.42	28.67	35.18	35.56	40.73	41.00	44.24	47.50	54.32	58.61	60.34	59.34	61.22
11	69.61	1.98	5.45	19.70	19.69	25.79	27.46	31.06	35.79	41.23	41.33	42.62	42.35	56.46	52.87	54.47	58.97
12	60.35	3.14	2.79	3.55	7.53	11.94	15.49	20.56	20.95	25.98	32.53	31.50	32.62	36.21	37.99	39.53	46.82
13	63.09	6.23	8.93	7.72	12.49	15.74	18.51	25.11	36.04	41.01	37.55	36.42	37.95	43.23	44.76	47.20	50.02
14	55.26	1.94	6.72	3.95	6.30	12.08	16.12	21.49	26.23	29.89	29.43	30.37	33.18	36.83	37.86	38.31	46.39
15	55.86	4.74	2.46	6.63	9.58	10.97	15.54	17.66	22.82	24.36	32.57	30.16	32.31	36.60	41.63	41.32	43.28
16	53.72	1.21	1.84	2.36	3.81	7.05	14.10	13.51	15.44	18.87	29.32	28.06	29.07	32.52	33.82	37.70	37.13
17	58.08	4.31	2.67	4.51	8.44	11.09	16.00	19.37	20.68	29.67	29.33	30.05	33.06	35.73	39.54	38.89	45.13
18	53.64	2.13	2.17	1.92	4.02	6.71	12.56	14.45	14.06	27.09	26.00	25.50	29.17	29.62	33.68	35.18	40.78
19	52.79	1.32	1.14	3.24	6.32	4.65	13.53	17.31	15.13	24.84	26.40	26.34	30.13	31.20	36.54	36.62	39.34
20	53.74	3.21	1.17	3.04	4.10	8.03	12.87	15.33	16.15	19.62	26.57	25.53	28.31	29.29	34.40	36.00	40.32

Table 1: Equivalent Continuous Noise Levels at various frequencies for Background Noise (Excluding Helicopter Noise)…Continue

Location	500Hz	630Hz	800Hz	1kHz	1.25kHz	1.6kHz	2kHz	2.5kHz	3.15kHz	4kHz	5kHz	6.3kHz	8kHz	10kHz	12.5kHz	16kHz	20kHz
1	58.49	59.97	60.44	60.18	60.94	59.78	59.63	58.44	57.21	55.04	52.35	49.67	47.09	43.57	38.61	31.35	25.49
2	59.27	59.62	59.13	59.77	59.37	60.31	59.76	58.39	57.52	55.90	53.25	51.02	50.16	46.86	41.57	34.61	27.85
3	60.82	61.52	61.70	61.78	60.66	61.21	58.86	57.65	60.61	54.75	51.56	47.80	45.69	41.16	37.39	31.79	23.64
4	51.08	53.84	56.15	56.10	56.12	55.10	54.45	51.03	50.82	48.95	45.77	41.83	42.00	36.13	30.29	24.98	21.79
5	54.73	60.34	58.40	54.82	55.48	57.28	51.93	53.00	52.24	49.59	45.73	42.84	42.47	36.62	34.32	26.91	20.99
6	62.61	61.41	61.88	61.76	60.86	61.42	59.96	57.86	57.48	55.75	52.23	48.66	47.49	40.45	34.69	30.04	30.37
7	37.26	39.67	41.22	41.80	41.74	37.45	39.81	37.80	41.60	39.83	32.29	33.01	29.71	23.10	22.49	14.90	15.16
8	51.32	54.02	56.82	56.85	56.98	55.96	55.23	51.81	51.54	49.62	46.32	42.12	42.63	36.29	30.16	24.71	21.44
9	53.94	60.82	56.99	54.01	54.71	56.68	51.81	52.91	51.76	49.37	46.10	42.94	42.88	36.71	34.81	27.31	21.24
10	62.35	61.94	61.66	61.72	61.08	60.70	60.30	58.00	57.54	56.19	52.47	48.68	47.88	40.57	34.74	30.32	31.22
11	60.03	58.81	60.72	58.66	54.18	54.67	53.86	52.57	50.98	55.79	46.98	43.72	46.52	38.42	32.06	25.97	22.13
12	41.14	48.91	44.60	45.90	46.13	47.29	42.65	44.41	44.54	43.55	38.64	37.78	36.68	32.94	26.33	27.72	17.50
13	54.43	54.23	53.31	51.05	52.03	52.43	48.73	48.58	48.40	47.00	44.24	41.08	43.69	35.32	35.74	27.92	20.94
14	43.60	49.71	51.08	45.30	47.63	48.36	44.11	43.61	46.39	42.72	38.63	36.59	34.35	29.17	25.11	20.73	18.51
15	50.40	45.85	45.85	46.48	46.58	47.02	43.93	44.93	43.96	43.13	41.86	35.90	33.78	26.27	25.95	18.13	18.25
16	37.99	40.87	41.43	41.98	41.14	39.90	39.62	41.14	40.00	36.87	35.32	34.21	36.39	32.35	23.51	18.21	15.09
17	44.16	50.52	46.39	43.15	45.63	45.18	42.05	41.55	44.14	40.53	38.65	38.51	40.83	30.00	27.79	19.77	19.65
18	41.69	40.81	43.93	39.26	41.52	37.42	39.56	37.53	41.13	37.07	34.46	36.48	30.84	21.54	22.38	16.23	16.42
19	41.18	42.98	41.13	38.93	38.84	40.22	40.10	38.39	40.36	35.80	32.73	35.21	36.38	21.38	21.24	15.84	14.71
20	36.75	43.03	40.24	39.48	40.41	41.52	39.55	39.25	42.28	36.21	32.74	35.98	39.82	25.99	21.85	16.65	15.81

