Investigation of the connection between elephant acoustic communication signals and locomotive induced air-borne noise

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ABSTRACT

Railways are the world's largest linear infrastructures, and they are one of the most widely utilized modes of transportation due to their capacity, speed, and reliability, as well as their potential to alleviate traffic congestion and pollution. These trains, on the other hand, have been one of the leading causes of rising elephant mortality rates in Sri Lanka. Elephant-train collisions are a lesser known but significant source of elephant deaths in Sri Lanka. These train-elephant crashes have resulted in significant losses for the railway administration, as well as making elephants one of Sri Lanka's endangered species. In this study, an attempt was made to identify the relationship between elephant sensitivity to locomotive-induced air-borne noise frequency ranges. In this study, locomotive-induced noise data were gathered from diesel locomotives used in Sri Lanka and elephant acoustic data were collected from Sri Lankan elephants. The results show that most locomotives produced critical frequencies of air-borne noise around 40 Hz to 80 Hz and the elephant acoustics signals consist of low frequencies from about 0 Hz to 100 Hz with higher sound pressure levels. Therefore, it can be assumed that elephants are also attuned to sensing acoustics within 0 Hz to 100 Hz range. As a result, it is safe to imply that elephants should be able to sense the locomotive induced noise at a 100 m away from an approaching train, even if they would not have enough time to move out of the way.

Keywords: Locomotives, Air-borne noise, Acoustic communication, Frequency weightings, Sound pressure levels

1. INTRODUCTION

Railways, as critical infrastructure, play a vital part in the transportation system as a widely used form of transportation and a cost-effective mode of commuting and cargo conveyance across long and short distances [1]. Railways are a good way to minimize traffic jams and pollution, however, there is rising concern about the environmental impact of railway transit systems' air-borne noise. The locomotive-induced air-borne noise is mainly generated by trains and tack structures [6].

Even though trains generate air-borne noise, the survival and wellbeing of many animals are threatened by trains due to the train-animal collisions occurring continuously [3]. Every year, a considerable number of animals are killed in fatal incidents on railway tracks in Sri Lanka, with elephants being the most common casualties [9] . In the last two years total 27 elephants have been died from train-elephant collisions according to the department of wild life conservation.

For Sri Lankans, the elephant is a symbol of pride as well as cultural and religious significance. Although the Sri Lankan Elephant is smaller in size than the average African Elephant, it is the largest of the three Asian subspecies. Elephants use all their senses in communication and out of that acoustic communication is the most prevalent mode [7]. According to the literature, elephants use acoustic communication signals to maintain their clan-based behavior and to communicate between separated groups even a few kilometers away [10]. Despite this, train elephant collisions occur on a regular basis, and this is a lesser-known but significant source of elephant deaths in Sri Lanka. Since in this study an attempt was taken to identify the relationship between the elephant sensitivity to locomotive induced air-borne noise frequency ranges.

2. METHODOLOGY

A total of 77 trains were used to collect the locomotive-induced air-borne noise data for this study. The data were gathered from the western province, Sri Lanka over three days during the daytime. The measurements were taken at 70 kmh^{-1} speed and under normal environmental conditions.

The locomotive-induced air-borne noise was determined from a distance of 25 m away from the center of the railway and started recording data when the train was approximately 100 m away from the data detection spot. The Bruel and Kjaer type 2250 single-channel sound level meter [2] connected with Bruel and Kjaer type 4189 free-field microphone was used to record and store the locomotive-induced air-borne noise data. The zero weighted (Z) frequencies in the range of 12.5 Hz to 20 kHz were measured using the sound level meter. During the locomotive-induced noise data analysis, it was analyzed in a 3D graphical format using MATLAB software by applying A-weighting and C-weighting factors to check the presence of low frequencies in the noise.

The elephant acoustic data were collected from a female elephant. The data were collected during the daytime on a single day under normal environmental conditions. The data collection was carried out during a holiday in order to minimize the disturbance occurring from external sources towards the measurements. Since the elephant was alone there was no chance to observe the acoustic communication between mates. However its owner had an extremely good interaction with the elephant, which was good enough to make the elephant show reactions and communicate with him in response to his different activities and behaviors. During their communication, different types of elephants' acoustic signals, such as rumbles, roars, trumpets, etc. were observed, and all of them were recorded using the B&K type 4193 infrasound microphone and B&K LAN-XI meter.

