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Analyzing Train Vibrations to Observe There Relationship with Animal and Human Hearing Ranges

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ABSTRACT

Human-animal conflict is one of the burning issues in the world as well as in Sri Lanka. Animals lose their lives due to many reasons including deforestation, illegal killing, shooting because of false fear, etc. Railways built through animal habitats are yet another less identified big issue for the high mortality rate of animals. Among the victims, elephants are most common. In order to find a sustainable solution for this wildlife issue,it's important to have a basic understanding of the situation. Elephants are considered as one of the most sensitive mammals on the earth. Therefore it'sof common understanding that they must be able to detect the vibration of nearly coming train. But still, train elephant collisions donot show any decrease in the recent past. This study is done to identify the relationship between the frequency ranges which animals are sensitive to, and the vibrations generating through a moving locomotive, considering both airborne and ground-borne vibrations. This survey is done mainly to get an understanding of the vibration patterns of different locomotive types used in Sri Lanka. For that, both power set type and engine type trains were used for the observations. The results show that most of the trains produce airborne noise in the range of 40Hz to 160Hz, while the ground-borne vibration differs in the range of 8Hz to 36Hz.The principal findings show that the animals including human beings are not sensitive to such low frequencies resulting in train collisions.

1. INTRODUCTION

Many animals roam widely across landscapes in the quest to meet their daily, seasonal and annual biological needs of food, water, shelter, and mates.[1] In an increasingly industrialized world, however, transport networks (railways, roads, waterways) or so-called "linear infrastructures" restrict the movement of wildlife populations by fragmenting their habitat, increasing edge effects, constricting ecological corridors, blocking animal movement, and increasing the risk of mortality due to direct collisions with motorized vehicles. Roads are perhaps the most widespread and pervasive form of "linear infrastructure" that have greatly impacted wildlife populations in the more developed parts of the world through habitat loss, restriction of animal movements, alteration of animal behavior, and directly injuring or killing very large numbers of animals in collisions with vehicles. There has been much attention paid to mitigating wildlife road kills through the appropriate design of roadways in many developed countries. In contrast, only limited attention has been paid to wildlife–train collisions, although this has also been happening on significant scales in many countries.[2]

Elephants hold symbolic, cultural and economic importance in Sri Lanka. They attract tourists, support logging operations, and have significance in religious events. Being the largest mammal on the earth, elephants hold greater value in wildlife. The Sri Lankan subspecies is the largest and also the darkest of the Asian elephants with patches of depigmentation.[3]

The survival and wellbeing of elephants are threatened by many factors such as illegal killing, destroy their habitats for increasing demand for land with increasing population, killing or shooting because of the false fear of elephants, etc. But still, we can see that human being is responsible for the high mortality rate of elephants.[4]

Train elephant collision is yet less identified but hugely caused factor of the death rate of elephants in Sri Lanka. Last year, on September 18, that four elephants died after colliding with an oil train at Puwakpitiya, between Gal Oya and Palugaswewa, on the Colombo-Batticaloa railway line. Later, another three, a mother elephant and two calves died on the same railway line, at Namalgama between Welikanda and Poonani. The same week, another elephant was reported hit, critically wounded and died later. The year so far, recorded 12 elephant deaths by train collision according to the Department of Wildlife Conservation (DWC). During 2017 it had been seven. These few details show that this problem is now a big issue in Sri Lanka.Therefore the main objective of this study is to find out a connection between locomotive induced ground vibrations, airborne vibrations, and elephant communication which will be used in the coming future to minimize the train elephant collisions.

Train locomotives generate ground vibrations while they move. These differ according to their locomotive type, train speed, ground quality, etc. [1]. Hearing range describes the range of frequencies that can be heard by humans or other animals. The human range is commonly given as 20 to 20000 Hz, although there is a considerable variation between the individual, especially when it comes to higher frequencies. But human hearing is most sensitive in the 2000-5000 Hz range.

Some animal species can hear frequencies well beyond the human hearing range. Some dolphins and bats can hear up to 100000 Hz frequencies. Elephants can hear sounds at 14-16 Hz, while some whales can hear infrasonic sounds as low as 7 Hz.The low-frequency sounds, termed "infrasound," can travel several kilometers, and provide elephants with a "private" communication channel.

Elephants create seismic waves when they move or “rumble” that complement the audible sound we hear and that can be detected using geophones placed in the ground. These rumbles have fundamental frequencies in the infrasonic range below 30Hz, which means that they cannot be heard by humans. Using computer models, the scientists estimated that the seismic signals produced by the elephants could travel distances up to about 2.2 km [5].

