Traffic Noise Control by Periodically Arranged Trees

Preeti Gulia[1], Arpan Gupta[2]
[1,2b]*Indian Institute of Technology, Mandi*
[1]*preeti_gulia@students.iitmandi.ac.*

Abstract**—**This paper presents a computational work based on sonic crystals to reduce noise pollution using an array of trees. Sonic crystals are structure in which sound hard objects are arranged in a periodic pattern and are mainly used to control noise. Transport noise in urban area is one of the main sources of noise pollution in environment. The paper demonstrates an idea of reducing transport noise pollution by using 'Thuja' trees arranged in a periodic pattern on the sides of road or railway track. This paper presents 3-D model of sonic crystal having thuja green trees as scatterers. Finite element method is used for studying transmission loss through sonic crystals made of thuja trees. The result shows a significant sound attenuation within frequency ranges up to 500 Hz which indicates that trees can be used to overcome noise pollution. The simulation results imply that thuja sonic crystal satisfies the Bragg's prediction of band gaps. A comparison is also made between sound attenuation for two 3-D model one with a line sound source and second with plane sound source.

Keywords— *noise reduction; sonic crystal; environmental noise*

I. INTRODUCTION

In the era of advance technology, noise pollution is one of the biggest problems for human being as well as for wild life. Noise pollution is very unpleasant and distracting sound in environment. Noise pollution can be measured in term of intensity, frequency and duration of sound. A noise with a very high intensity can cause harmful effect to human ears. Noise pollution affects the state of mind of human being and causes discomfort, strain and insomnia due to disturbance in the environment. Increasing urbanisation and industrialization in our country results increase in noise pollution. A huge part of noise pollution is contributed by the transportations. Noise pollution can be reduced by using noise barriers like sonic crystal. In sonic crystal, sound hard objects are arranged in a periodic pattern embedded on a low acoustic impedance material. In this paper, trees are used as sound hard object. Trees contribute a lot to the environment providing oxygen, absorbing carbon di-oxide, reducing air pollution and supporting wild life etc. Along with this, trees can also be used to reduce noise pollution by growing in a periodic arrangement. T. V. Renterghem and D. Bottledooren [1] in 2002 studied the effect of belt of tree behind a noise barrier in the wind. They took measurements along the highway and found that efficiency of noise barrier with belt of tree is increasingly better than the noise barriers without tree belt, with increasing wind speed.

When a number of trees are present between sound source and receiver, sound waves collide with foliage of trees. Therefore, some part of it gets reflected and other is transmitted. So, trees act like noise filter. A lot of work is done in this field. T. V. Renterghem , D. Bottledooren and K. Verheyen [2] in 2012 did an experiment with a vegetation belt of periodically arranged trees and computation was done by means of three dimension finite difference time domain method (FDTD). The result showed that sound attenuation increases with increasing stem diameter and decreasing spacing between trees. H. T. Huisman and K. Attenborough [3] in 1991 measured the reverberation and sound attenuation in term of frequency in pine forest for depth up to 100 m and got 11 dB sound attenuation.

In this paper, thuja is used as periodic scatterer. Thuja green giant is a fast growing evergreen tree which can grow in any type of soil. Leaves of this plant start to create a very dense barrier at an average height of 5 to 6 feet [4]. Sound attenuation in denser barrier is larger than a sparse barrier. Mature height of thuja green giant can reach at 20 to 30 feet but it can be trimmed once in a year at desired height[5]. In this study, thuja's height is taken as 8 feet arranged in a row.

V. Pathak, D Tripathi and V. K. Mishra [6] in 2008 studied a vegetation belt of different width and height. Then they monitored the noise level and found that area without vegetation belt was highly polluted as compare to area with vegetation belt. A number of experiments are carried out on vegetation belt. C. F. Fang, D. L. Ling [7] in 2005 examined the effect of noise reduction for six vegetation belts. They placed amplifier in front of each belt and noise meter at different heights behind the each belt and calculated the relative attenuation. The result showed that relative attenuation has a positive relationship with tree height and belt width.