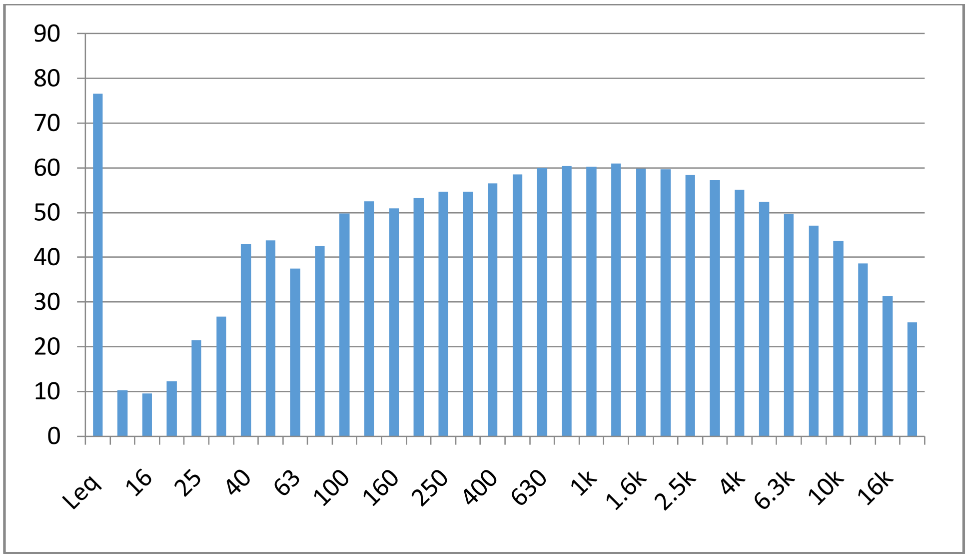


Figure 3: One-third octave frequency band at Location 1

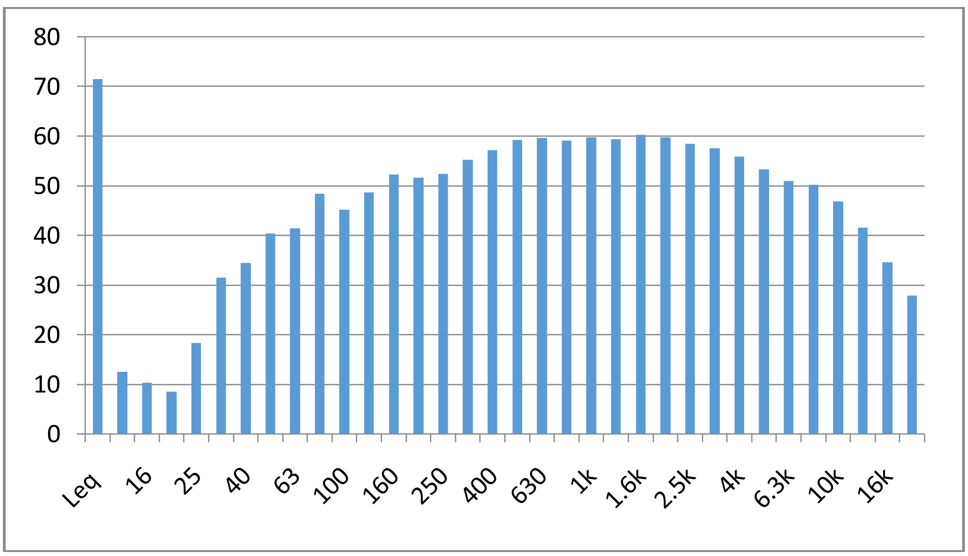


Figure 4: One-third octave frequency band at Location 2

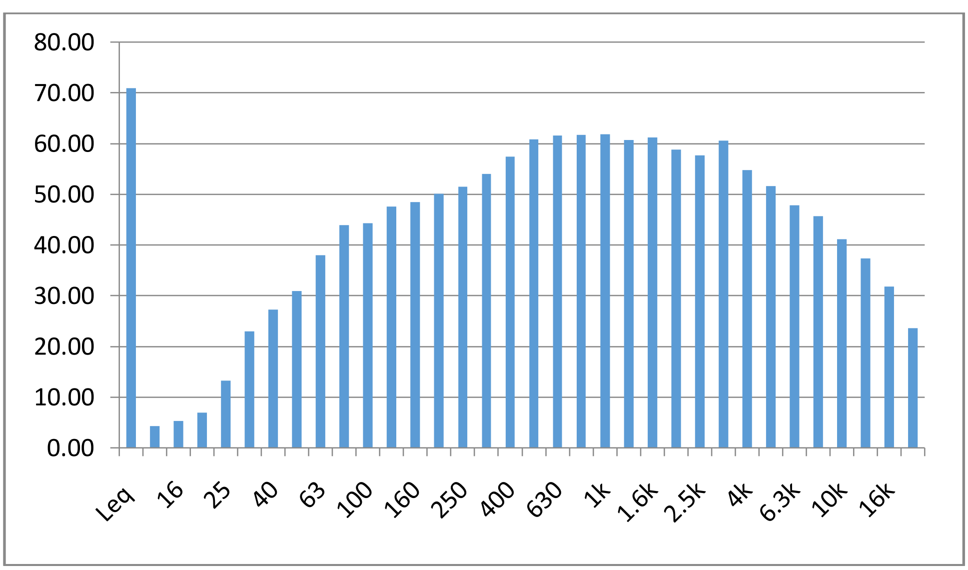


Figure 5: One-third octave frequency band at Location 3

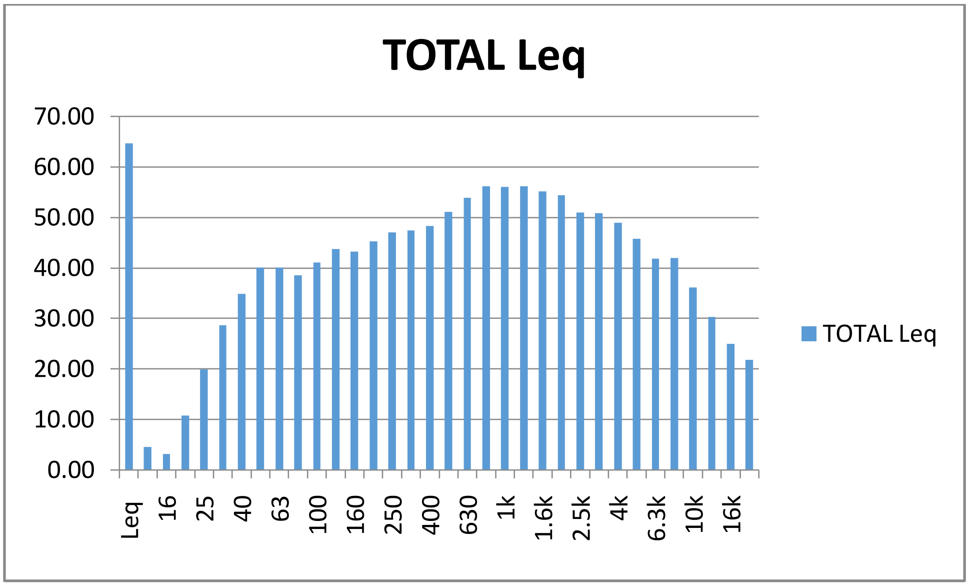


Figure 6: One-third octave frequency band at Location 4

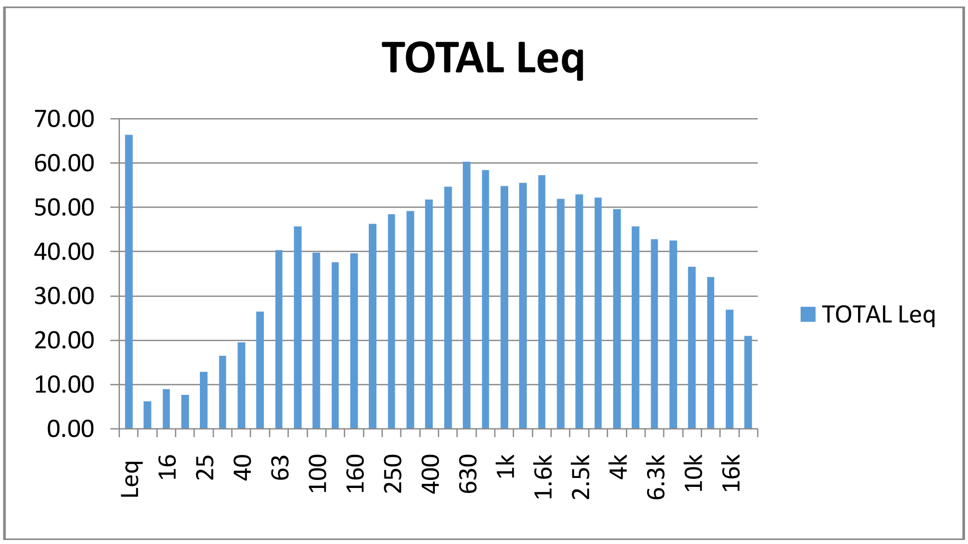


Figure 7: One-third octave frequency band at Location 5

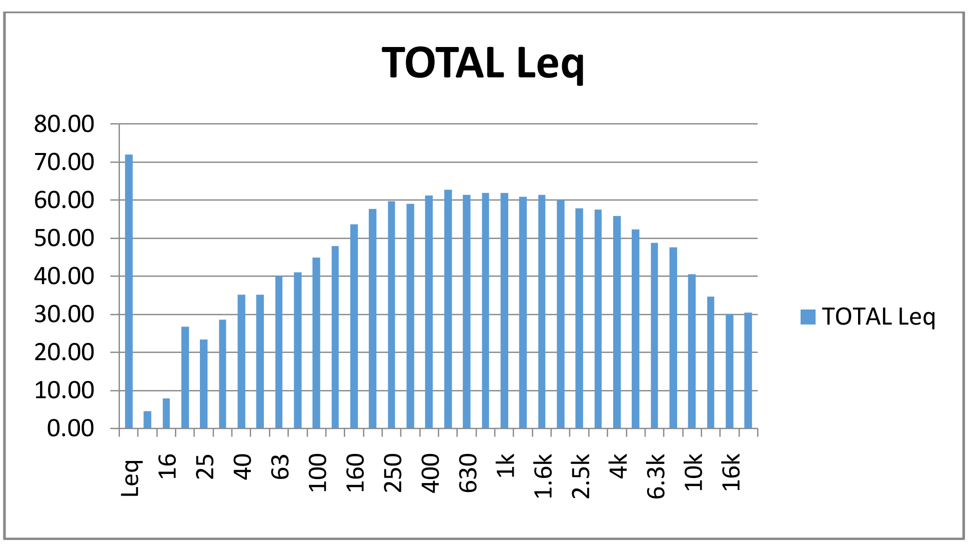


Figure 8: One-third octave frequency band at Location 6

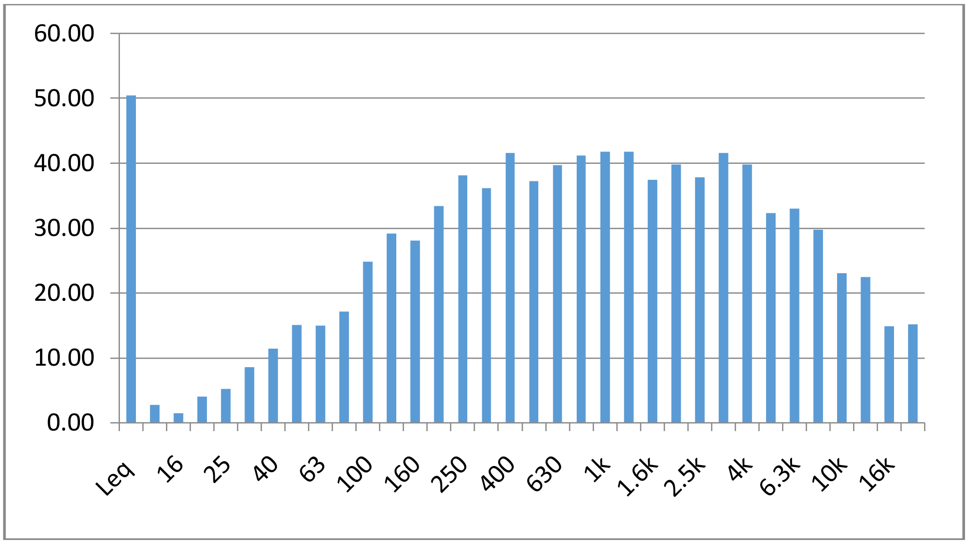


Figure 9: One-third octave frequency band at Location 7

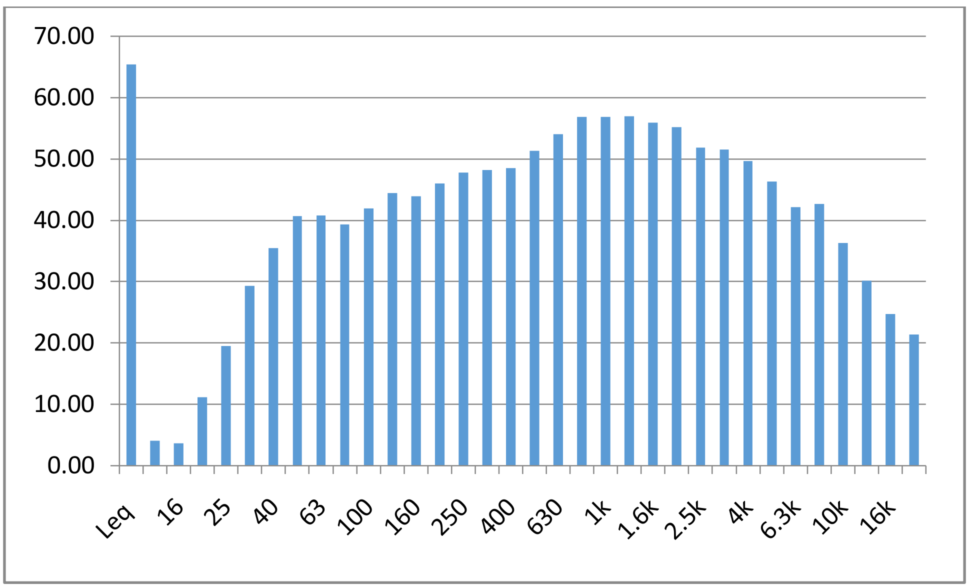


Figure 10: One-third octave frequency band at Location 8

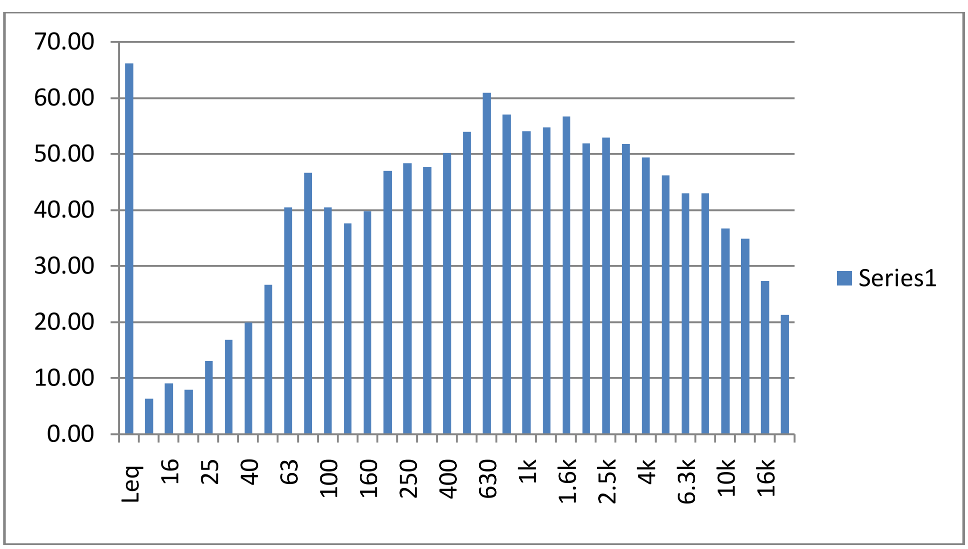


Figure 11: One-third octave frequency band at Location 9

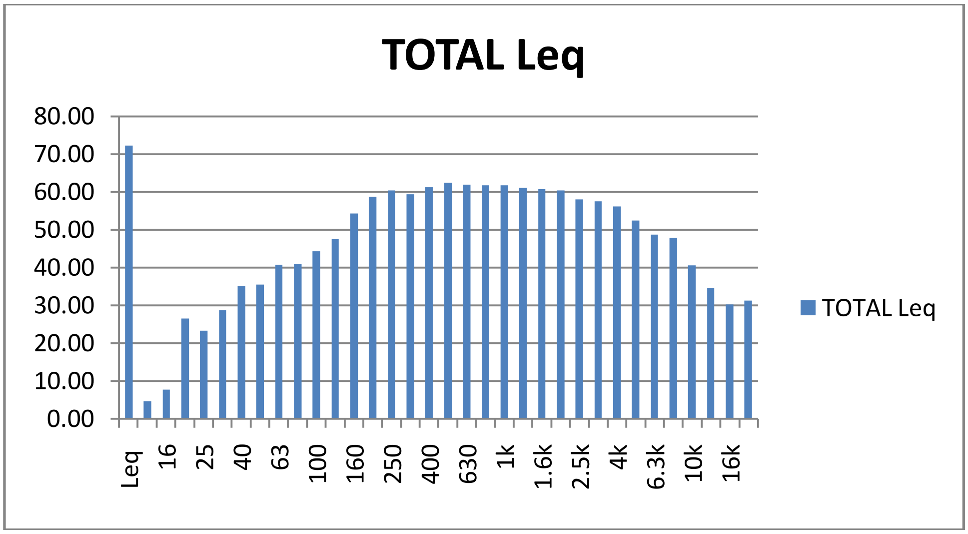


Figure 12: One-third octave frequency band at Location 10

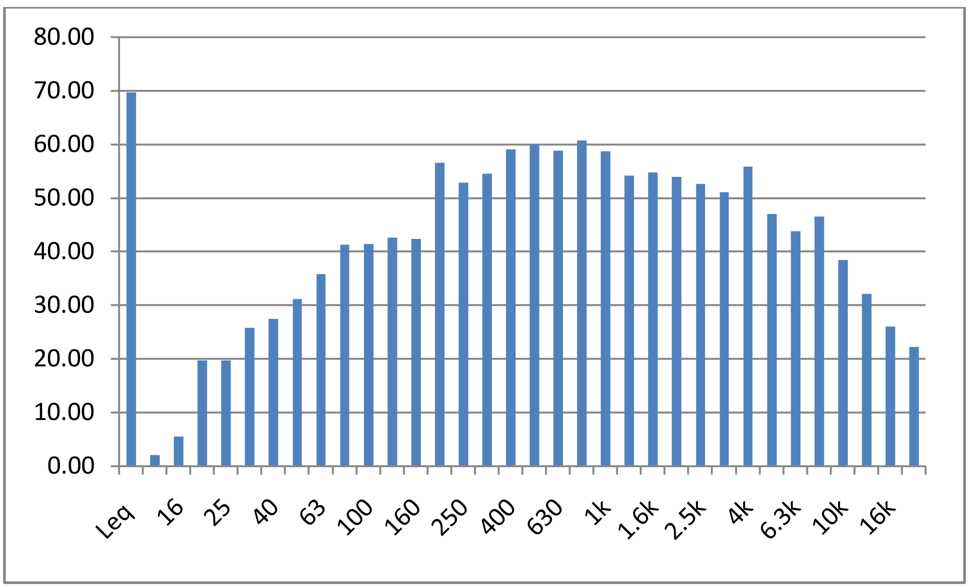


Figure 13: One-third octave frequency band at Location 11

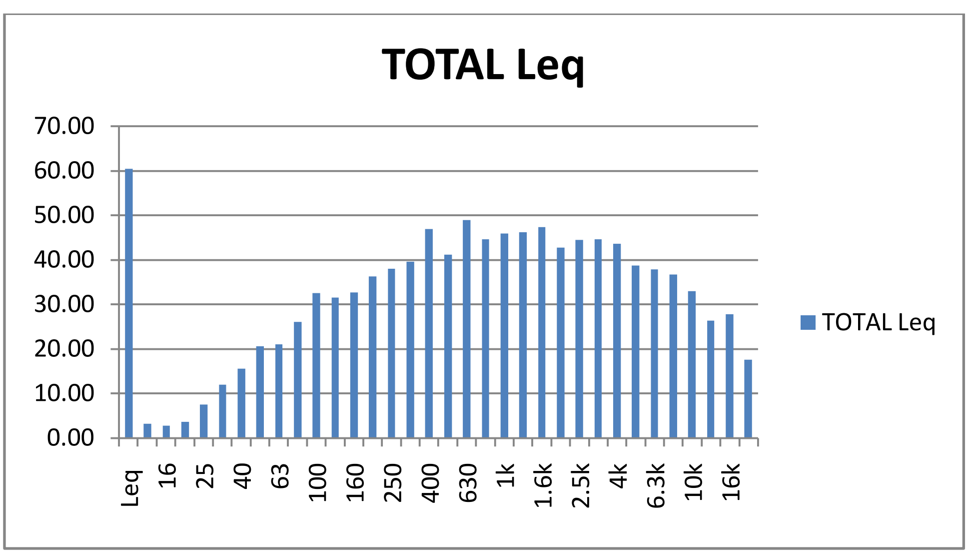


Figure 14: One-third octave frequency band at Location 12

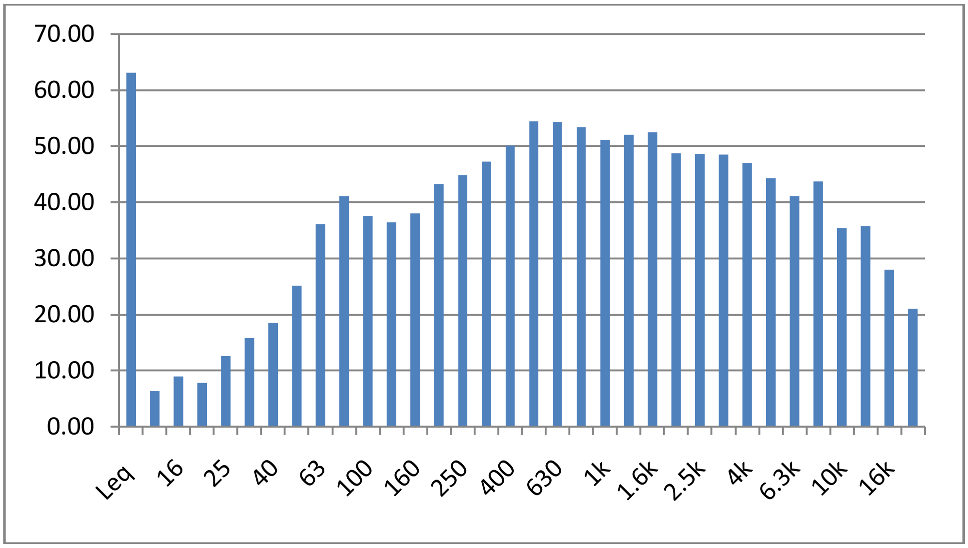


Figure 15: One-third octave frequency band at Location 13

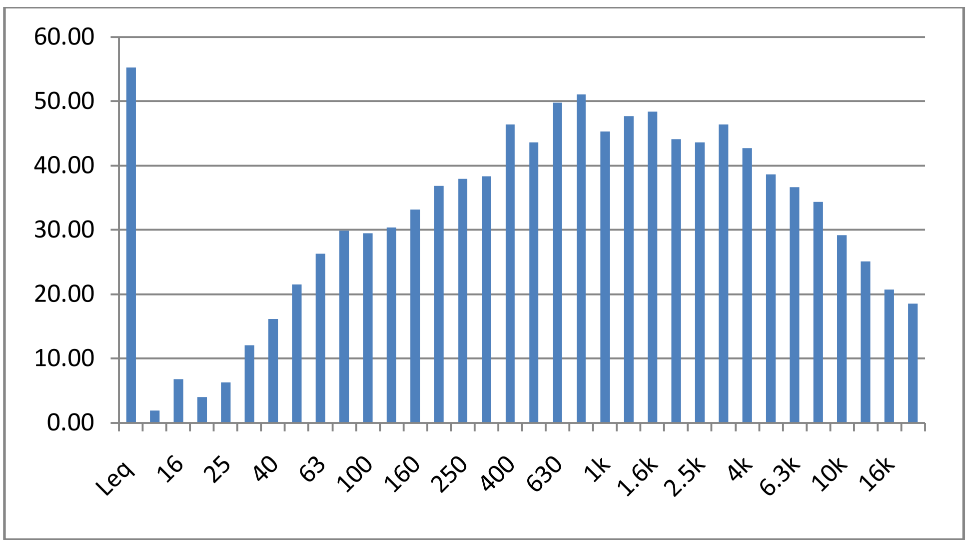


Figure 16: One-third octave frequency band at Location 14

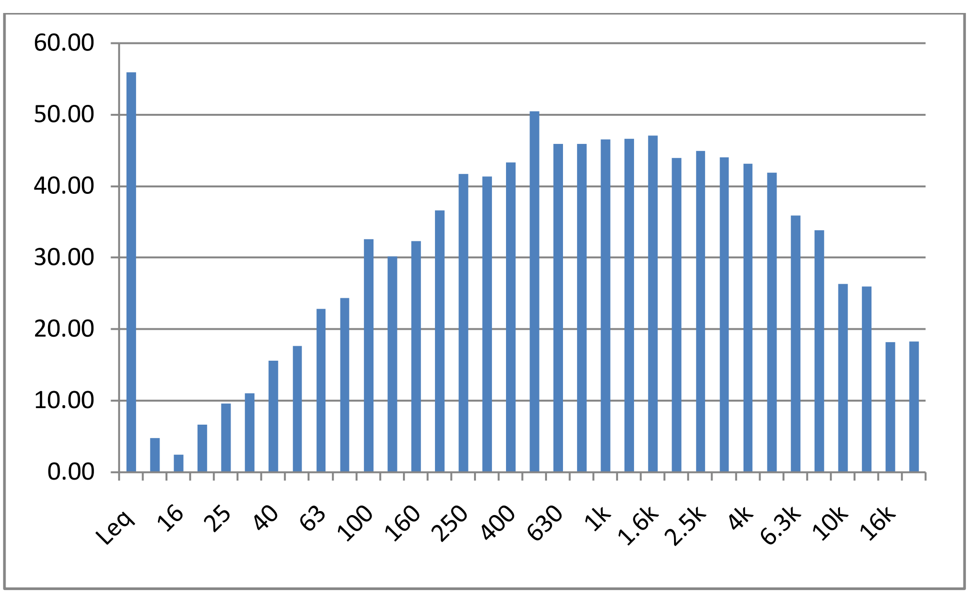


Figure 17: One-third octave frequency band at Location 15

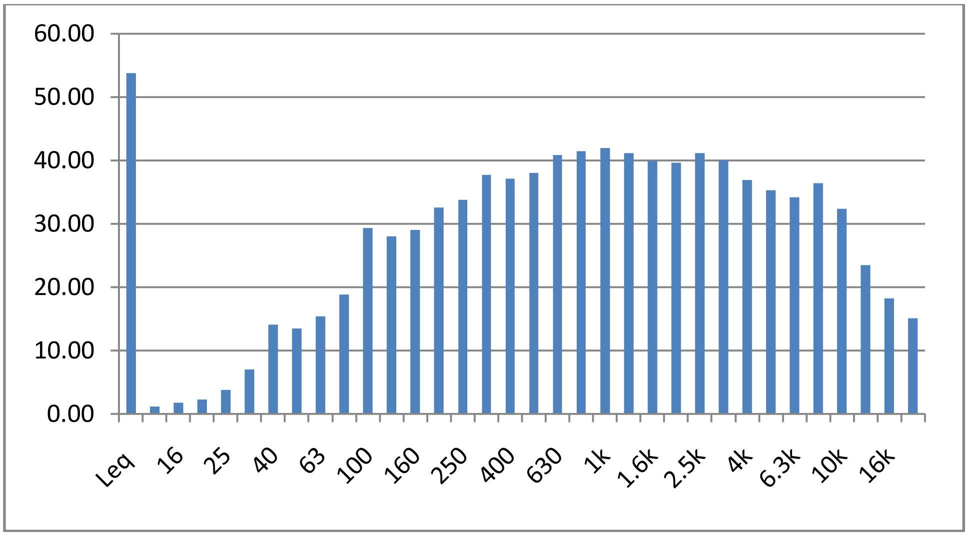


Figure 18: One-third octave frequency band at Location 16

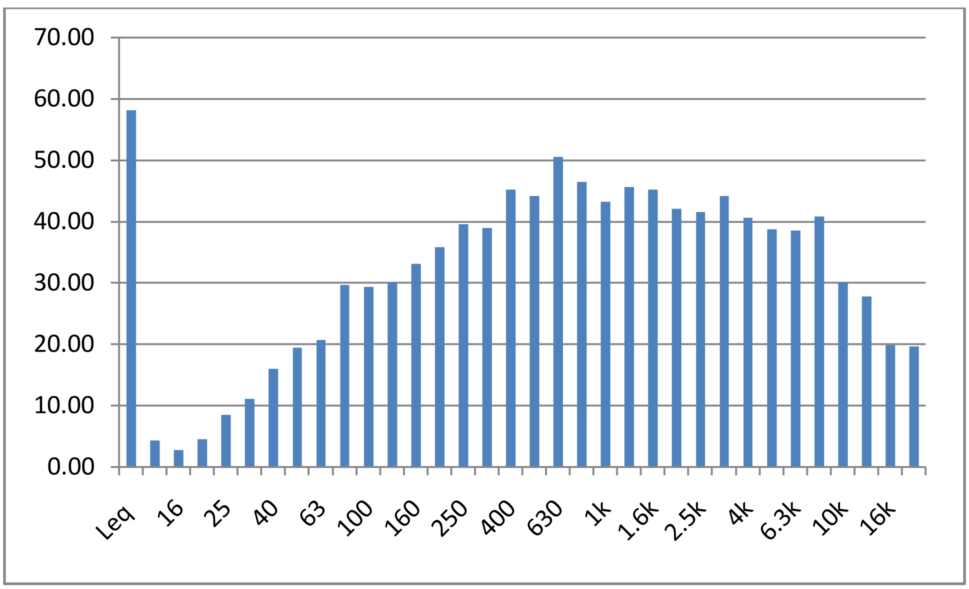


Figure 19: One-third octave frequency band at Location 17

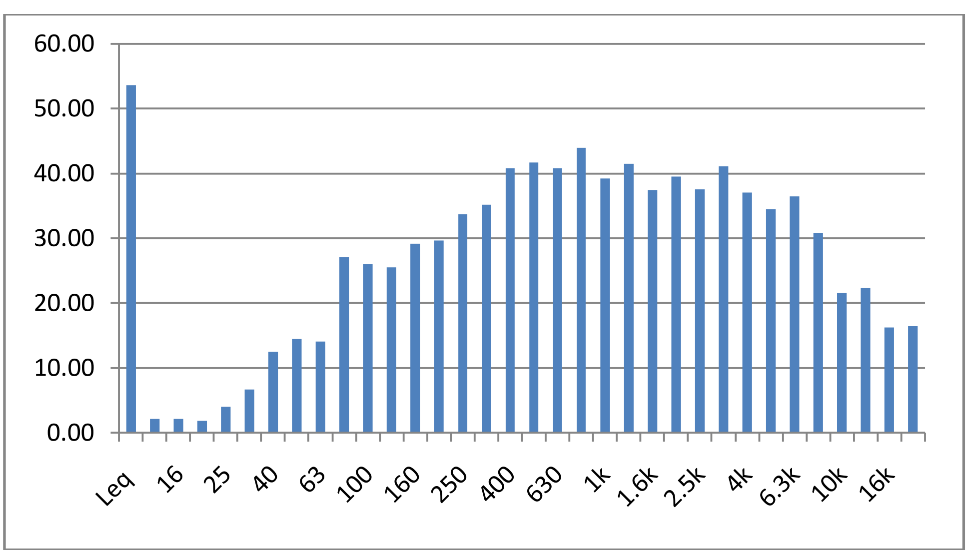


Figure 20: One-third octave frequency band at Location 18

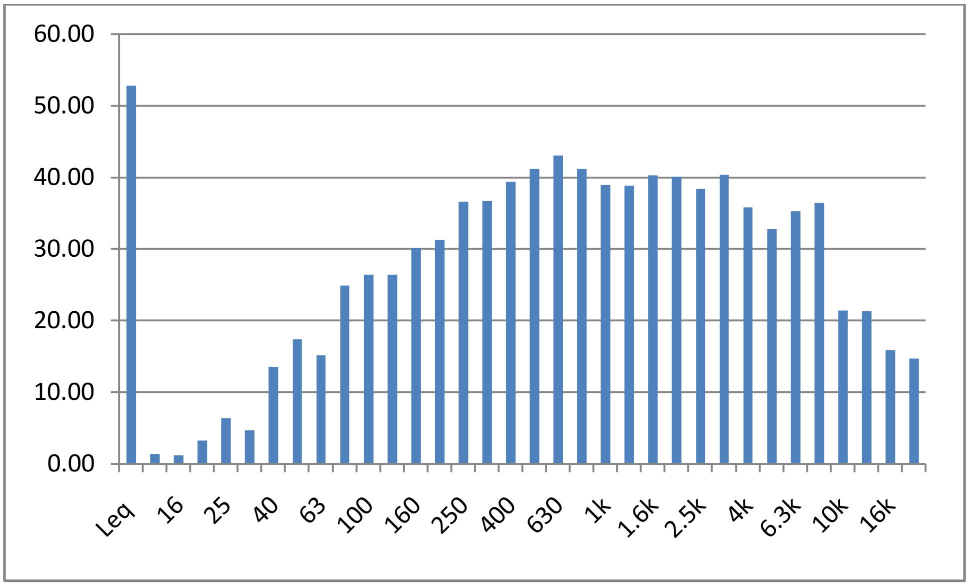


Figure 21: One-third octave frequency band at Location 19

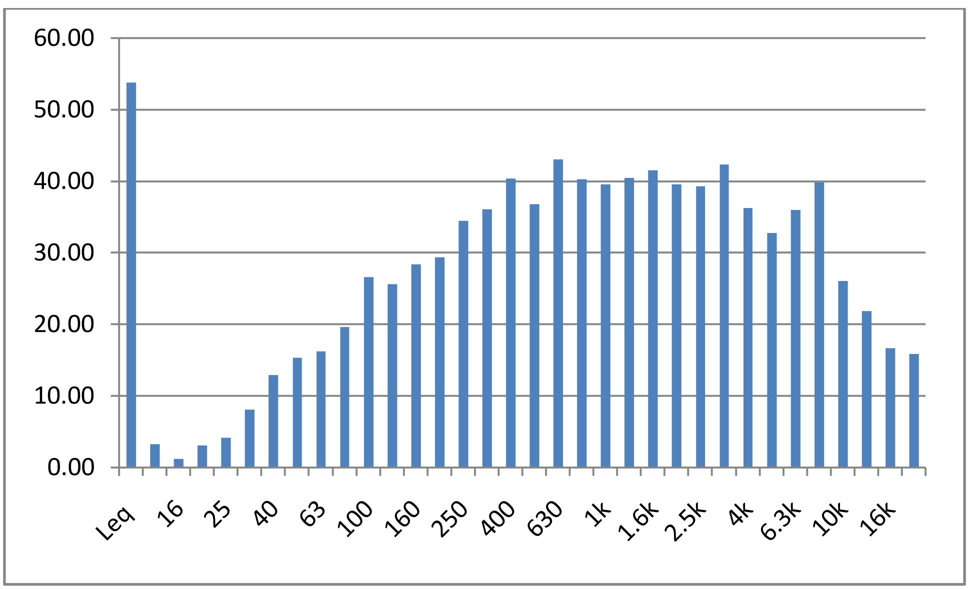


Figure 22: One-third octave frequency band at Location 20

Table 2 represents the total sound including background noise.

Table 2: Equivalent Continuous Noise Levels at various frequencies for Combined Noise (Including Helicopter Noise)