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2. METHODOLOGY

The data for this study are collected from outdoor measurements contained with medium-stiff soil conditions near Gampaha,Veyangoda area. This site was selected because of the minimum disturbances occurring from the outer sources towards the measurement. A preliminary study was conducted in the Wallawatta area in order to identify the basic effectivefrequency ranges in which the instruments should be tuned.

The following instruments and software were used to determine the vibration and noise levels

2.1. Noise measurement

Noise data logger : Modular precision Level Analyzer, Bruel and Keajer Type2270, Enhanced sound analysis softwareBZ 7202 versions 2, Bruel and Keajer.
Field calibrator : Bruel and Keajer type 4231 acoustic calibrator traceable tointernational standard.
Measurement mode : Zero weighted Frequency range from 12.5Hz to 20kHz

Following noise level descriptors were measured simultaneously during the measurement.
L_{Aeq} - Equivalent continuous sound levels at a set time interval.
L_{AFmax} - Maximum Time A-weighted sound levels at a set time interval.
L_{Peak} - Maximum peak at a set time interval

2.2. Vibration measurement:

Vibration data logger: Pulse Multi-Channel Analyzer, Bruel and Kjaer (B&K)type 3160- A-042 International standard, Model LAN-XI
Field calibrator: Vibration exciter type 4294 traceable.
Measurement mode:Max. The peak value in velocity mode (mm/sec.) and frequencyrange 0Hz to 200Hz. Identified Predominant Frequencies.

The ground-borne vibration, as well as the airborne noise, was determined from a distance of 20m away from the center of the railway while the accelerometers were kept on the ground level. The microphone was located approximately at a height of 1.5m from the ground level. Three sensors were mounted in X, Y & Z directions on a metal block and it was placed on the ground level. The level of vibration was simultaneously measured in three perpendicular directions.

Seventy-seven trains were observed during the peak hoursfrom 3 p. m. to 7 p.m. within 3 days of the survey. Data were collected under two main categories, engines and power sets.Under each category, trains were sectioned again according to their class types. Trains moving to both up and down directions were considered and measurements were taken under normal speed and prevailingenvironmental conditions.

Table 1: Train categories

Power sets	Number of times	Engines	Number of times
S3	1	W2	1
S8	9	W3	1
S9	3	M2	2
S10	15	M4	1
S11	14	M5	2
S12	9	M6	3
S13	4	M7	1
		M8	1
		M9	4
		M10	2
		M11	4

Figure 1: Power Set

Figure 2: Engine

Under all data collected, the highest effective three frequency values obtained for each train were taken into consideration. Then the occurrence of those frequency values as a percentage of the whole data set was calculated and those with the highest values were concluded as the most critical frequencies.

3. RESULTS AND DISCUSSION

According to the survey, the following graphs show the effective frequencies detected from both train types, engines, and power sets, separated into ground-borne vibration and airborne noise.