The data were collected in the range of 0 Hz to 6.4 kHz with a resolution of 1 Hz. Also, the free environment noise measurement was taken in order for the comparison with elephant acoustic signals during the data analysis. Before analyzing the elephant acoustic signals, they were compared with the pre-recorded environment noise contour plot in order to verify the occurrence of elephant acoustic communications during the collection of data. Then the collected acoustic data were analyzed using Z-weighted and A-weighted Fast Fourier Transform (FFT) peak averaging.

3. RESULTS AND DISCUSSION

3.1 Locomotive induced air-borne noise signal analysis

The graphs in figure 1 represent the Z, A, and C weighted locomotive induced air-borne noise plots of one selected train (all the other trains showed a similar pattern as well). When analyzing figure 1 (a), Z-weighted plot by critically considering the curser values at data points, it is noticeable that for a particular one second period, starting from the low frequencies, the sound pressure levels are increased and the maximum value is given mostly around 50 Hz, 63 Hz or 80 Hz which are below 100 Hz. Then, again the sound pressure levels are reduced towards the higher frequencies during the same one-second time period. This means when the train is far away, about 100 m and for a considering one second period, the most prominently occurred frequencies are low frequencies. But with time when the train is near to the detection site after about 40 seconds in time, it can be seen that both the low and high-frequency sound pressure levels occurr at higher decibel levels around 60 dB to 70 dB compared to the time where the train is far away (100m away) from the measuring site.

When studying the A-weighted plot in figure 1 (b) (which is obtained by the application of one third octave band weighting factors of A-weighting on the original data set in figure 1 (a)), it can be noted that the sound pressure levels of the low frequencies up to about 100 Hz are vastly reduced compared to the higher frequencies. This is due to the application of the weighting values (weighting factors) on the low frequencies are much higher than in higher frequencies [5]. This shows that there are low frequencies present in the locomotive-induced air-borne noise.

A-weighting is the standard weighting of the audible frequencies and reflects the response of the human ear to noise [8]. The human threshold of hearing is at the level of about 0 dB to 120 dB-130 dB according to literature [4]. But according to the A-weighted plot in figure 1 (b), at low frequencies, there are sound pressure levels near 0 dB (after the application of weighting factors of A-weighting to the original (Z-weighted) data set). This means there exist low frequencies in locomotive-induced air-borne noise, which are below the human perception levels of hearing.

The C-weighting curve corresponds better with the human response to high-frequency noise compare to low frequencies [11]. Since in the C weighting plot of figure 1 (c), it can be seen that there is not much variation of the sound pressure levels at lower frequencies compared to the zero-weighting plot in 1 (a). But there is a significant amount of variation in sound pressure levels at higher frequencies in C weighting. This response shows that there exist high frequencies in locomotive-induced air-borne noise, but their degree of sound pressure level is much low compared to the sound pressure levels in low frequencies.

The aforesaid facts are confirmed by further analysis in the critical frequency range between 0Hz and 200 Hz, as illustrated in figure 2.