Location	Leq	12.5Hz	16Hz	20Hz	25Hz	31.5Hz	40Hz	50Hz	63Hz	80Hz	100Hz	125Hz	160Hz	200Hz	250Hz	315Hz	400Hz
1	80.20	15.50	8.50	11.60	21.03	27.46	42.92	43.13	39.52	44.28	48.91	52.77	56.46	53.21	56.48	60.00	63.91
2	72.87	9.84	17.03	19.83	18.29	31.63	38.04	41.34	41.49	48.19	45.52	50.44	54.65	53.88	54.53	56.04	59.44
3	73.74	4.32	5.35	29.50	19.01	23.92	36.40	32.62	41.83	46.69	48.07	51.99	52.38	55.26	57.91	60.23	61.70
4	72.60	3.16	8.47	20.69	23.52	29.69	33.66	39.91	49.16	40.36	42.70	48.65	46.84	49.51	53.04	56.38	59.74
5	75.47	4.11	7.82	37.85	33.86	30.89	43.25	38.18	49.72	47.76	54.57	59.99	56.71	59.53	62.46	65.58	69.22
6	75.23	4.97	6.47	27.84	25.71	28.19	34.12	37.65	41.30	45.00	51.49	57.25	62.18	64.31	66.17	65.77	65.14
7	71.26	3.83	0.93	25.67	21.08	24.00	22.32	32.18	38.79	42.88	38.63	48.66	54.35	50.14	63.43	47.64	48.26
8	70.51	2.67	5.31	16.32	22.19	28.38	33.55	38.78	49.07	38.59	40.61	45.44	44.37	48.47	51.65	54.56	56.62
9	70.37	4.38	7.29	36.91	33.90	28.63	41.99	33.59	48.22	45.58	50.87	54.51	52.83	57.75	59.30	65.44	66.43
10	75.85	3.55	5.82	26.48	24.91	27.69	33.92	37.74	41.57	44.15	47.28	56.40	61.90	62.89	66.17	64.81	63.35
11	72.95	1.72	3.53	20.59	23.49	24.46	28.20	34.14	37.26	41.36	46.74	53.89	57.97	61.15	64.04	61.29	62.75
12	68.28	2.18	2.53	28.80	28.88	21.41	37.79	29.99	44.77	32.04	45.69	53.87	46.59	54.00	56.56	58.69	66.19
13	68.79	4.27	6.89	31.18	33.38	25.46	37.38	33.98	47.84	40.40	50.27	54.90	51.74	57.71	58.02	63.19	66.39
14	67.95	1.16	4.95	28.78	28.75	21.74	32.87	31.08	43.29	32.44	47.64	51.67	50.99	56.69	56.44	62.50	62.18
15	67.47	3.03	1.56	27.98	33.53	25.99	33.65	31.04	44.09	33.69	47.69	49.40	49.32	57.33	55.16	58.82	65.28
16	67.81	0.87	2.25	26.58	28.27	18.39	34.40	28.09	42.18	26.87	42.45	49.43	46.93	48.49	53.47	53.59	66.36
17	67.90	2.75	1.64	30.86	30.71	25.94	37.99	32.99	44.51	35.77	46.14	50.90	48.88	57.10	53.26	58.73	66.75
18	67.43	1.27	1.58	29.84	28.88	21.51	34.25	27.18	43.21	31.08	41.63	45.03	48.72	52.58	51.79	54.58	62.85
19	67.64	1.16	0.69	30.82	26.37	23.30	36.45	33.03	40.38	30.62	44.55	50.91	44.32	56.76	51.81	56.30	64.15
20	67.32	2.19	0.73	27.68	26.02	20.23	32.41	31.96	41.32	30.31	43.77	45.27	46.20	52.90	53.30	55.83	62.77