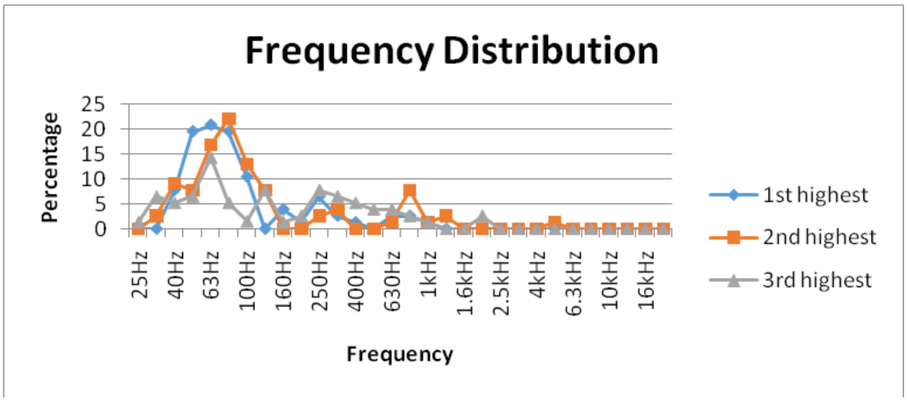

Figure 3: Airborne noise detection

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Figure 3 above shows the percentage occurring of the frequency range detected from the sound level meter. It gives the overall explanation about the effective first three highest frequencies of airborne noise detected for each train observed (both engines and power sets). Considering the 1sthighest frequency from the graph, 20.8% of all the trains show their highest airborne noise frequency as 63Hz. In the range of 100Hz to 1kHz, there are only a few amounts of frequencies detected while 125Hz and 500Hz don't appear at all. But there were no frequencies detected in the range of 1.25kHz to 20kHz.In addition to this, a clear view can be seen if we consider the two train types, engines, and power set separately. Considering the train type with engines, 18.2% of them show their highest airborne noise frequency as 80Hz and 100Hz. Engine type trains do not show any lower frequencies below 40Hz or higher frequencies beyond 800Hz. But a significant amount of trains, 13.6% produces frequencies in the range of 50Hz, 63Hz, and 160Hz. But an unexpected significant percentage of 9.1% was detected in 630Hz. When we consider the trains with power sets, the frequency distribution is quite larger than the trains with engines. The highest airborne noise vibration can be seen in 63Hz with a percentage of 23.6% in the trains with power sets. A significant amount of percentages can be seen in 50Hz and 80Hz too. Lower frequencies than 40Hz and higher frequencies below 1.25kHz have not appeared in the frequency distribution. But anyhow, some unexpected frequencies beyond 100Hz like 200Hz, 250Hz, 800Hz, 1kHz has occurred with lesser percentages than 10%.

Moving on to the second-highest frequency of airborne noise of both the train types, 22.1% of the trains show 80Hz as their second-highest frequency. A significant percentage of 16.9% of all the trains produce noise of 63Hz as the second highest frequency. At the same time, 13% of the trains produce noise with 100Hz frequency in the second-highest range. Some percentages below 10% have appeared in the frequency range of 125Hz to 1 kHz while some frequencies in that range like 160Hz, 200Hz, 400Hz, and 500Hz are not detected. Beyond this limit there is an unexpected occurrence of 5kHz with a percentage of 1.3% was detected in the survey.

Considering the third highest frequency from figure 3, the airborne noise frequency distribution is quite large. The highest percentage occurrence is 14.3% in 63Hz while all the other percentages are below 10%. But all the frequencies between 25Hz to 1 kHz were detected in the third-highest frequency distribution. An unexpected frequency of 2kHz was observed here with a percentage of 2.6%.

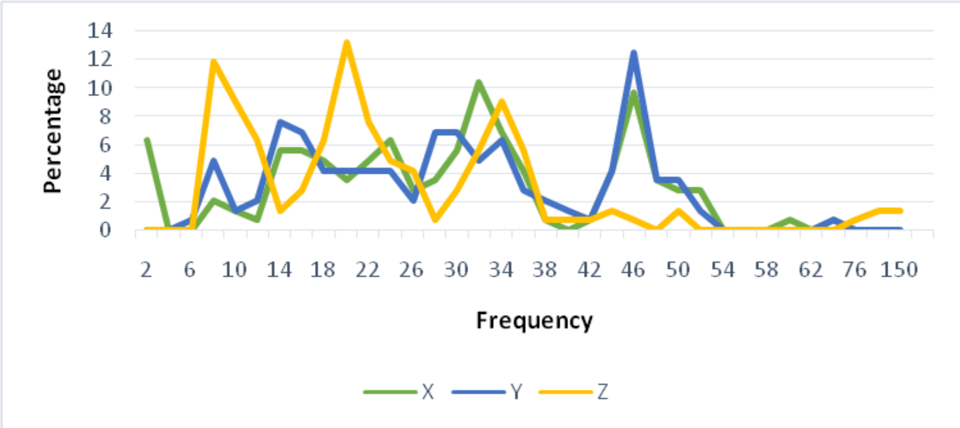


Figure 4: Ground borne vibration detection

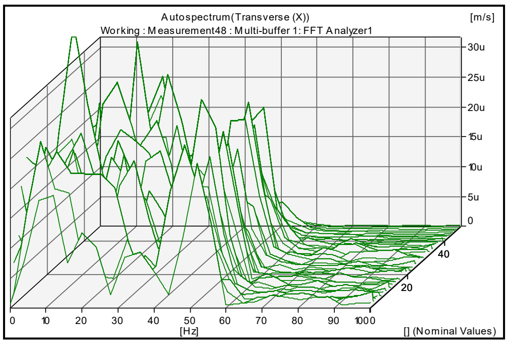
Figure 4 above shows the ground-borne vibration occurrence of both engine and power set types of trains divided into main three axes X, Y, and Z.

