PHONONIC VIBES

THE ART OF NOISE MANAGEMENT

UNIVERSIDADE D COIMBRA

METAVISION

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Numerical Modeling of Phononic Crystal-based Ventilated Noise Barrier for Traffic Noise Attenuation

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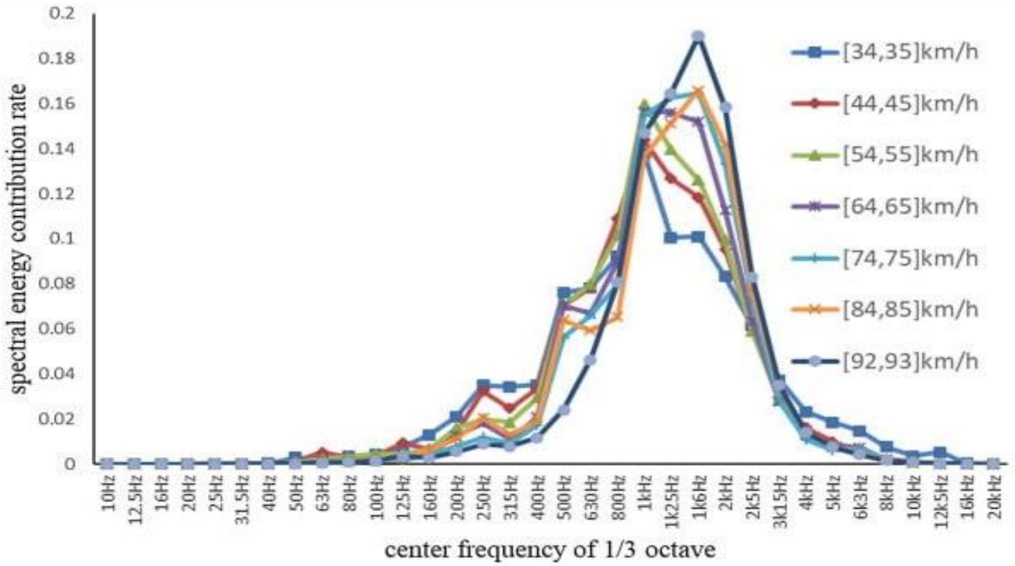
Noise Pollution and Current Mitigation Strategies

- Heavy traffic, constant noise, discomfort
- Stress, hearing impairment, ecosystem imbalance,
- Barriers placed to reduce noise propagation
- Tall structures, absorb, reflect, and deflect sound
- Concrete, glass, steel, materials used

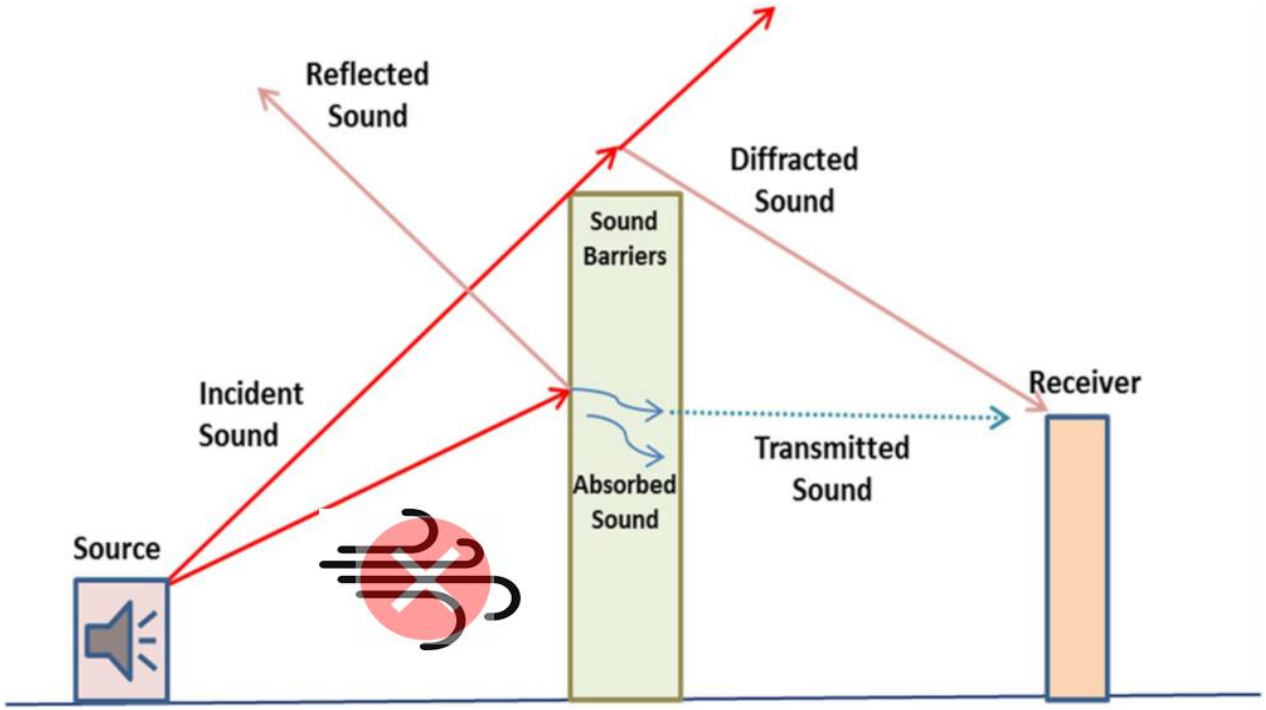
Sound block Barrier [1]