Locat ion	500H z	630H z	800H z	1kHz	1.25kH z	1.6kH z	2kHz	2.5kH z	3.15kH z	4kHz	5kHz	6.3kH z	8kHz	10kH z	12.5kH z	16kH z	20kH z
1	65.01	64.88	66.12	64.69	65.23	69.95	67.44	70.64	67.67	60.82	61.01	54.08	50.83	49.04	41.62	34.79	27.66
2	59.66	62.25	61.70	61.27	60.42	61.96	60.80	59.25	58.57	56.89	54.49	52.09	50.54	47.47	42.02	34.57	27.38
3	64.07	64.40	64.45	64.28	63.51	63.13	61.42	60.36	60.61	56.71	53.81	50.93	48.42	41.96	36.61	30.62	23.89
4	59.92	61.94	62.24	63.81	64.81	61.16	59.39	58.56	58.82	58.01	56.93	57.11	60.17	48.68	54.07	48.48	35.59
5	67.90	67.31	67.26	67.45	66.50	65.44	63.41	64.02	61.70	59.99	57.63	54.17	49.05	41.59	34.99	26.04	20.62
6	66.05	64.68	63.67	63.66	62.01	61.19	59.75	58.34	57.36	55.54	52.17	49.01	46.84	40.91	35.77	31.79	29.19
7	47.88	51.69	49.86	50.35	46.59	44.73	50.83	44.53	46.84	51.80	48.45	45.34	41.70	29.43	28.04	26.11	18.64
8	55.33	57.53	60.93	64.22	61.57	60.43	56.25	54.77	56.23	53.89	54.49	52.98	59.16	48.15	50.87	45.61	31.06
9	65.76	65.99	63.73	64.97	61.56	64.68	62.76	63.18	58.68	55.95	52.64	53.41	47.17	39.10	34.18	25.50	20.42
10	65.29	62.13	61.56	61.97	62.11	58.76	58.41	56.78	57.75	54.30	51.49	47.55	46.13	39.54	35.65	31.71	28.97
11	61.62	60.22	59.51	61.08	58.14	53.36	52.38	53.72	55.18	53.99	46.47	45.07	45.13	38.63	34.77	26.72	22.68
12	63.47	56.42	59.22	57.05	57.91	58.06	54.67	57.65	51.85	46.36	48.00	48.43	42.20	37.54	27.14	24.92	16.04
13	64.42	61.72	63.19	60.54	59.75	61.67	59.56	58.65	55.77	51.76	51.51	52.37	44.78	38.83	34.15	25.37	19.01
14	60.51	61.20	62.82	58.76	57.96	56.90	58.42	58.94	56.12	47.74	47.13	49.83	39.07	37.07	28.16	18.69	17.15
15	60.45	59.04	62.39	59.54	56.21	60.28	57.23	57.38	52.53	50.02	48.99	51.01	42.06	37.96	28.45	17.96	16.32
16	62.65	55.06	56.03	56.00	53.76	52.28	49.72	55.17	50.41	43.34	44.69	48.87	40.30	35.03	25.08	15.82	12.97
17	59.62	56.72	62.39	58.38	55.89	58.06	56.74	57.82	51.99	49.07	47.26	51.16	40.62	34.08	29.71	18.74	18.16
18	54.99	54.38	60.56	55.77	52.98	57.86	51.18	55.45	49.31	46.51	43.74	52.02	37.68	33.88	27.64	15.37	14.77
19	55.58	56.81	57.15	58.95	51.27	54.97	51.57	52.86	50.93	46.70	44.07	50.51	37.56	29.09	26.31	16.97	14.32
20	59.71	56.56	60.08	54.86	55.48	55.30	51.98	52.56	49.73	46.42	41.68	50.24	39.04	33.91	25.88	15.81	14.16

