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Determination of maximum noise from train horn using additional parameters

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Abstract: *The maximum noise produced by the train horn is calculated keeping in mind various factors like Doppler's effect (Christian Doppler 1842) on frequency of noise emitted and dampening of sound with distance. The critical angle and noise are calculated using calculus and MATLAB. Suggestions regarding the shape, orientation, placement and height of the barriers are also mad in the end keeping in mind the regulations provided.*

I. Introduction

1.1 Train Horn Noise

Under the Train Horn Rule (49 CFR Part 222), locomotive engineers must begin to sound train horns at least 15 seconds, and no more than 20 seconds, in advance of all public grade crossings. If a train is traveling faster than 60 mph, engineers will not sound the horn until it is within ¼ mile of the crossing, even if the advance warning is less than 15 seconds.

Train horns must be sounded in a standardized pattern of 2 long, 1 short and 1 long blasts. The pattern must be repeated or prolonged until the lead locomotive or lead cab car occupies the grade crossing. The rule does not stipulate the durations of long and short blasts.The maximum volume level for the train horn is 110 decibels which is a new requirement. The minimum sound level remains 96 decibels.

1.2 Train Horn Rule

In response to an increase in nighttime collisions at locations with state whistle bans, Congress enacted a law that required FRA to issue a Federal regulation requiring the sounding of locomotive horns at public highway-rail grade crossings. It also gave FRA the ability to provide for exceptions to that requirement by allowing communities under some circumstances to establish "quiet zones."

The Final Rule on Use of Locomotive Horns at Highway-Rail Grade Crossings, published in the Federal Register on April 27, 2005, was intended to:

- Maintain a high level of public safety by requiring the sounding of locomotive horns at public highway-rail grade crossings;
- Respond to the concerns of communities seeking relief from train horn noise by considering exceptions to the above requirement and allowing communities to establish "quiet zones"; and
- Take into consideration the interests of localities with existing whistle bans.

II. Literature Review

2.1 CPCB (Central Pollution (noise) Control Board)Norms

The ambient noise standards being followed in India for different types of zones are (CPCB, 1991)

Sr. no.	Area	L_{eq} dB	
		Day Time	Night Time
1.	Industrial area	75	70
2.	Commercial Areas	65	55
3.	Residential Area	55	45
4.	Silence Zone	50	40

Table 2.1 Noise Level Standards for Residential Area in India (Arvind Kumar Shukla(2011))

The noise levels at night are generally 10 dB lower as compared to day time because of almost 50-60% reduction in volume of traffic going through. Hence due to noises from other sources being lower the noise level standards are lower.

2.2 A-Weighted sound pressure level

A-weighting is the most commonly used of a family of curves defined in the International standard IEC 61672:2003 and various national standards relating to the measurement of sound pressure level.

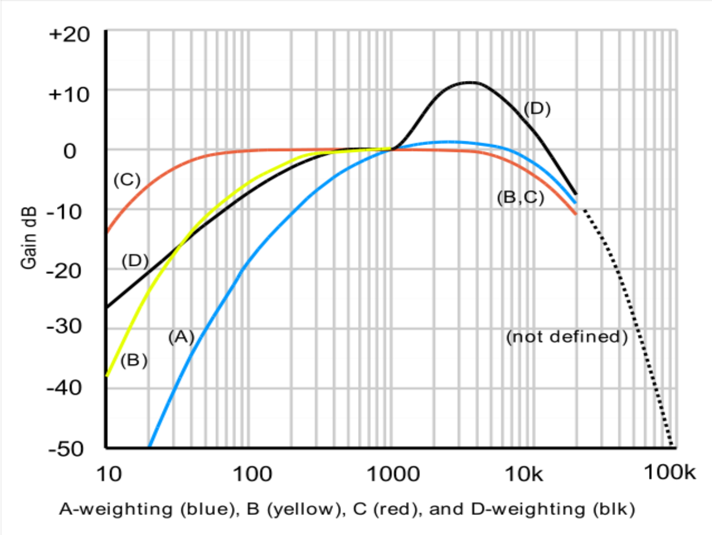

Fig 2.1: A-Weighted sound level(Nilsson, Mats E 2007)

2.3 Doppler Effect

The Doppler effect is observed whenever the source of waves is moving with respect to an observer. The Doppler effect can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding. It is important to note that the effect does not result because of an actual change in the frequency of the source.