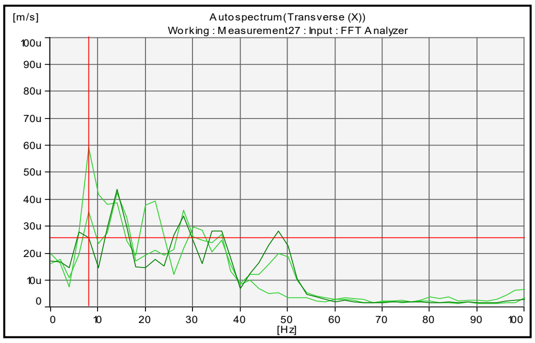
From the graph, it is clear that the frequency towards X direction has a significant percentage of distribution only in the range of 14Hz to 36Hz. The highest occurrence is in 32Hz with a percentage of 10.4%. Significant percentages between 5% to 7% can be seen between 14Hz to 36Hz towards X direction. But an unexpected 9.7% was observed in 46Hz and also 6.3% of the trains show 2 Hz frequency unexpectedly. An insignificant amount of percentages are occurring beyond 38Hz except at 46Hz. But if we consider the two locomotive types, engines and power sets separately we can have a clear view of the frequency distribution of the ground-borne vibration. When considering along the X-axis, the frequencies of engine type trains differ from 12Hz to 36Hz.Two unexpected high percentages are occurring in 2Hz and 44Hz -48Hz with significant percentage values. The highest percentage of 11.9% of trains with engines show 32Hz frequency. But in power sets the critical frequency is in the range of 14Hz to 36Hz with the highest percentage of 11.7% in 32Hz. Here also some unexpected frequenciescan be seen in 2Hz and 46Hz.

Moving on to the Y direction, from Figure 4 above, considering both train types, the critical frequencies along this direction is from 14Hz to 50Hz. The highest frequency is in 46Hz with a percentage of 12.5%. Beyond 50Hz, the percentage of effective frequencies along the Z-axis is low. But in addition, when we consider the two train types separately trains with engine locomotives show a critical frequency range of 8 Hz to 34Hz and 44Hz to 50Hz while trains with power sets have a critical range of 14Hz to 34Hz along the Y direction. But the unexpectedly high percentage is occurring in 46Hz with a percentage of 9.3%.

Considering the ground-borne vibrations towards Z-direction produced from both engine and power set train types, the critical frequencies occur in the range of 8Hz to 36Hz. The highest effective frequency is 20Hz with a percentage of 13.2%. A significant percentage can be seen in 8Hz. Even beyond 38Hz, some percentages below 2% can be seen where some unusual high frequencies over 70Hz also detected. When we consider the two locomotive types separately it can clearly be seen that there is no significant difference between both engine and power set locomotive types. In both, frequency ranges lie between 8Hz to 36Hz and the highest percentage of trains show 20Hz as their critical frequency towards the Z-axis.

From this, we can conclude that the ground-borne vibration of trains critically occurs in the range of 8Hz to 38Hz in both engine and power set locomotive types.



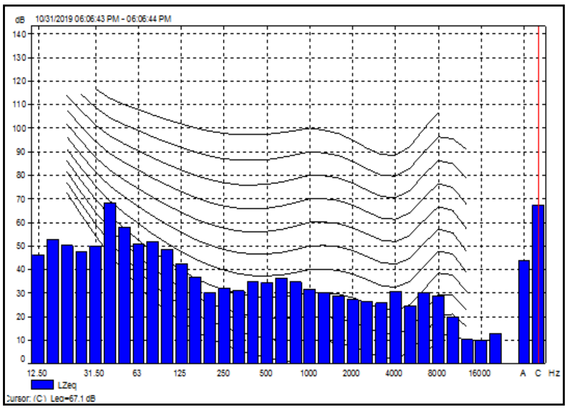


.**Figure 5:** Maximum peak velocity vs. Frequency with time

Figure 6: Frequency along X, Y, and Z

Above plots show an example of the auto spectrum (transverse axis) of a ground-borne Vibration data obtained from Pulse LanXI. The peaks in the graphs clearly show the areas in which the highest frequencies are detected throughout the train moving time.