Road traffic Noise Spectrum [2]

Problem Statement

- Limit noise barrier height to 2-3m due to high wind load
- High wind load leads to high rotational loads
- Blocks airflow and affect ventilation
- Prevents wind deflection, creating a high-pressure zone
- Bulky design adds to structural constraints and high visual impact on the landscape
- More material utilized due to high effective area



Schematics showing how these barriers have constraints [3]

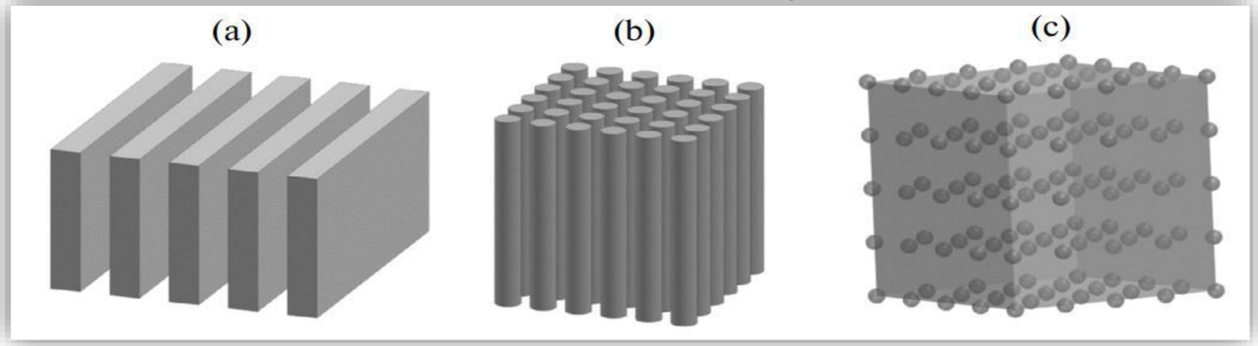
Possible Innovative Solution: Metamaterial Ventilated Barriers

- Utilize periodic structures to manipulate sound waves
- Structure consists of regularly spaced unit cells
- Designed to control sound transmission or achieve sound insulation
- Manipulates wave behavior through scattering, interference, resonance, and absorption
- Effective for achieving specific frequency ranges of sound insulation
- Less material utilized and sustainable

Acoustic Metamaterials for sound Insulation/Sound Transmission Loss (STL)

Periodic Structures

Other types



(a) 1-D sonic crystal consisting of periodically arranged plates; (b) 2D sonic crystal with cylinders arranged in a square array; (c) 3D sonic crystal consisting of a periodic arrangement of spheres in a cubic arrangement [4].