$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v - v_s}\right) * f_{source} \qquad (1)$$

f' = apparent frequency
v = velocity
λ' = apparent wavelength
v_s = speed of source
f_{source} = frequency of source

2.4 Sound pressure level (SPL)

The decibel dB or dB SPL (Sound pressure level) in acoustics is used to quantify sound pressure levels and intensities relative to a reference on a logarithmic scale. The intensity level IL of a sound intensity I is defined by

$$IL = 10\log_{10}\left(\frac{I}{I_o}\right) \qquad (2)$$

I_o = Reference intensity

Since the intensity carried by a traveling wave is proportional to the square of the pressure amplitude, the intensity level can be expressed as the sound pressure level as

$$SPL = 10\log_{10}\left(\frac{P_e^2}{P_o^2}\right) = 20\log_{10}\left(\frac{P_e}{P_o}\right) \qquad (3)$$

Where P_e the measured effective is pressure amplitude of the sound wave and P_o is the reference effective pressure amplitude. The effective sound pressure is the root mean square of the instantaneous sound pressure over a given interval of time.

2.5 Relationship between SPL and frequency

As it is visible from above formula there is no direct co-relation between SPL and frequency but still for sounds near 3000 to 4000 Hertz, the ear is extra-sensitive; these sounds are perceived as being louder than a 1000 Hertz sound of the same intensity. At frequencies lower than 300 Hertz, the ear becomes less sensitive; sounds with this frequency are perceived as being less loud than a sound of the same intensity and 1000 Hertz frequency. The loss of sensitivity gets bigger as one goes to lower frequencies. Also, at very high frequencies sensitivity is again reduced.

2.6 Damping

The sound intensity is related to distance by inverse square rule:

$$I = \frac{1}{d^2} \tag{4}$$

I = Sound intensity
D= Distance
Since,

$$I = kp^2 \tag{5}$$

p = pressure
So,

$$p = \frac{1}{d} \tag{6}$$

The inverse relationship will be used in this report

2.7 Noise Meter

A sound meter is an instrument that measures sound pressure level, commonly used in noise pollution studies for the quantification of different kinds of noise, especially for industrial, environmental and aircraft noise.

2.8 Noise Barrier

Noise barriers are exterior structures provided to protect sensitive land uses from noise pollution. In fact, noise barriers are the most effective tools of mitigating roadway, railway, and industrial noise sources. The way of increasing (propagating) or decreasing (attenuating) of noise between the source and the receptor is dependent on various factors such as location of barriers and receptors, height and materials of noise barriers etc. Roadside noise barrier have shown to reduce the near road air pollution concentration levels. Within 15–50 m from the roadside, air pollution concentration levels at the lee side of the noise barriers can be to reduce up to about 50% compared to open road values

2.9 Noise Barrier Efficiency

The efficiency of noise barrier should be such that the noise levels are less than the above standards.

$$\eta = \frac{IL}{L_{eq}} * 100 \tag{7}$$

IL = insertion loss, the loss of noise due to insertion of noise barrier
L_{eq} = is the L at a receiver resulting from the operation of a single piece of equipment over a specified time period

Insertion loss can be estimated by using the model proposed by Kurze and Anderson (Kurze 1971). It is the result of compiling data of many researchers onto a single plot and developing a curve fit for a point source. The equation is given below:

$$IL = 5 + 20\log\left(\frac{\sqrt{2\pi N}}{tanh\sqrt{2\pi N}}\right) \tag{8}$$

Where:
N is defined as the Fresnel number, a non-dimensional measure of how much farther the sound must travel as a result of the barrier. It is calculated with the following equation:

$$N = (a + b - l) * \frac{f}{c}$$

l = the original length of the direct path from source to receiver
a and **b** = the lengths of the two straight-line segments comprising the path as modified by the noise barrier from receiver and source
f = is the sound frequency in Hz taken to be 500 Hz for construction site
c = speed of sound in m/s taken as 324m/s