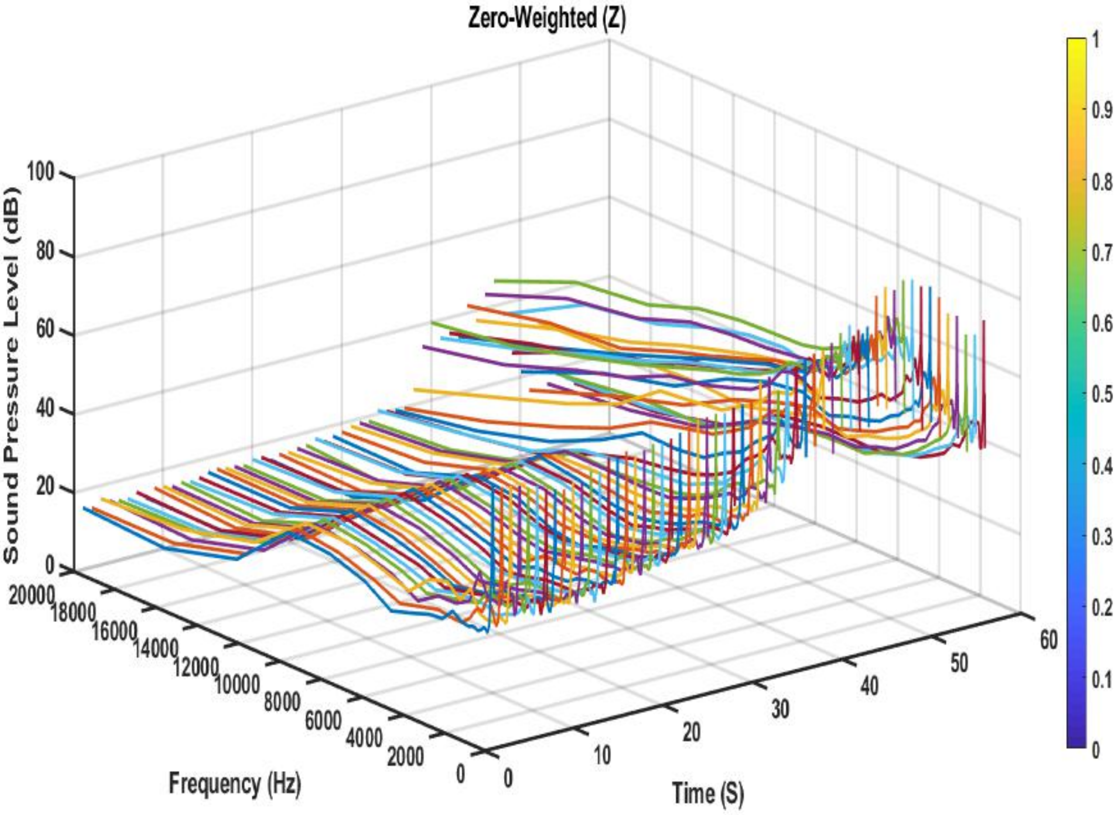
Zero-Weighted (Z)
Sound Pressure Level (dB)
Frequency (Hz)
Time (S)

Figure 1 (a)

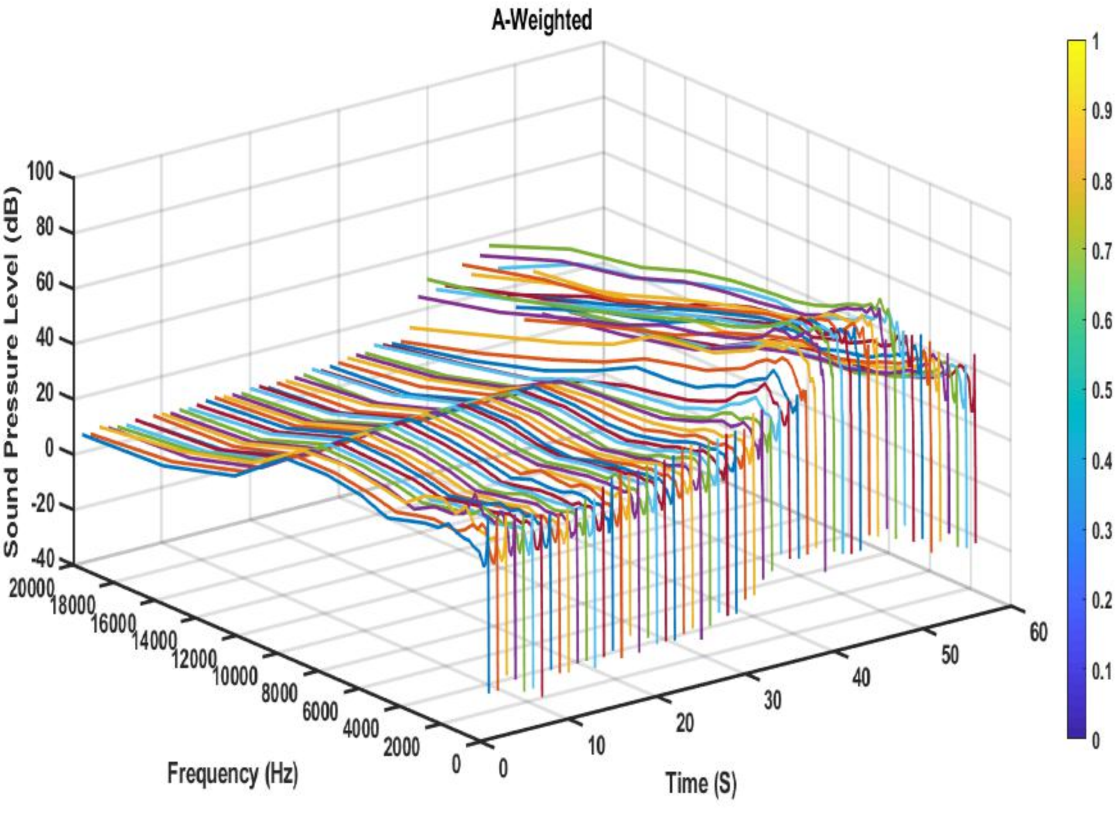
A-Weighted
Sound Pressure Level (dB)
Frequency (Hz)
Time (S)