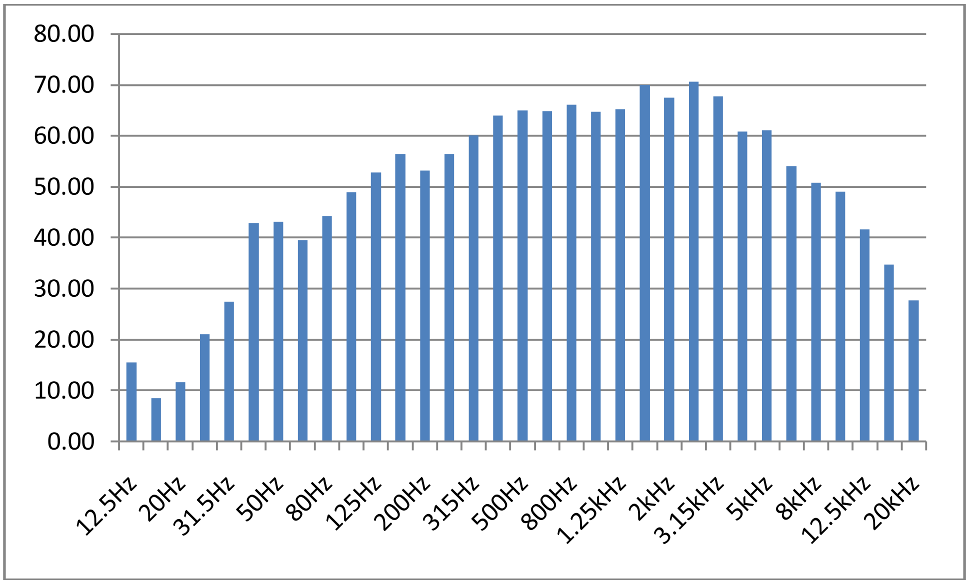


Figure 23: One-third octave frequency band at Location 1

Location 1

An examination of Fig. 23 above shows no evidence of tonal noise.

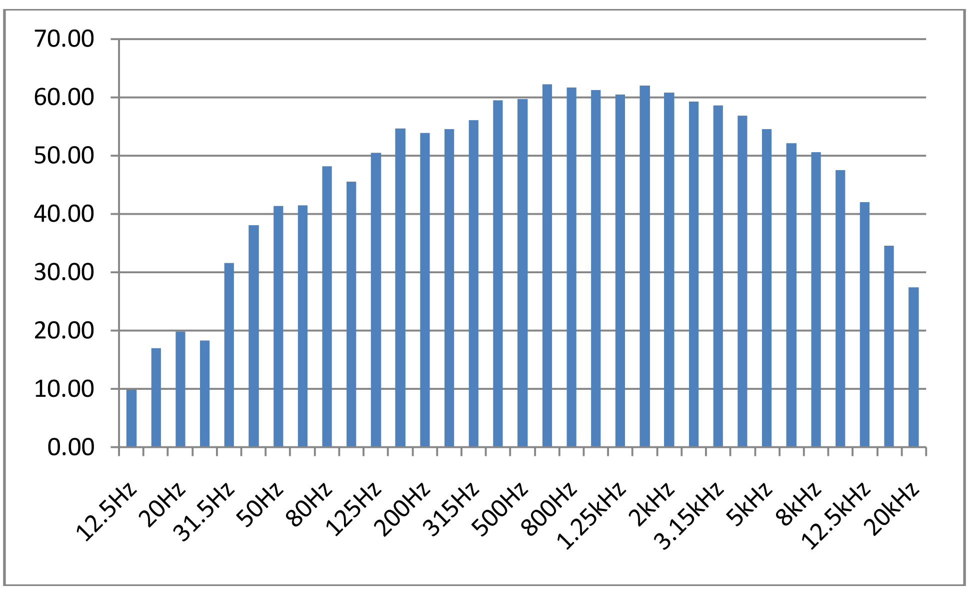


Figure 24: One-third octave frequency band at Location 2.

Location 2

An examination of Fig. 24 above shows no evidence of tonal noise.

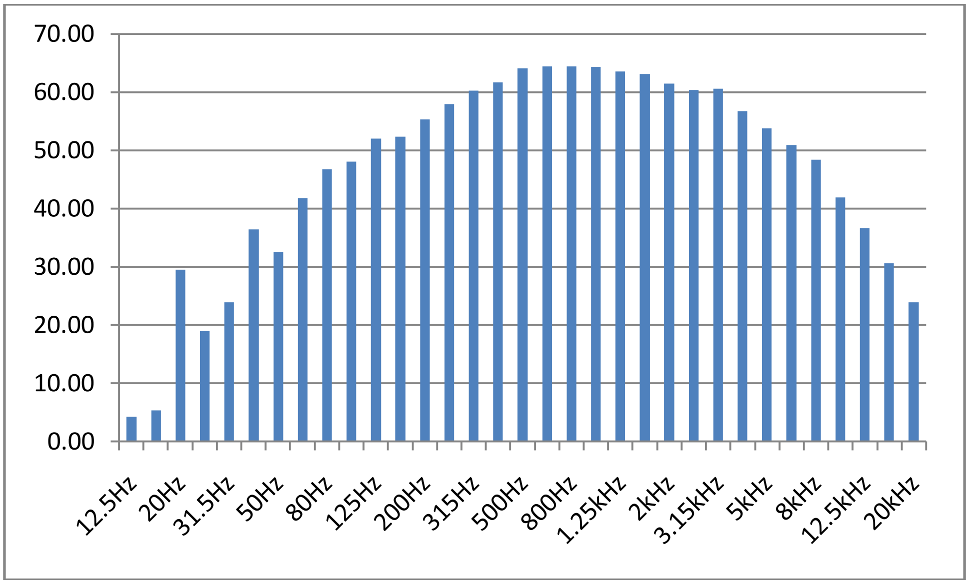


Figure 25: One-third octave frequency band at Location 3

Location 3

An examination of Fig. 25 above shows a protruding band at 3rd position counting from the left and this corresponds to the 20 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 20 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 20 Hz,

29.50 – 19.01 = 10.49 dB< 15 dB

29.50 – 5.35 = 24.15 dB > 15 dB

Hence, there is no tonal noise.

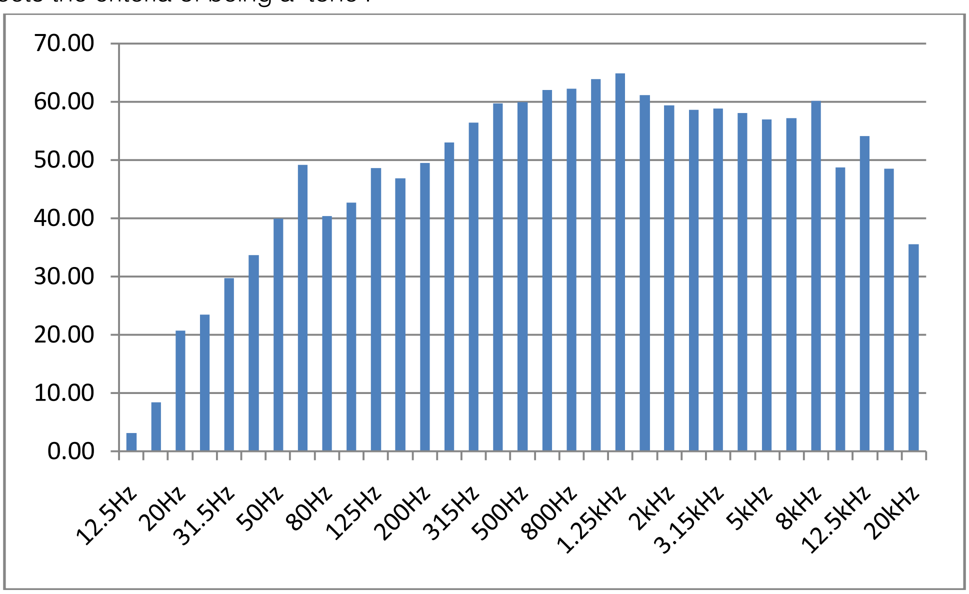


Figure 26: One-third octave frequency band at Location 4

Location 4

An examination of Fig. 26 above shows a protruding band at 8th position counting from the left and this corresponds to the 63 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 63 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 63 Hz,

49.16 – 40.36 = 8.8dB< 15 dB

49.16 – 39.91 = 9.25 dB< 15 dB

Hence, there is no tonal noise.

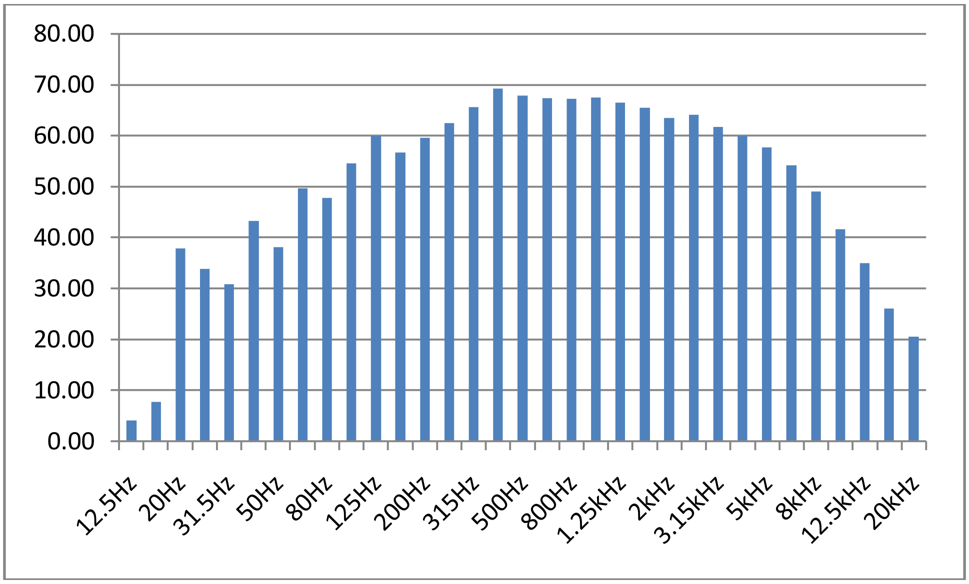


Figure 27: One-third octave frequency band at Location 5

Location 5

An examination of Fig. 27 above shows no evidence of tonal noise.