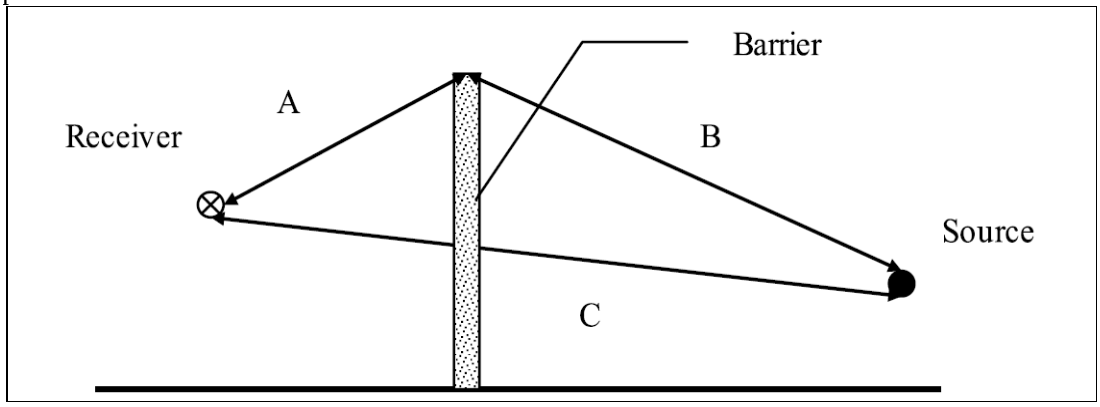

Fig 2.2 Geometry of Source, Barrier and Receiver (Arvind kumar shukla (2011)

III. Calculation Of Horn Noise

3.1 SPL vs. Frequency

As explained above there is no direct relation between SPL and frequency so we need to find a relation between them. This was accomplished by getting the relation of SPL and frequency from their graph. Here the correlation between speakers at 500hz and train horn is assumed.

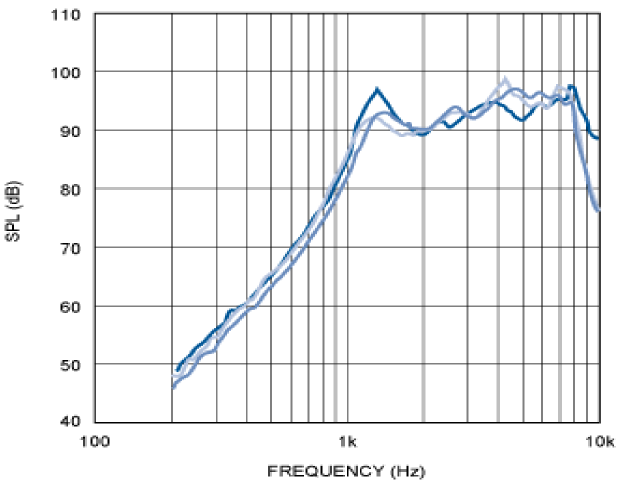

Fig 3.1 : SPL vs Frequency for speakers

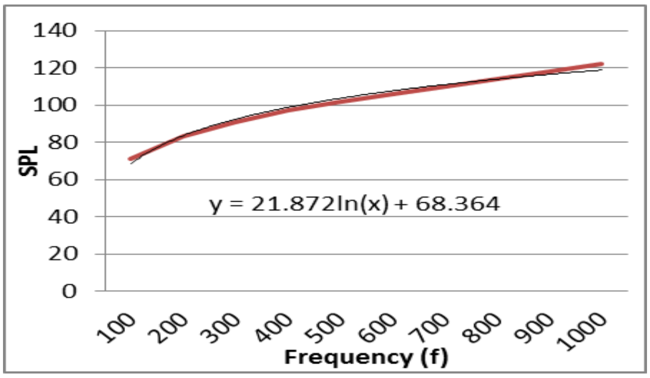

Fig 3.2 : SPL vs Frequency for Train horn

So relationship between them from graph is:

$$SPL = 21.872 * \ln(f) + 68.364 \quad (9)$$

3.2 Doppler Equation

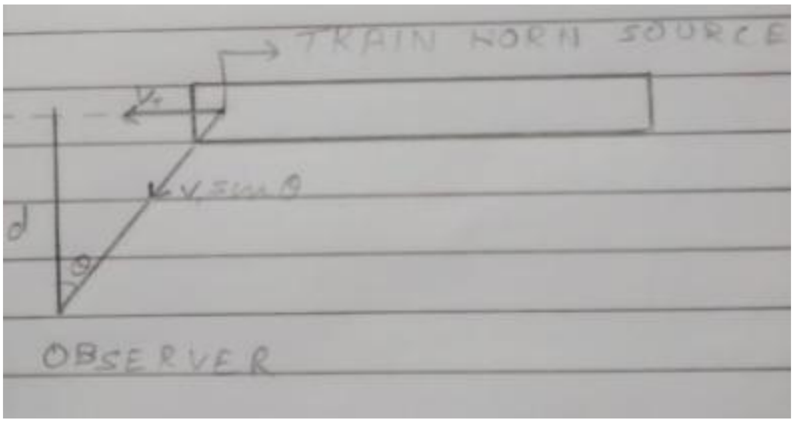

Fig 3.3: Schematic Diagram

Relative velocity between source and observer along the line at any point = $v_T \sin\theta$

v_T = speed of train

Doppler equation (1):