Figure 1 (b)

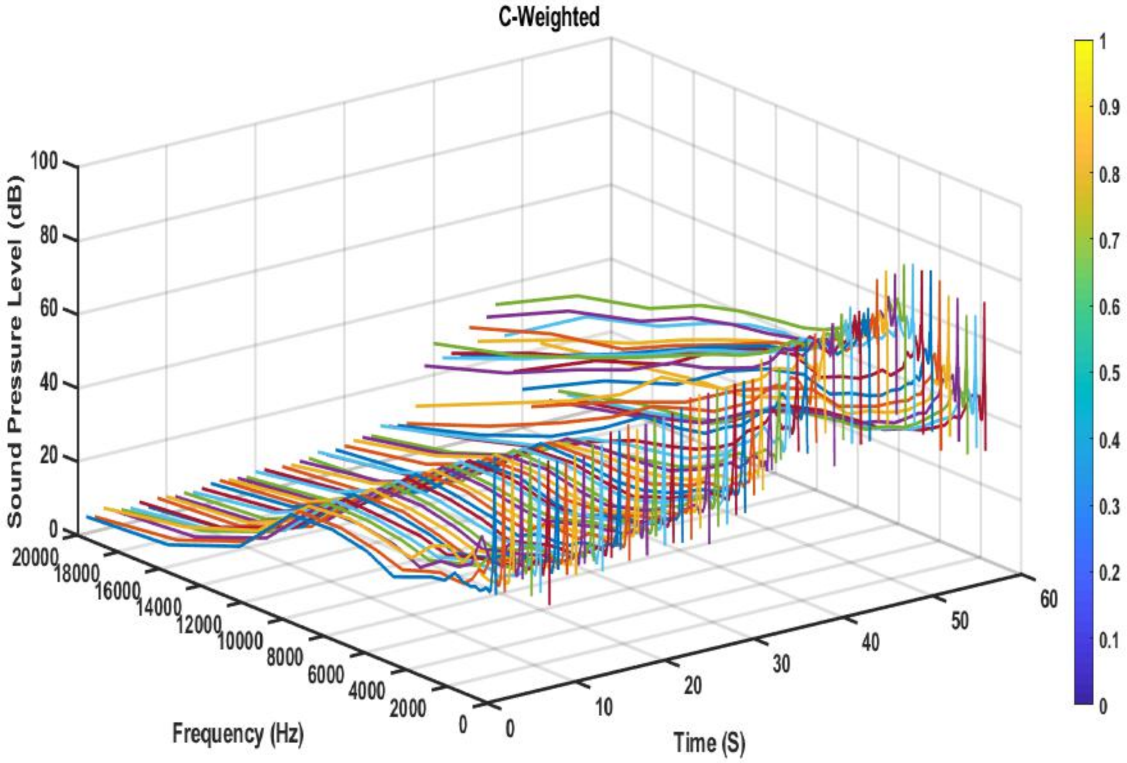

Figure 1 (c)

Figure 1: 3D plot between time, frequency, and sound pressure level of locomotive induced air-borne noise (a) Zero (Z)-Weighted (b) A-Weighted (c) C-Weighted