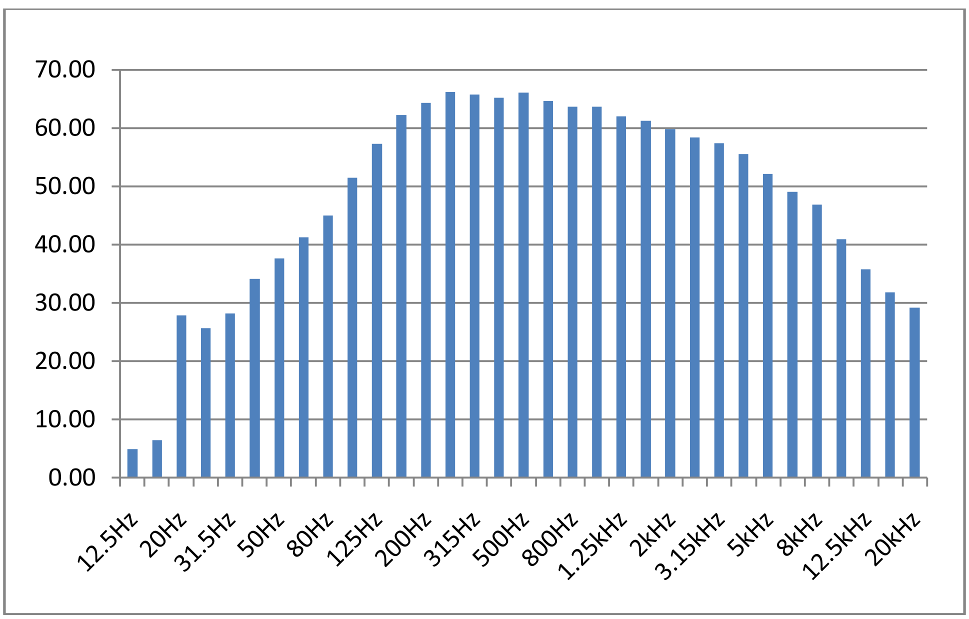


Figure 28: One-third octave frequency band at Location 6

Location 6

An examination of Fig. 28 above shows no evidence of tonal noise.

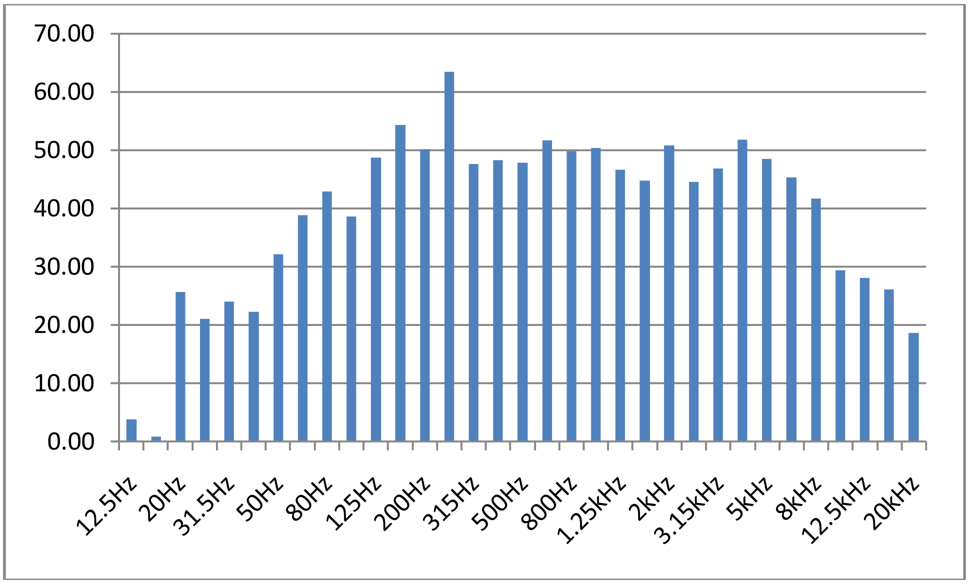


Figure 29: One-third octave frequency band at Location 7

Location 7

An examination of Fig. 29 above shows a protruding band at 14th position counting from the left and this corresponds to the 250 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 250 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 250 Hz,

63.43 – 47.64 = 15.79 dB> 8 dB

63.43 – 50.14 = 13.29 dB> 8 dB

Hence, there is tonal noise at 250 Hz

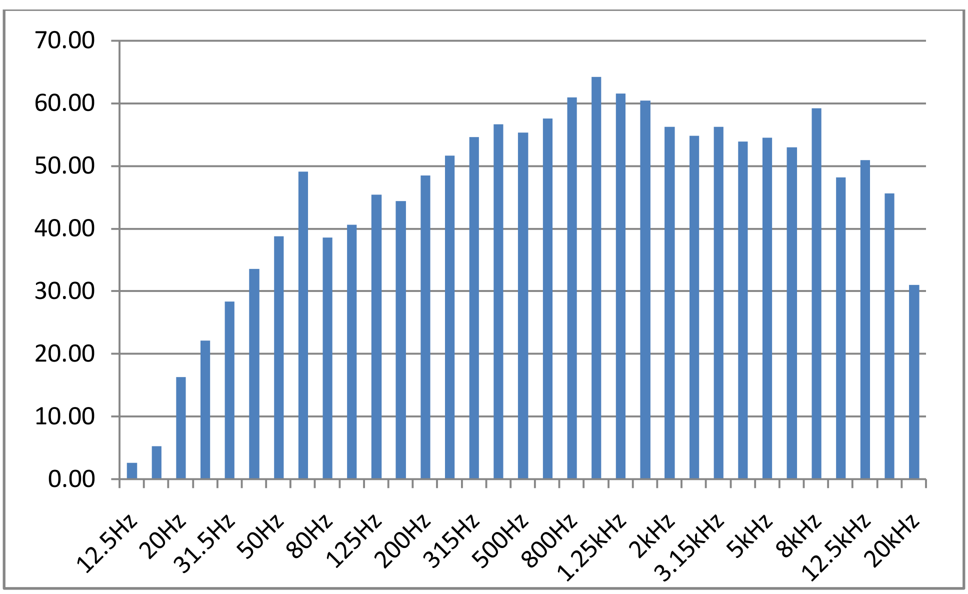


Figure 30: One-third octave frequency band at Location 8

Location 8

An examination of Fig. 30 above shows a protruding band at 8th position counting from the left and this corresponds to the 63 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 63 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 63 Hz,

49.07 – 38.59 = 10.48 dB < 15 dB

49.07 – 38.78 = 10.29 dB < 15 dB

Hence, there is no tonal noise.

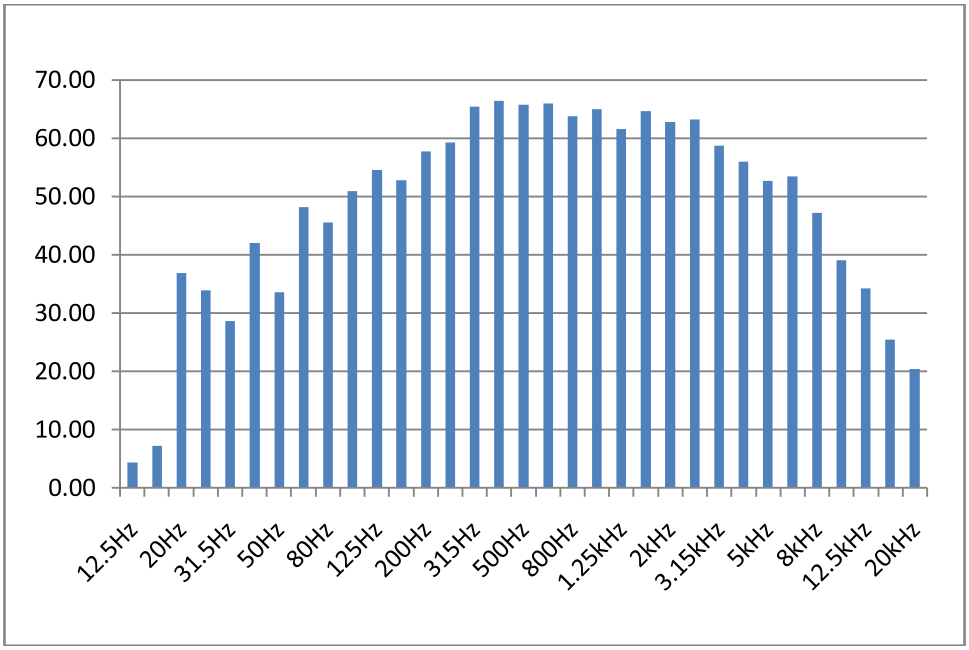


Figure 30: One-third octave frequency band at Location 9

Location 9

An examination of Fig. 30 above shows a protruding band at 6th position counting from the left and this corresponds to the 40 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 63 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 40 Hz,

41.99 – 33.59 = 8.4 dB < 15 dB

41.99 – 28.63 = 13.36 dB < 15 dB

Hence, there is no tonal noise.

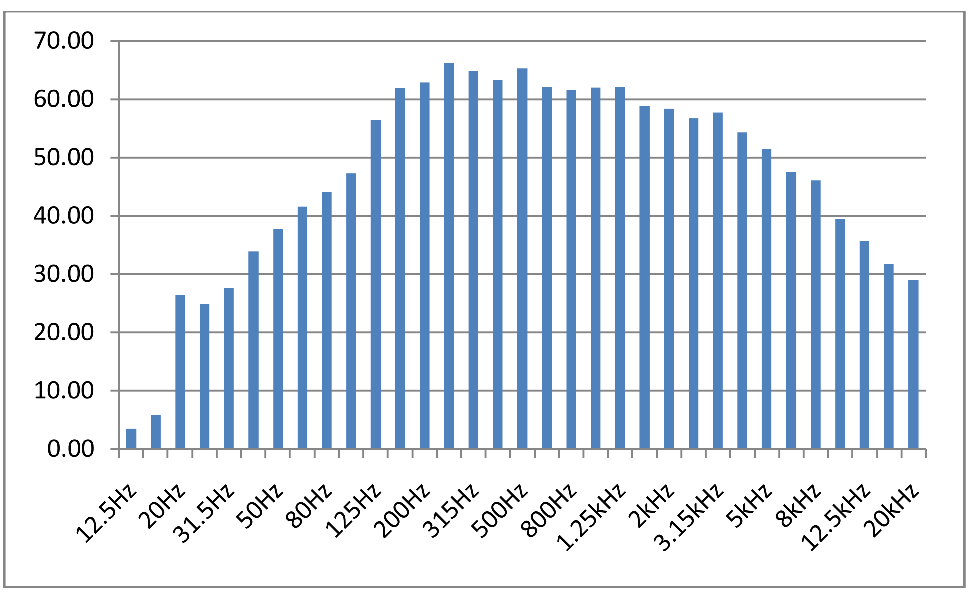


Figure 31: One-third octave frequency band at Location 10

Location 10

An examination of Fig. 31 above shows no evidence of tonal noise.

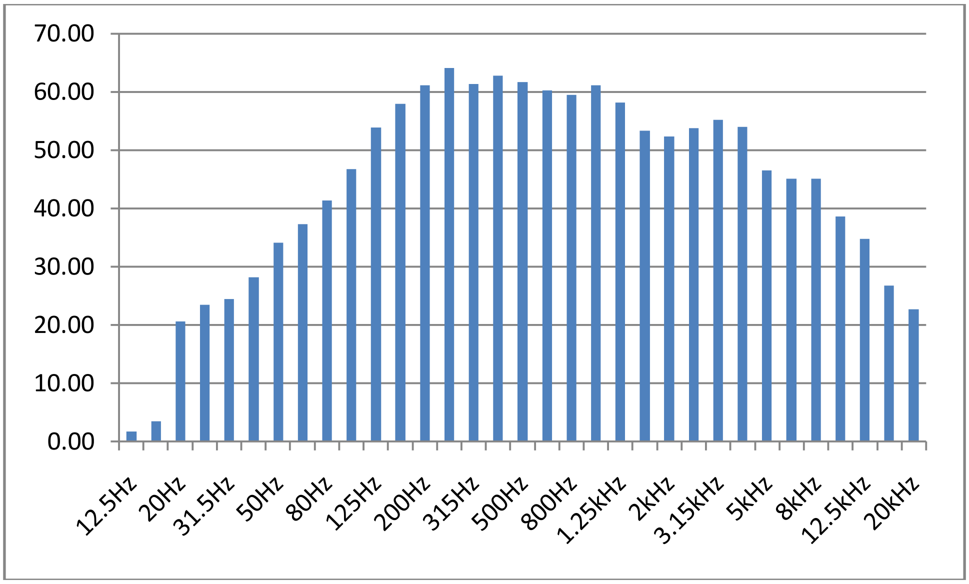


Figure 32: One-third octave frequency band at Location 11

Location 11

An examination of Fig. 32 above shows no evidence of tonal noise.