L Huddart [8] in 1990 used vegetation belt for transport noise screening. He did a field study and gave a report in which effectiveness of vegetation to reduce transport noise is described using five different types of vegetation belt of depth up to 30 m. The result showed that sound reduction depends on the foliage and absorbing quality of ground enhanced by plant root system.

A. K. Pal, V. Kumar and N. C. Saxena [9] in 2000 did experiment using array of plants to reduce noise pollution at some plantation sites and coalfield in India. They found that sound attenuation is increasing with increase in frequency. Present work also verifies this result with thuja sonic crystals with edge sound source. Sonic crystals are the periodic array of sound hard scatterers. Sonic crystals are used to reduce noise within certain frequency range. This frequency range is called band gap. A. Gupta, K. M. Lim and C. H. Chew [10] in 2013 used a quasi 2-D model of sonic crystals for sound attenuation and found a sound attenuation of 37 dB at frequency 3500 Hz.

SC Ibanez, S. C. Rubio and J. V. S. Perez [11] in 2015 experimented with three dimensional model of a sonic crystal to reduce the environmental noise pollution. They split this 3-D problem into 2-D problem and measured the total insertion loss for it. And they got a significant sound attenuation in very low computation cost.

This paper uses the combination of both trees and concept of sonic crystals and use trees in terms of scatterers embedded in air. In this work, we study three dimensional model of sonic crystal in which five thuja green giants arranged in a straight line with some periodic distance. The paper presents two models one with an edge sound source and second with a plane sound source.

II. MODEL SPECIFICATION

This three dimension model has five trees which are arranged in a straight line shown in fig 1. Trunk diameter of trees is 0.8 feet and height is 8 feet. Centre to centre distance of trees is 5 feet. The simulation domain considered is a three dimensional cuboid of 30 feet width, 10 feet depth and 10 feet height. For material properties of this system, density of air is taken 1.25 Kg/m^3 and speed of sound in air is 343 m/s. Total 409788 number of tetrahedral elements are created after meshing using Nyquist criteria and size of mesh is defined by $\frac{c_c}{5\,x\,f}$.

Where, c_c is speed of sound in air and f is the frequency. Here we have taken five points per unit wavelength for meshing. Sound wave is coming from left side of cuboid. Plane wave radiation boundary condition is applied on left, right and top face of lattice and remaining boundaries are considered as sound hard. The whole finite element procedure is solved in COMSOL Multiphysics.

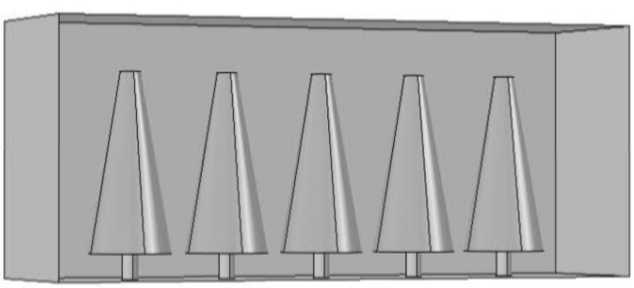

Fig. 1 3-D Model of sonic crystal made of thuja trees used for analysis

III. SOUND TRANSMISSION ANALYSIS

Here we have calculated a sound transmission loss through the 3-D model of thuja sonic crystal with two different type of sound source. In first model, a power edge source is provided at one of the bottom edge of cuboid and in second model, plane wave is coming from left side of cuboid. At right hand side, sound is measured as a plane wave in both model and sound transmission loss or attenuation is measured by subtracting the sound pressure level at receiver from sound pressure level at the source.