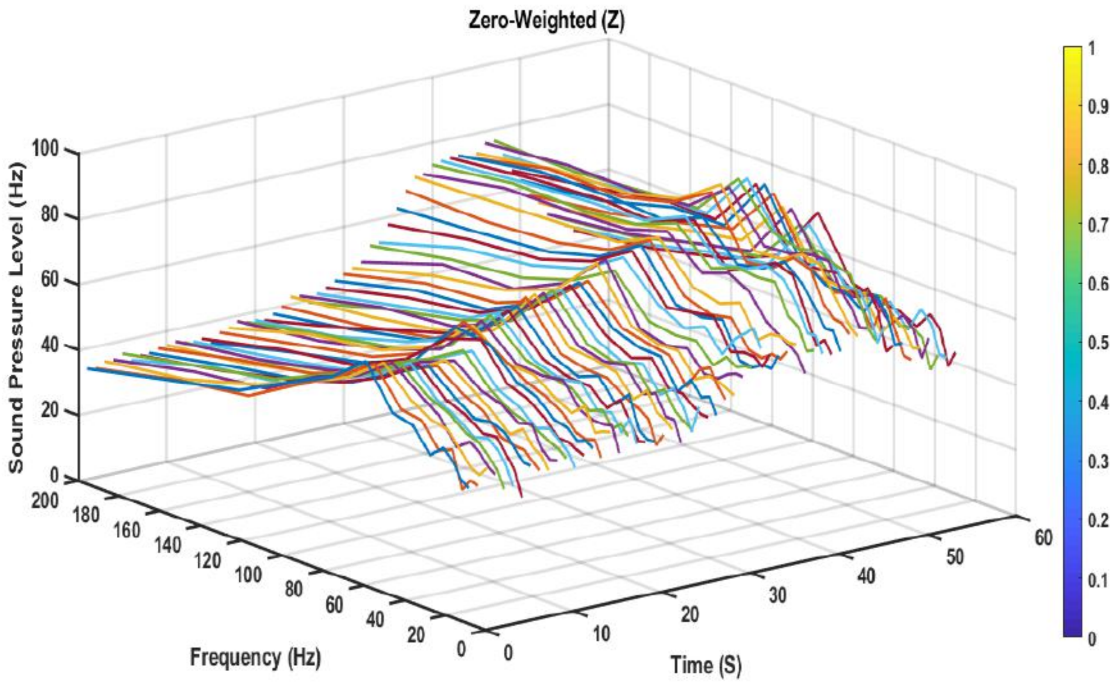

Figure 2 (a)