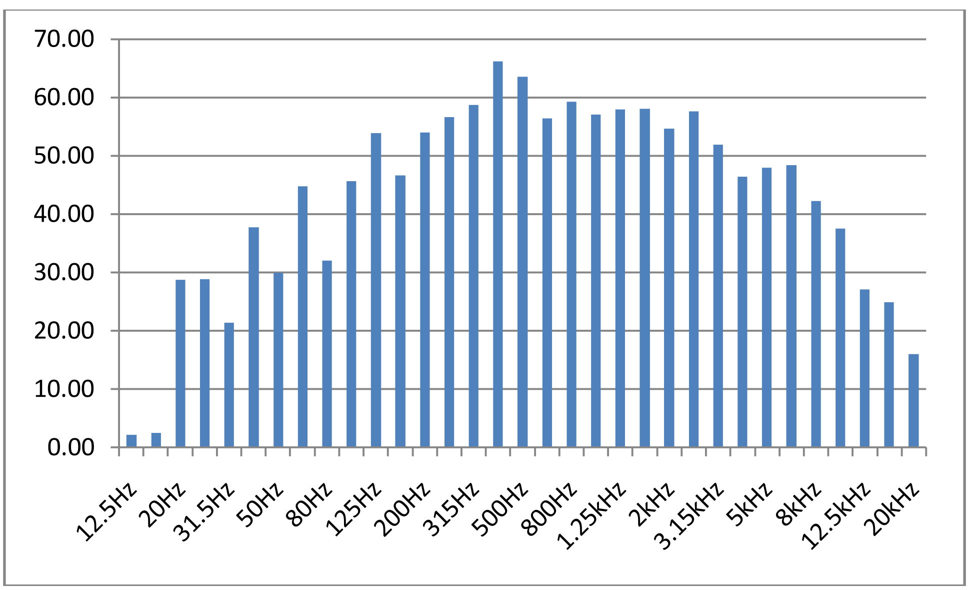


Figure 33: One-third octave frequency band at Location 12

Location 12

An examination of Fig. 33 above shows protruding bands at the 8th and 11th positions counting from the left and this corresponds to the 63 Hz and 125 Hz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz and 125 Hz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,

44.77 – 32.04 = 12.73 dB < 15 dB

44.77 – 29.99 = 14.78 dB < 15 dB

At 125 Hz,

53.87 – 46.59 = 7.28 dB < 15 dB

53.87 – 45.69 = 8.18 dB < 15 dB

Hence, there is no tonal noise.

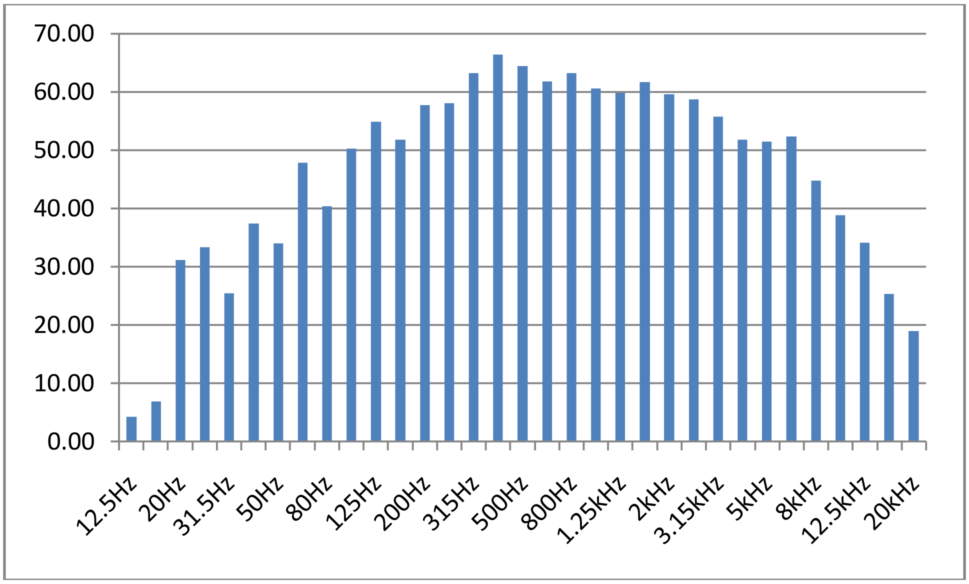


Figure 34: One-third octave frequency band at Location 13

Location 13

An examination of Fig. 34 above shows no evidence of tonal noise.

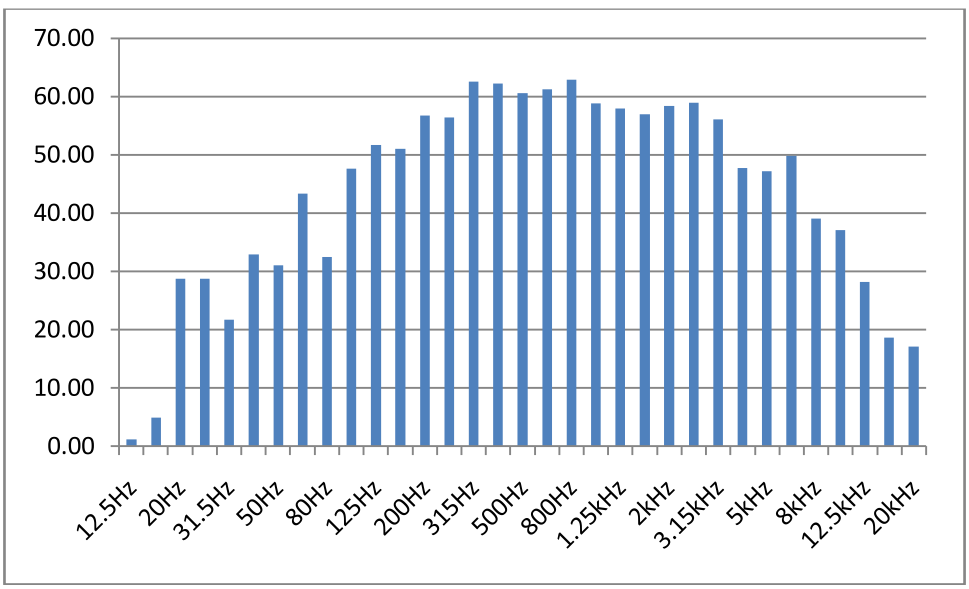


Figure 35: One-third octave frequency band at Location 14

Location 14

An examination of Fig. 35 above shows a protruding band at 8th position counting from the left and this corresponds to the 63 Hz one-third octave band. Referring to Table 2, we subtract the noise level values (at 63 Hz) from its immediate adjacent bands right and left to see if it meets the criteria of being a 'tone'.

At 63 Hz,
43.29 – 32.44 = 10.85 dB < 15 dB
43.29 – 31.08 = 12.21 dB < 15 dB
Hence, there is no tonal noise.

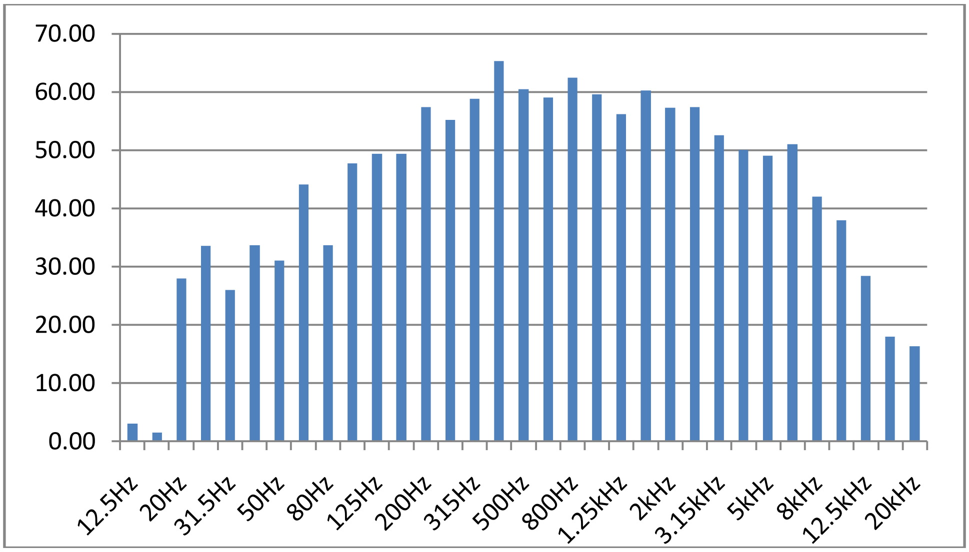


Figure 36: One-third octave frequency band at Location 15

Location 15

An examination of Fig. 36 above shows protruding bands at the 8th and 16th positions counting from the left and this corresponds to the 63 Hz and 400 Hz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz and 400 Hz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,

44.09 – 33.69 = 10.40 dB < *15 dB*

44.09 – 31.04 = 13.05 dB < *15 dB*

At 400 Hz,

65.28 – 60.45 = 4.83 dB < *8 dB*

65.28 – 58.82 = 6.46 dB < *8 dB*

Hence, there is no tonal noise.

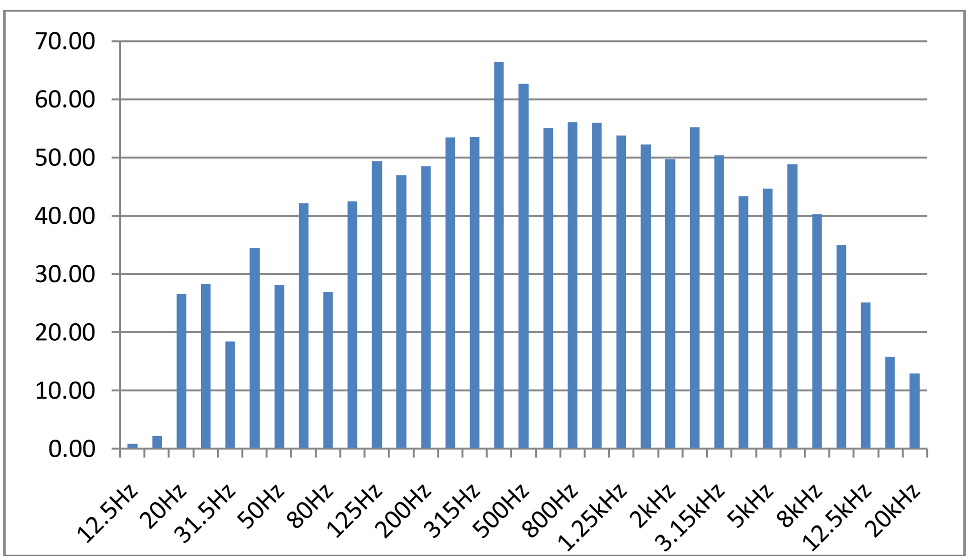


Figure 37: One-third octave frequency band at Location 16

Location 16

An examination of Fig. 37 above shows protruding bands at the 8th, 24th and 28th positions counting from the left and this corresponds to the 63 Hz, 2.5 kHz and 6.3 kHz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz, 2.5 kHz and 6.3 kHz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,

42.18 – 26.87 = 15.31 dB > *15 dB*

42.18 – 28.09 = 14.09 dB < *15 dB*

At 2.5 kHz,

55.17 – 50.41 = 4.76 dB < *6 dB*

55.17 – 49.72 = 5.45 dB < *6 dB*

At 6.3 kHz,
48.87 – 40.30 = 8.57 dB < 6 dB
48.87 – 44.69 = 4.18 dB < 6 dB

Hence, there is no tonal noise.