Figure 5 displays the 3D view of the transverse axis deviation of the ground-borne vibration in maximum peak velocity vs. frequency with time (s) plot. It clearly shows that the peak velocities lie in the range of 0Hz to 60Hz in the train concerned above. Figure 6 shows the deviation of frequencies along all three directions X, Y and Z with velocity. Z-axis has the highest peak values than X and Y axes which can be clearly seen from the plot.



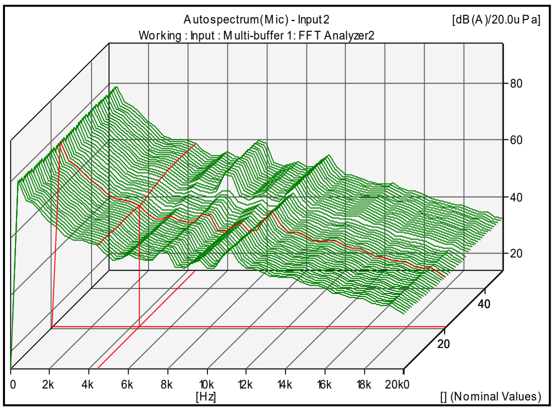
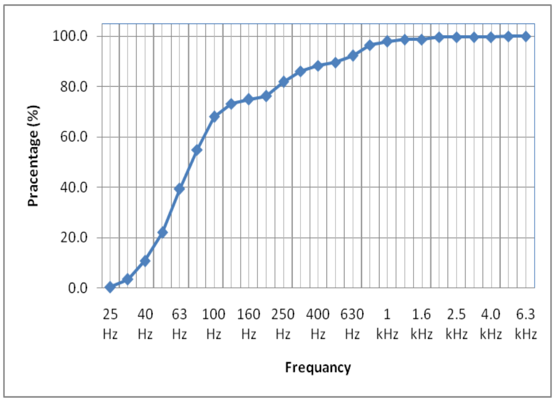


Figure 7: Plot by noise meter

Figure 8: Plot by Pulse LanXI

Above figure 7 shows the pattern of air borne noise obtained by Noise Meter, where it clearly shows the critical frequencies occurring in the range of 30Hz to 60Hz. Figure 8 shows the 3D plot of ground borne vibration detected for a particular train.



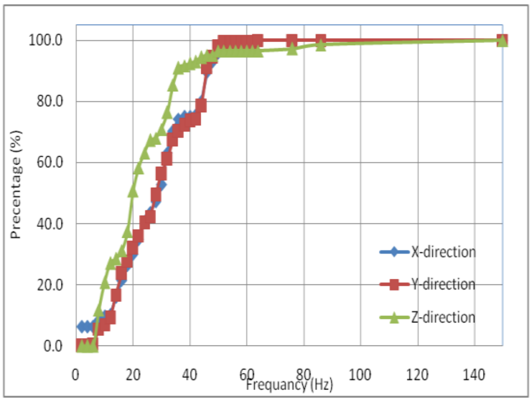


Figure 9: Airborne noise detection (Cumulative percentage)

Figure 10: Ground-borne vibration detection (Cumulative percentage)

Figure 9 shows the cumulative percentage of trains producing airborne noise in an overall scale of both engine and power set types. It can be clearly seen that more than 50% of the trains produce noise below 100Hz. Even though the human hearing range of frequency said to be in the range of 20Hz to 20 kHz, that range is not effective to each and every individual. It depends on person to person on many factors. According to Global Widex, human hearing is most sensitive without any discomfort in the 2000Hz to 5000Hz frequency range. This amounts to the conclusion that human beings may not detect the near coming train because most of the critical frequencies of airborne noise it produces are not in their hearing range. This may be a major reason for train human collisions too. Not only human beings but animal train collisions increasing day by day in forest areas may also causefor this reason.

Figure 10 shows the cumulative ground-borne vibrations along with X, Y and Z directions as a percentage of both train types. It can be clearly seen that the vibrations along Z direction are higher compared to two other directions.

5. CONCLUSION

With the advancement of transportation. Train animals and train human collisions have increased. One of the main reasons for this is the inability to identify the vibrations produced by a moving train. This study was conducted to find the effective vibration frequencies produced by the train. The results show that the critical range of ground-borne vibrations of trains is from 8Hz to 36Hz considering both engine and power set locomotive types. The effective range of airborne noise is from 31.5Hz to 800Hz.

It is recommended to expand this survey to identify the sensitive frequency ranges of animals and humans categorized under their age and gender to make the observations more clear. Also, this research can be further improved by moving into finer data by categorizing the trains into their class types and obtaining effective frequencies under each class.

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