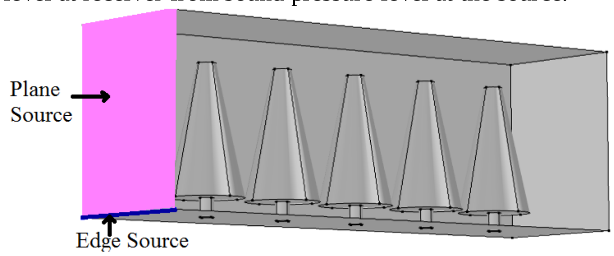

Fig. 2 Thuja sonic crystal with plane and bottom edge sound source

A. Model with Power Edge Source

In this work, five thuja trees are arranged at some periodic distance. Left face assumed as road side. So, bottom edge represents road noise and acts like edge sound source.

Fig. 2 shows a thuja sonic crystal with line source in which sound source presents at the bottom edge of cuboid shown in blue color.

The power edge source equation is defined by equation (1):

$$\nabla.\frac{1}{\rho_c}(\nabla p_t \quad q) \quad \frac{k_{eq}^{2} p_t}{\rho_c} = \frac{2}{L_{edge}}\sqrt{2\pi\frac{L_{edge}P_{ref}c_c}{\rho_c}}\,dl \qquad (1)$$

Where, p_t is the total acoustic pressure, c_c is speed of sound, ρ_c is density of air, K_{eq} is the wave number, P_{ref} is the reference power per unit length and L_{edge} is the length of edge.

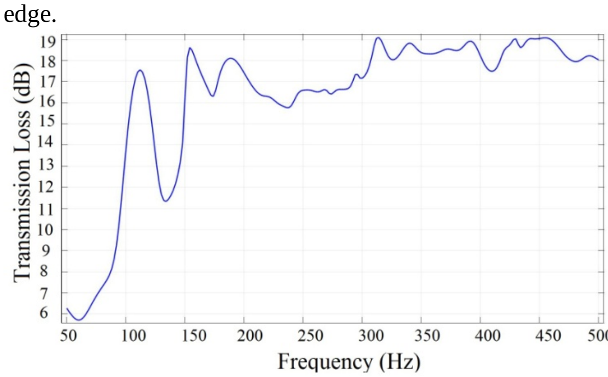

Fig. 3 Sound attenuation through the structure with edge source

Power of incoming wave is defined as $w\_in = P_{ref}\,x\,L_{edge}$

Power of outgoing wave is defined *as w_out= (absolute pressure)*^{2}*/(2 x* ρ_c *x* c_c*)*

Transmission loss is given by: $t = 10\ x\ log10\ (\frac{W_{in}}{W_{out}})$

Sound hard boundary conditions are applied on the all thuja giants. Radiation boundary conditions are applied at inlet, outlet and top face to avoid reflection on ground. Sound attenuation is measured in terms of dB. When Power reference of 10W/m is applied on the bottom edge of inlet of the model, a maximum sound attenuation of 19 dB is obtained in the structure between 50 Hz to 700 Hz as shown in fig. 3.

According to Bragg's criteria, first peak of transmission loss comes at the first Bragg's frequency. First Bragg's frequency is calculated by (c_c/(2 x a)). In this case, first Bragg's frequency will be 112.5 Hz. In fig. 2, we can see that centre of first band gap is found at frequency 112Hz.

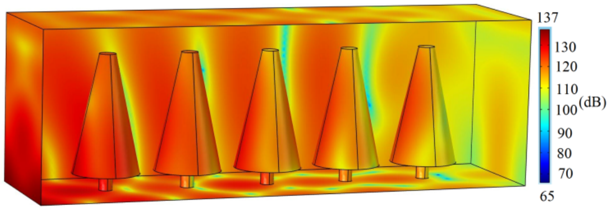

Fig. 4 Pressure plot in the 3-D model at frequency 148Hz

Sound pressure Variations in 3-D sonic crystal at frequency 148 Hz and 450 Hz are shown in fig. 4 and fig. 5 respectively. At 148 Hz, sound level of outgoing wave is 12 dB less than the incoming waves. Color bar in fig. 4 presents value of sound pressure levels by means of colors. Variation in colors from dark red to dark blue on color bar shows decrease in sound pressure level (SPL). Sound attenuation is the difference between sound pressure level at inlet and sound pressure level at output. So, we can easily estimate the sound attenuation in the structure by seeing the pressure plot with color bar. At right face in fig. 4, change in color from red to yellow shows the significant sound attenuation in the model.