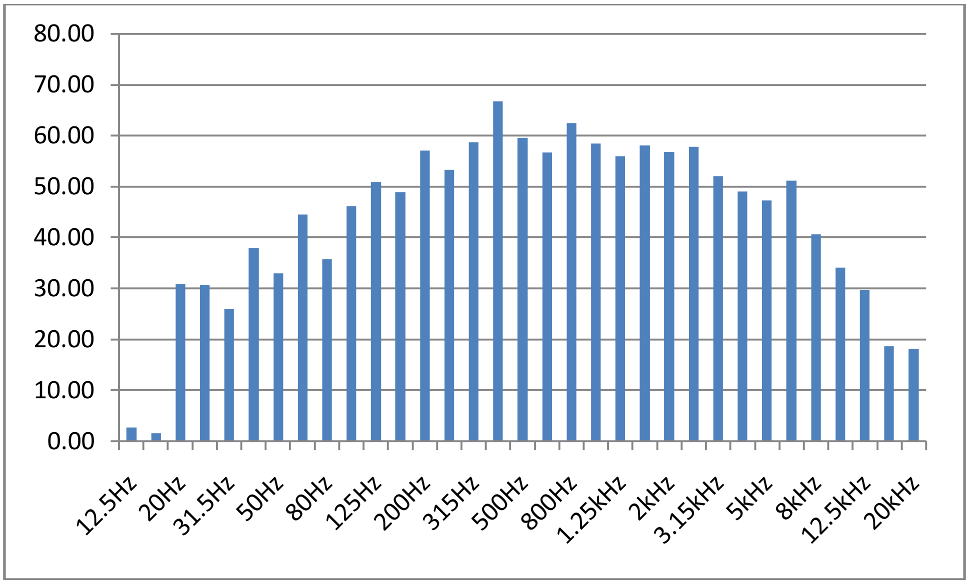


Figure 38: One-third octave frequency band at Location 17

Location 17

An examination of Fig. 38 above shows protruding bands at the 8th, 16th, 19th, and 28th positions counting from the left and this corresponds to the 63 Hz, 400 Hz, 800 Hz, and 6.3 kHz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz, 400 Hz, 800 Hz, and 6.3 kHz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,
44.51 – 35.77 = 8.74 dB < 15 dB
44.51 – 32.99 = 11.52 dB < 15 dB

At 400 Hz,
66.75 – 59.62 = 7.13 dB < 8 dB
66.75 – 58.73 = 8.02 dB > 8 dB
At 800 Hz,
62.39 – 58.38 = 4.01 dB < 6 dB
62.39 – 56.72 = 5.67 dB < 6 dB

At 6.3 kHz,
51.16 – 40.62 = 10.54 dB > 6 dB
51.16 – 47.26 = 3.90 dB < 6 dB

Hence, there is no tonal noise.

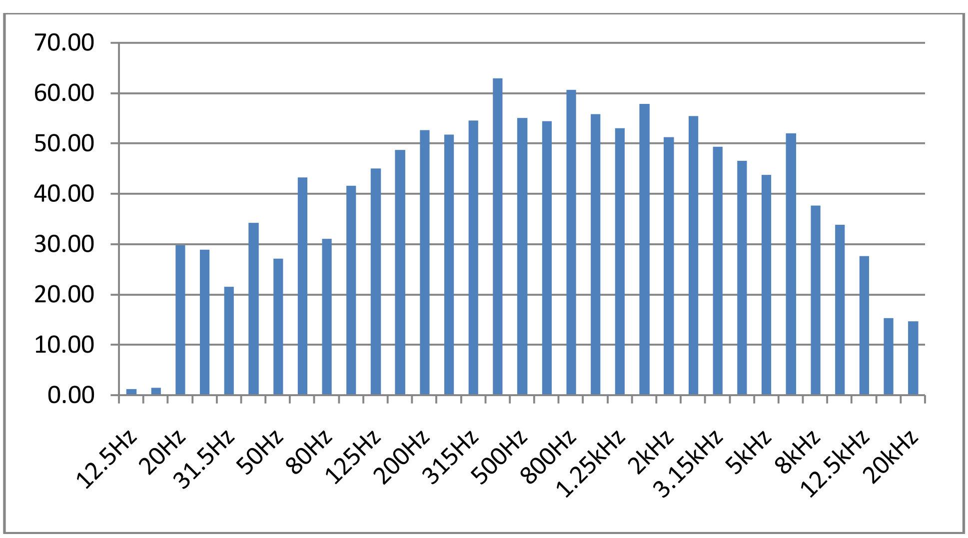


Figure 39: One-third octave frequency band at Location 18

Location 18

An examination of Fig. 39 above shows protruding bands at the 6th, 8th, 16th, and 28th positions counting from the left and this corresponds to the 40 Hz, 63 Hz, 400 Hz, and 6.3 kHz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 40 Hz, 63 Hz, 400 Hz, and 6.3 kHz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 40 Hz,
34.25 – 27.18 = 7.07 dB < 15 dB
34.25 – 21.51 = 12.74 dB < 15 dB

At 63 Hz,
43.21 – 31.08 = 12.13 dB < 15 dB
43.21 – 27.18 = 16.03 dB > 15 dB

At 400 Hz,
62.85 – 54.99 = 7.86 dB < 8 dB
62.85 – 54.58 = 8.27 dB > 8 dB

At 6.3 kHz,
52.02 – 37.68 = 14.34 dB > 6 dB
52.02 – 43.74 = 8.28 dB > 6 dB

Hence, there is tonal noise at 6.3 kHz

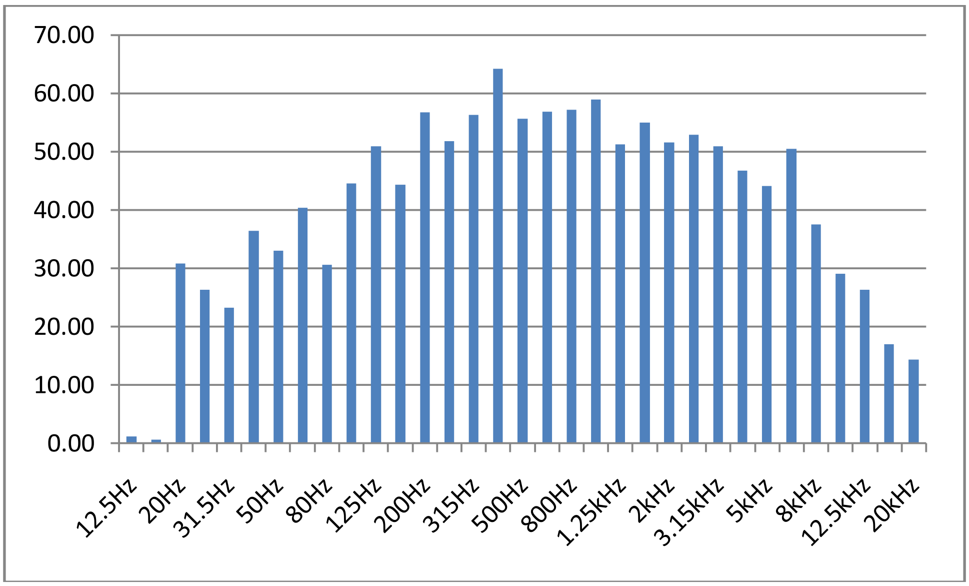


Figure 40: One-third octave frequency band at Location 19

Location 19

An examination of Fig. 40 above shows protruding bands at the 8th, 11th, 13th, 16th, and 28th positions counting from the left and this corresponds to the 63 Hz, 125 Hz, 200 Hz, 400 Hz and 6.3 kHz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz, 125 Hz, 200 Hz, 400 Hz and 6.3 kHz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,
40.38 – 30.62 = 9.76 dB < 15 dB
40.38 – 33.03 = 7.35 dB < 15 dB

At 125 Hz,
50.91 – 44.32 = 6.59 dB < 15 dB
50.91 – 44.55 = 6.36 dB < 15 dB

At 200 Hz,
56.76 – 51.81 = 4.95 dB < 8 dB
56.76 – 44.32 = 12.44 dB > 8 dB

At 400 Hz,
64.15 – 55.58 = 8.57 dB > 8 dB
64.15 – 56.30= 7.85 dB < 8 dB

At 6.3 kHz,
50.51 – 37.56 = 12.95 dB > 6 dB
50.51 – 44.07 = 6.44 dB > 6 dB

Hence, there is tonal noise at 6.3 kHz

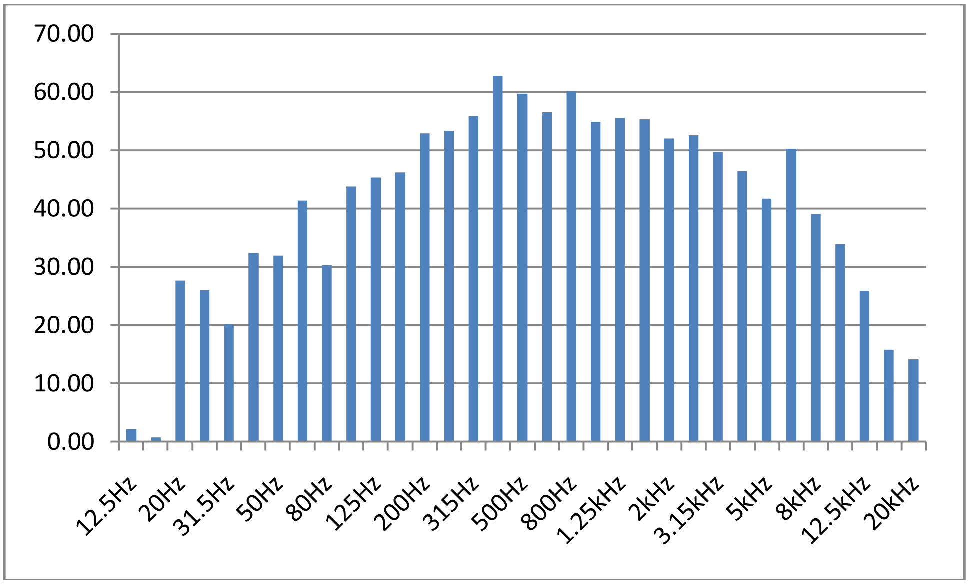


Figure 41: One-third octave frequency band at Location 20

Location 20

An examination of Fig. 41 above shows protruding bands at the 8th and 28th positions counting from the left and this corresponds to the 63 Hz and 6.3 kHz one-third octave bands respectively. Referring to Table 2, we subtract the noise level values (at 63 Hz and 6.3 kHz) from their immediate adjacent bands right and left to see if they meet the criteria of being 'tones'.

At 63 Hz,
41.32 – 30.31 = 11.01 dB < 15 dB
41.32 – 31.96 = 9.36 dB < 15 dB

At 6.3 kHz,
50.24 – 39.04 = 11.20 dB > 6 dB
50.24 – 41.68 = 8.56 dB > 6 dB

Hence, there is tonal noise at 6.3 kHz

VI. Conclusion and Recommendations

A one-third octave band frequency analysis was conducted at each noise measurement locations in order to assess any tonal component associated with helicopter flyover activity. Analysis of the one-third octave band frequency spectra measured at each of the noise monitoring locations from 7 am to 5 pm are presented in Tables 23-41. The frequency spectra showed that the helicopter noise contains tonal noise at locations 7 (at 400 Hz), 18 (at 6.3 kHz), 19 (at 6.3 kHz), and 20 (at 6.3 kHz)

From an examination of the one-third octave band frequency spectra, it is noted that spectra measured at all locations are generally broadband except for locations 7, 18, 19, and 20 which have pure tones in line with the ISO 1996-2 criteria. Tonal noise was mostly observed at the high frequency range at 6.3 kHz.

It can therefore be concluded that there is significant tonal content associated with helicopter flyover noise at locations 7, 18, 19, and 20 and therefore residents in these locations will experience higher level of annoyance and daytime sleep disturbance associated with tonal noise.

The results of the study clearly indicate that helicopter flyover noise generates tonal noise across a section of Mgbuoshimini community and this could produce increased annoyance and day-time sleep disturbance.

It is also clear from the results of this study that heliport is sited too close to the community and is operating outside the limits set out in ISO 1996-2:2007.

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None.

Conflicts of Interest

The authors declare that there is no conflict of interest.

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