$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v - v_s}\right) * f_{source}$$

$$f' = \frac{v}{\lambda'} = \left(\frac{v}{v - v_T \sin\theta}\right) * f_{source} \quad (10)$$

Using the relation between SPL and frequency

$$SPL = 21.872 * \ln(f) + 68.364 \quad (11)$$

$$SPL = A * \ln(f) + B \quad (12)$$

Putting (10) in (12) we get

$$SPL = A * \ln(\left(\frac{v}{v - v_T \sin\theta}\right) * f_{source}) + B \quad (13)$$

$$SPL' = \left(A * \ln\left(\frac{C}{D - E\sin\theta}\right) + B\right) \quad (14)$$

Adding the damping factor from (6)

$$SPL' = \frac{\cos\theta}{d}\left(A * \ln\left(\frac{C}{D - E\sin\theta}\right) + B\right) \quad (15)$$

Now ,
Values of constant,
The readings were taken at Delhi Cantt railway station and crossing for Chetak Express,

Train horn = 500 hz

v_T = 56 Km/hr=15.56m/sec

V=324m/s

Where,
A= 21.872, B=68.364, C=500*324=162000, D=324, E=15.56

Upon differentiating with respect to θ
$\theta_{critical}$ = 0.2947°
f' = 500.124 Hz
$\Delta SPL = 0.01dB$
$SPL_{FINAL} = 103.57dB$

3.3 Noise Barrier specifications

The value of Train horn is high for the pedestrians so,
A noise barrier needs to be constructed

SPL = 103.57dB
D=4.3m
Max Permissible= 75dB

We know that the barrier will be most efficient when we place the barrier at the centre of the train and pedestrian,
So,

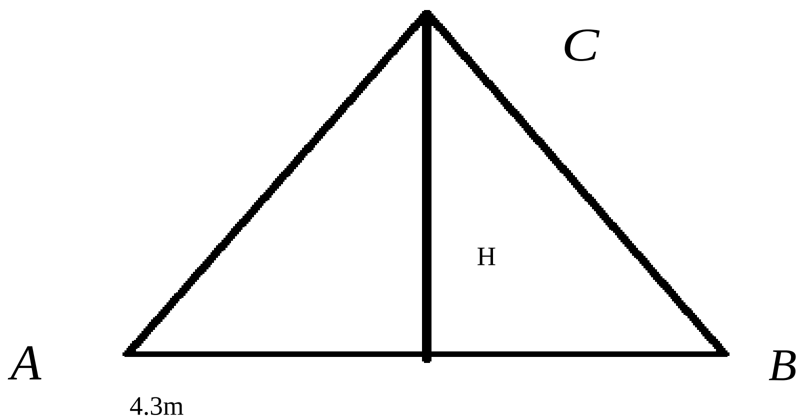

Fig3.4 barrier diagram

H= height of barrier
AB=4.3m
Let AC=CB= x
IL=28.57
So from (8)
We have,

$$IL = 5 + 20\log\left(\frac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}}\right)$$

$$28.57 = 5 + 20\log\left(\frac{\sqrt{2\pi N}}{\tanh\sqrt{2\pi N}}\right)$$

$\sqrt{2\pi N}$ =15.85
N=25.92
AC+BC-AB=25.92
AC+BC=30.22

Again by differentiating we get
H=14.96m

IV. Result

1. Variation of SPL with frequency is given by $SPL = 21.872 * \ln(f) + 68.364$ for sound with average reading of 104dB
2. $\theta_{critical}$ for chetak express comes out to be 0.2947°
3. f' for the train changed to maximum of 500.124 Hz for the observer 4.3m away from the engine
4. $\Delta SPL = 0.01dB$ after the application of Doppler effect and damping
5. Height of noise barrier required = 2m +14.96m =16.96, so a noise barrier of 17m of steel puff panel will be required to mitigate the noise.
6. This change will become significant as the speed of train rises and for bullet trains there is $\Delta SPL = 6dB$
7. The angle $\theta_{critical}$ changes to 2.5° for bullet trains.

V. Conclusion

The relation between frequency and SPL is established as given above. This is supported by the experimentally obtained values. It has also been shown that the sound level will be maximum for the $\theta_{critical}$ .Also there is definite change in the value of SPL. The change here is small but will become significant for higher values of train speed, distance of observer and frequency of train horn. There is a definite need of sound barrier and can be placed at a orientation as given in the figure.

Fig 6.1: Noise barriers oriented at an angle (www.noisebarriers-hosekra.com)

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