At 450 Hz, transmission loss is 19 dB. Fig. 5 shows a larger variation in colors from left edge (red) to right face (light green) of thuja sonic crystal which means that sound pressure level is reduced by higher amounts at this frequency.

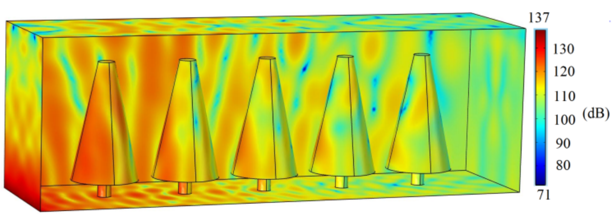

Fig. 5 Pressure plot in the 3-D model at frequency 450Hz

B. *Model With Incoming Plane Wave*

Fig. 2 shows a thuja sonic crystal with plane sound source. The plane wave equation is defined by equation (2):

$$\frac{\partial^2 p}{\partial x^2} - \frac{1}{c_c^2}\frac{\partial^2 p}{\partial t^2} = 0 \qquad (2)$$

Where, p is the acoustic pressure and c_c is speed of sound.

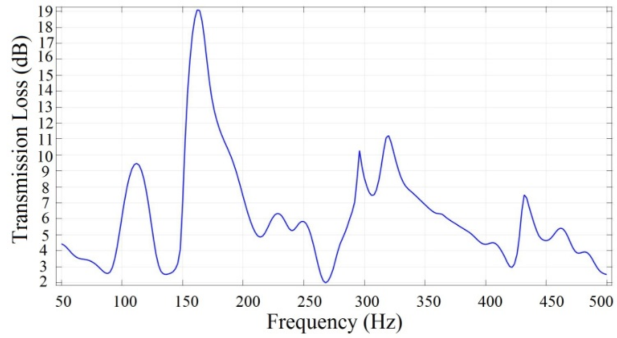

Fig. 6 Sound attenuation through the structure with plane source

Power of incoming wave is defined as *w_in*

= (incident pressure)^2/(2 x ρ_c x c_c)

Where, ρ_c is the density of air.

And remaining calculations are similar as first model.

Sound hard boundary conditions are applied on the thuja green giants. Pane wave radiation boundary conditions are applied on both side at inlet and outlet with top face to avoid ground reflection.

Fig. 6 shows the transmission loss through thuja trees with a planar sound source over a frequency from 50 Hz to 500 Hz. When a pressure field of 1 Pa is incident on left face of thuja trees, noise is attenuated up to 19 dB through structure shown in fig. 6.

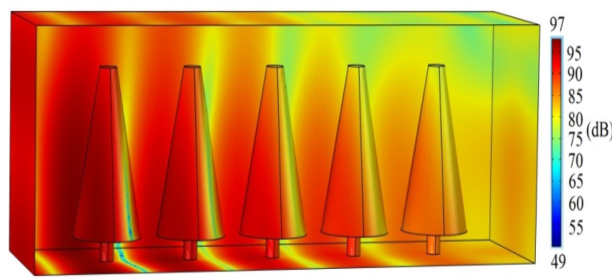

Fig. 7 Pressure plot in the 3-D model at frequency 112Hz

Fig. 7 and fig. 8 shows the pressure variation through thuja trees at frequency 112 Hz and 164 Hz respectively. Sound attenuation at 112 Hz is 9 dB and sound attenuation at 164 Hz is 19 dB.

At 164 Hz, there is red and saffron color (~88 dB) on left face and light blue and light green (~68dB) on the right face of model shown in fig. 8. It deduces that there is high amount of noise reduction at frequency this frequency.