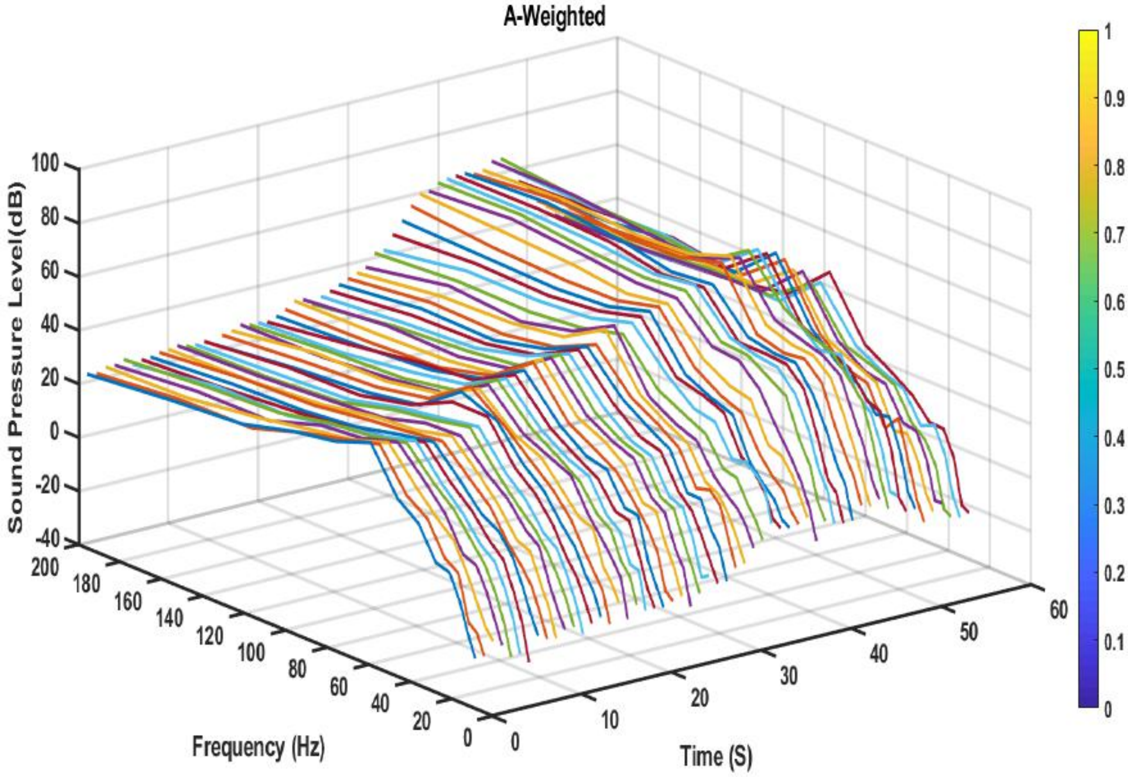

Figure 2 (b)

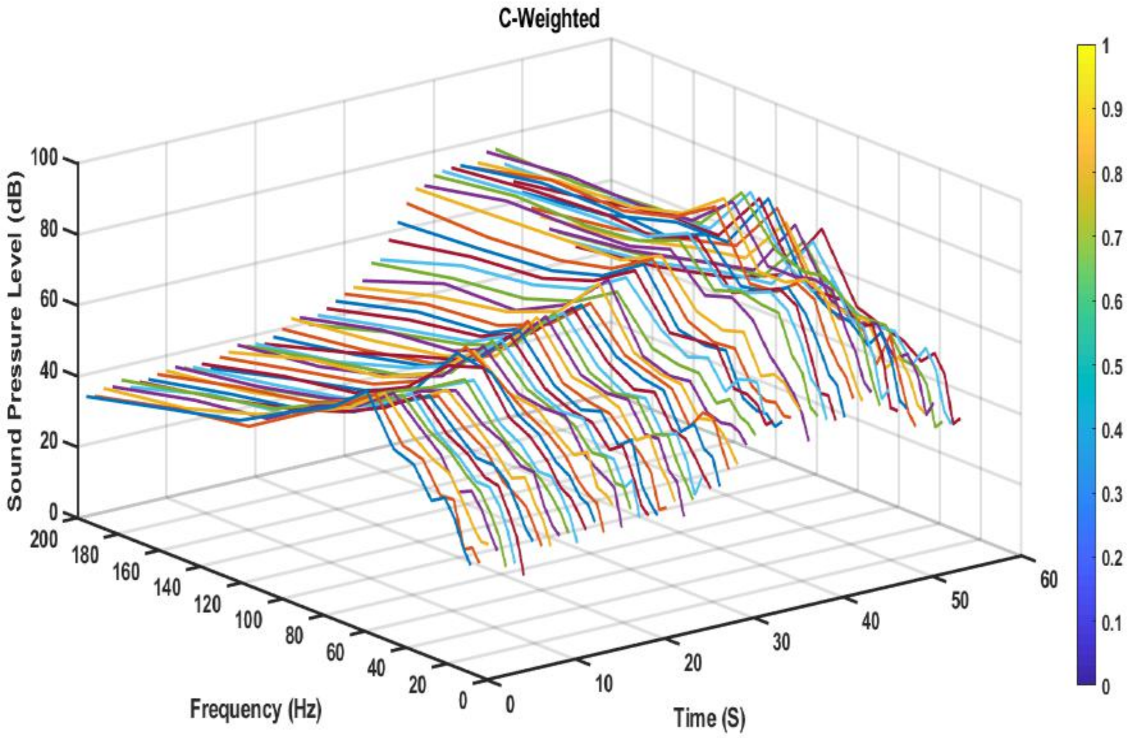

Figure 2 (c)

Figure 2: Further analyzed 3D plots between time, frequency, and sound pressure level of locomotive induced air-borne noise in the range of 0 Hz to 200 Hz frequency range (a) Zero (Z)-Weighted (b) A-Weighted (c) C-Weighted

3.2 Elephant acoustic signal analysis

According to the Z-weighted plot of an elephant rumble call in figure 3 (a), it can be identified that the critical frequencies of elephant acoustic signals have occurred between 0 Hz to 1 kHz frequency range. Much higher sound pressure levels around 55 dB to 75 dB can be identified in lower frequency ranges around 0 Hz to 100Hz than higher frequencies around 1 kHz. But in the A-weighted plot, as shown in figure 3 (b), only lower sound pressure levels below 40 dB can be identified within this 0 Hz to 100 Hz range. So, the higher sound pressure levels that occurred in the Z-weighted plot around the lower frequencies have been reduced below 40 dB in the A-weighted plot.

According to the Z-weighted plot of an elephant roar call in figure 4 (a), the critical frequency range of elephant acoustic signal have occurred between 0 Hz to 500 Hz frequency range with higher sound pressure levels around 50 Hz to 70 Hz. But according to figure 4 (b), the sound pressure level of the A-weighted plot in the 0 Hz to 100 Hz frequency range of the respective roar call has been reduced to about 25 dB and from 100 Hz to 500 Hz it has been reduced to around 40 Hz to 55 Hz.

Similarly, when considering the trumpet call in the Z-weighted plot in figure 5 (a), even though it has much higher sound pressure levels around 60 dB to 75 dB in lower frequencies below 1 kHz, in the A-weighted plot it has been reduced to about 25 dB to 35 dB in 0 Hz to 100 Hz frequency range, confirming the presence of low frequencies in trumpet calls.

According to the literature, Z-weightings represent no alteration to the actual measurement while A-weighting represents the human perception of hearing [8]. According to this analysis elephants are able to communicate using low-frequency acoustics in the range of 0 Hz to 100 Hz with much higher sound pressure levels as can be identified from the Z-weighting plots of the rumble, roar, and trumpet calls. Also, this analysis further confirms that the human ear can only perceive much lower sound pressure levels from those acoustics as can be seen from the A-weighting plots of the same rumble, roar, and trumpet calls.

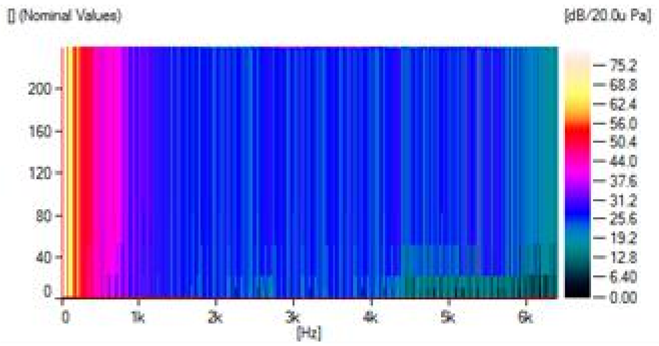

Figure 3 (a)

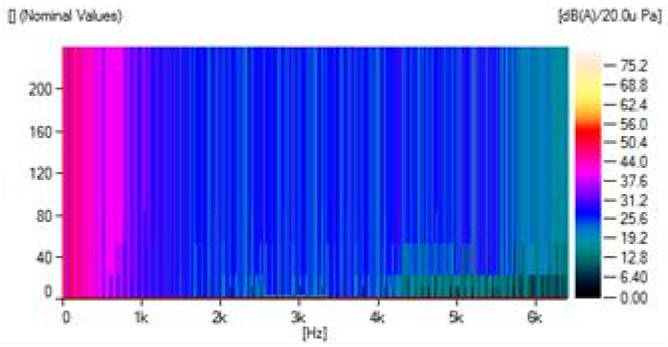

Figure 3 (b)

Figure 3: (a) Z-weighting (b) A-weighting FFT peak averaging contour plots of an elephant rumble call. The color bar on the right side of the graph indicates the sound pressure level values in decibels. The Y-axis indicates the nominal value of time and the X-axis indicates the frequency in Hertz.