This model also satisfied the Bragg's prediction of band gap. First peak of sound attenuation appears at first Bragg's frequency of 112 Hz.

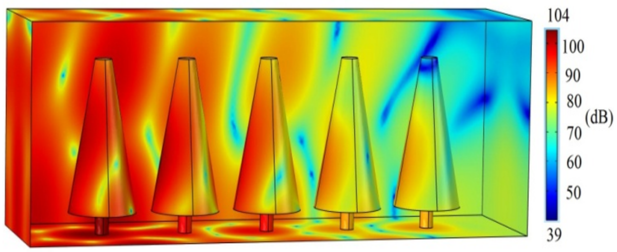

Fig. 8 Pressure plot in the 3-D model at frequency 164Hz

C. Comparison Between Two Model

Result shown in Fig. 9 represents the transmission loss in three dimensional thuja sonic crystal with edge sound source versus plane sound source.

Maximum sound attenuation in both models is same but band gaps are different in some frequency range. First band gap appears between 90 Hz to 134 Hz in both models and both model matches with Bragg's prediction of band gaps. In case of line source, attenuation is increasing with increase in frequency but in case of plane sound source, sound attenuation is decreases after 164 Hz and some more band gaps appear with lower sound attenuation.

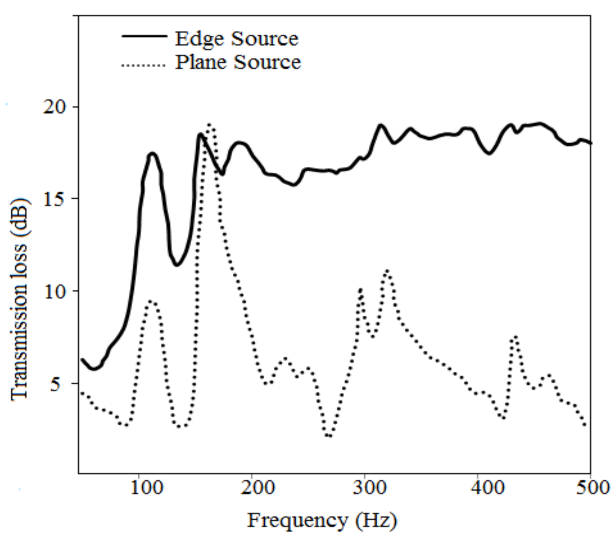

Fig. 9 Sound attenuation in thuja tree with edge and plane sound source

IV. CONCLUSION

This paper involves the calculation of sound transmission level for two 3-D model made by arranging thuja green giants at some regular distances.

This work shows that tress do not only reduce air pollution but also helps to reduce noise pollution. Present work will be helpful to reduce the traffic noise by planting trees with dense foliage at road sides. A comparison is done between two models of thuja giants with different sound source and found that maximum sound attenuation in both models is 19 dB but band gaps in case of a planar sound source are wider than model with bottom edge sound source. Edge sound source represents sound pressure level at road by means of transportation noise. Thuja green giants also satisfy the Bragg's prediction as position of first peak is found at 112.5 Hz in both models.

Results show that sound attenuation will increase with increase in frequency in case of edge source but this is not happen in model with plane source. A finite element modeling is done to compute the results for both models over a small frequency using COMSOL multiphysics. This design can be suited for transport noise pollution muffling. We can extend this work in future by arranging some different trees in periodic pattern in more than one row.

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Preeti Gulia, Ph.D scholar, received B.Tech from DCRUST, Murthal and M.Tech from NIT Kurukshetra. She is presently pursuing Ph.D in School of Engineering from Indian Institute of Technology, Mandi (India).

Dr. Arpan Gupta, Assistant Professor in School of Engineering, Indian Institute of Technology, Mandi. He is actively involved in research and teaching in the area of Acoustics, Vibration, Robotics, Sonic crystals and Metamaterial.