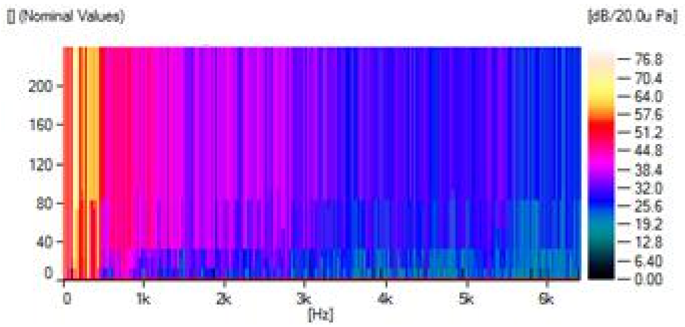

Figure 4 (a)

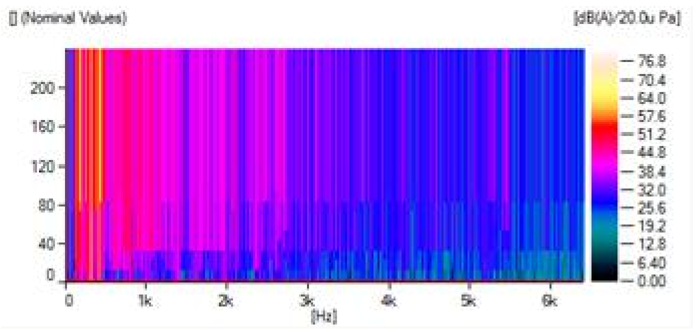

Figure 4 (b)

Figure 4: (a) Z-weighting (b) A-weighting FFT peak averaging contour plots of an elephant roar call. The color bar on the right side of the graph indicates the sound pressure level values in decibels. The Y-axis indicates the nominal value of time and the X-axis indicates the frequency in Hertz.

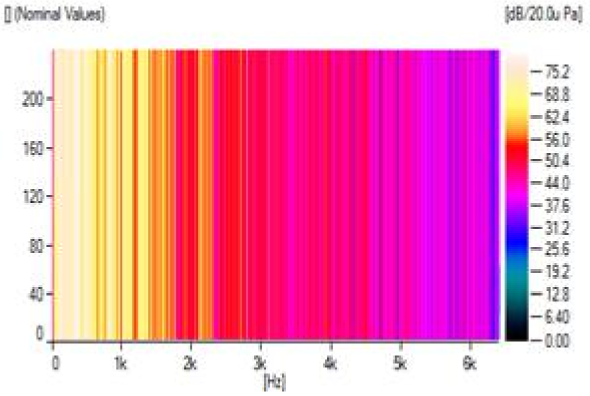

Figure 5 (a)

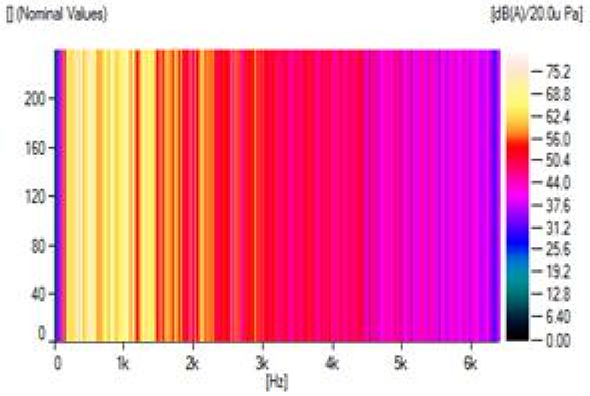

Figure 5 (b)

Figure 5: (a) Z-weighting (b) A-weighting FFT peak averaging contour plots of an elephant trumpet call. The color bar on the right side of the graph indicates the sound pressure level values in decibels. The Y-axis indicates the nominal value of time and the X-axis indicates the frequency in Hertz.

4. CONCLUSIONS

According to the locomotive-induced air-borne noise analysis, when the trains are approximately 100 m away from the measuring site, the most common frequencies of locomotive-induced air-borne noise consist of lower frequencies within the range of 40 Hz to 80 Hz. Most notably, about 99% of the locomotive-induced air-borne noise occurred below 100 Hz and about 1% of air-borne noise occurred between 100 Hz to 20 kHz.

Results of this study show that elephants are able to communicate using lower frequency acoustics in the range of 0 Hz to 100 Hz with much higher sound pressure levels which are below the human perception of hearing. Therefore, it can be assumed that elephants are also attuned to sensing acoustics within 0 Hz to 100 Hz range. As a result, it is safe to imply that elephants should be able to sense the locomotive induced noise at a 100 m away from an approaching train, even if they would not have enough time to move out of the way.

5. ACKNOWLEDGMENT

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