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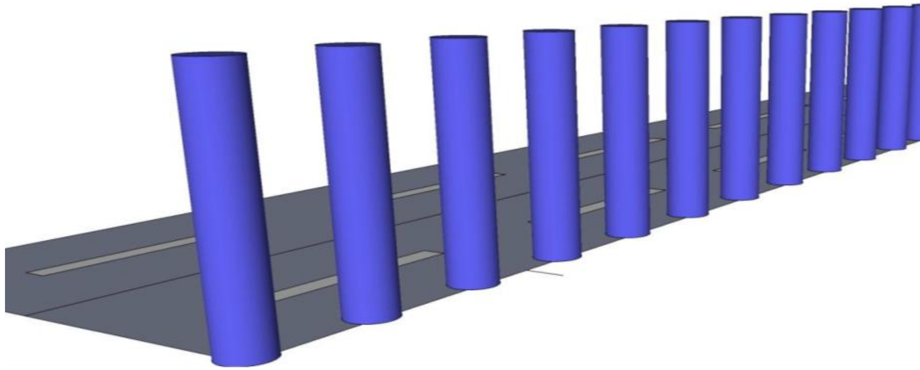
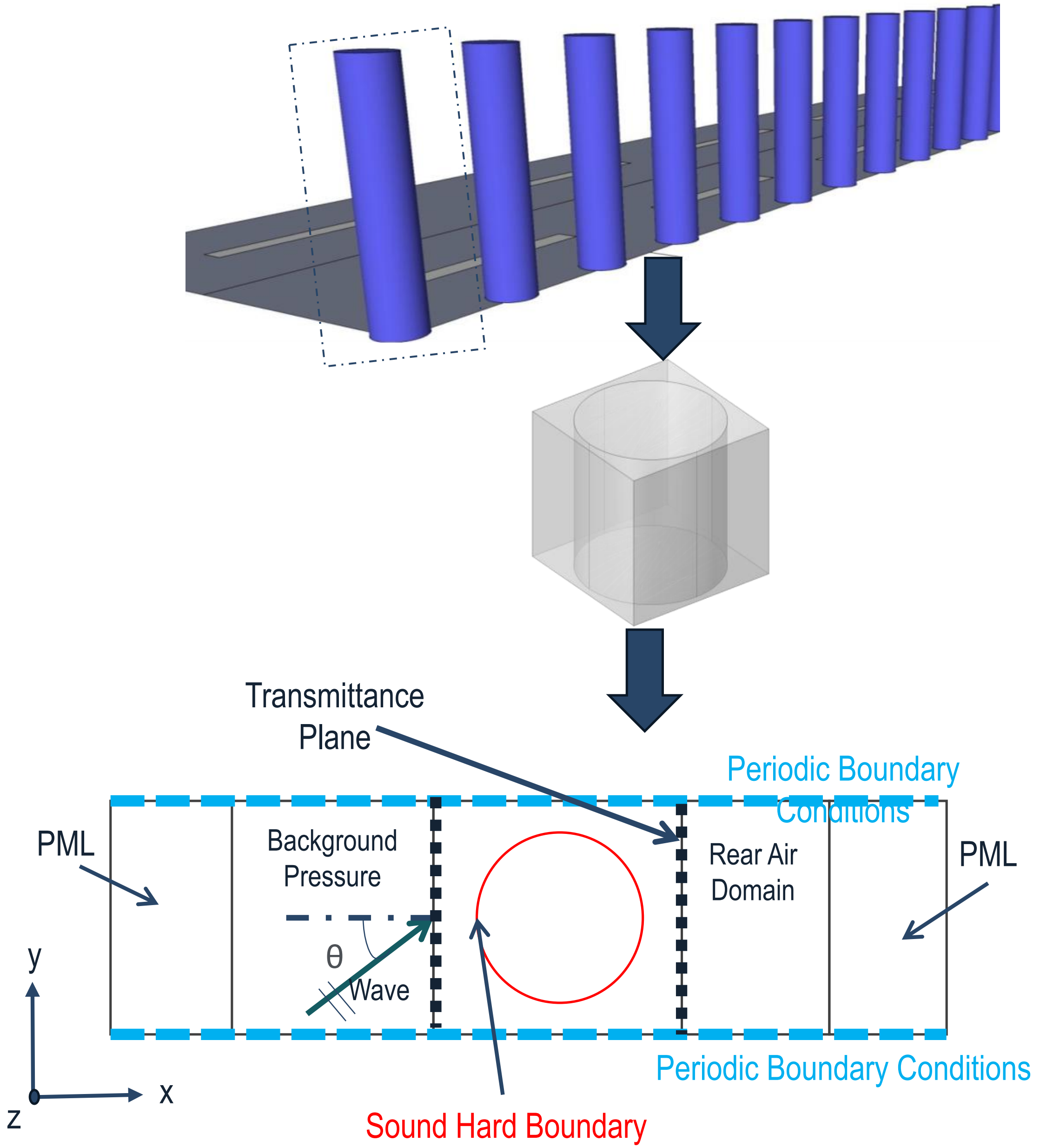
Objectives of the current study

- Target traffic noise with a ventilated metamaterial barrier
- Propose design guidelines for metamaterial ventilated barrier
- Investigate the Sound Transmission Loss (STL) for idealized and in-situ conditions
- Compare Unit Cell (UC) infinite modeling to finite size modeling
- Investigate the effect of geometrical parameters, incident angles, and the number of UCs
- Provide a baseline for future studies in numerical modeling and design of Metamaterial Ventilated Barriers



Methodology

- Multiple noise barriers placed vertically with spacing for airflow
- Stopband frequency determined by barrier parameters
- Proposed unit cell design and numerical model
- Utilizes Pressure Acoustics in the frequency domain
- Narrow region acoustics modeled for accuracy
- Considerations include barrier diameter, gap, and height
- Modeled as plane wave incidence and diffuse field conditions



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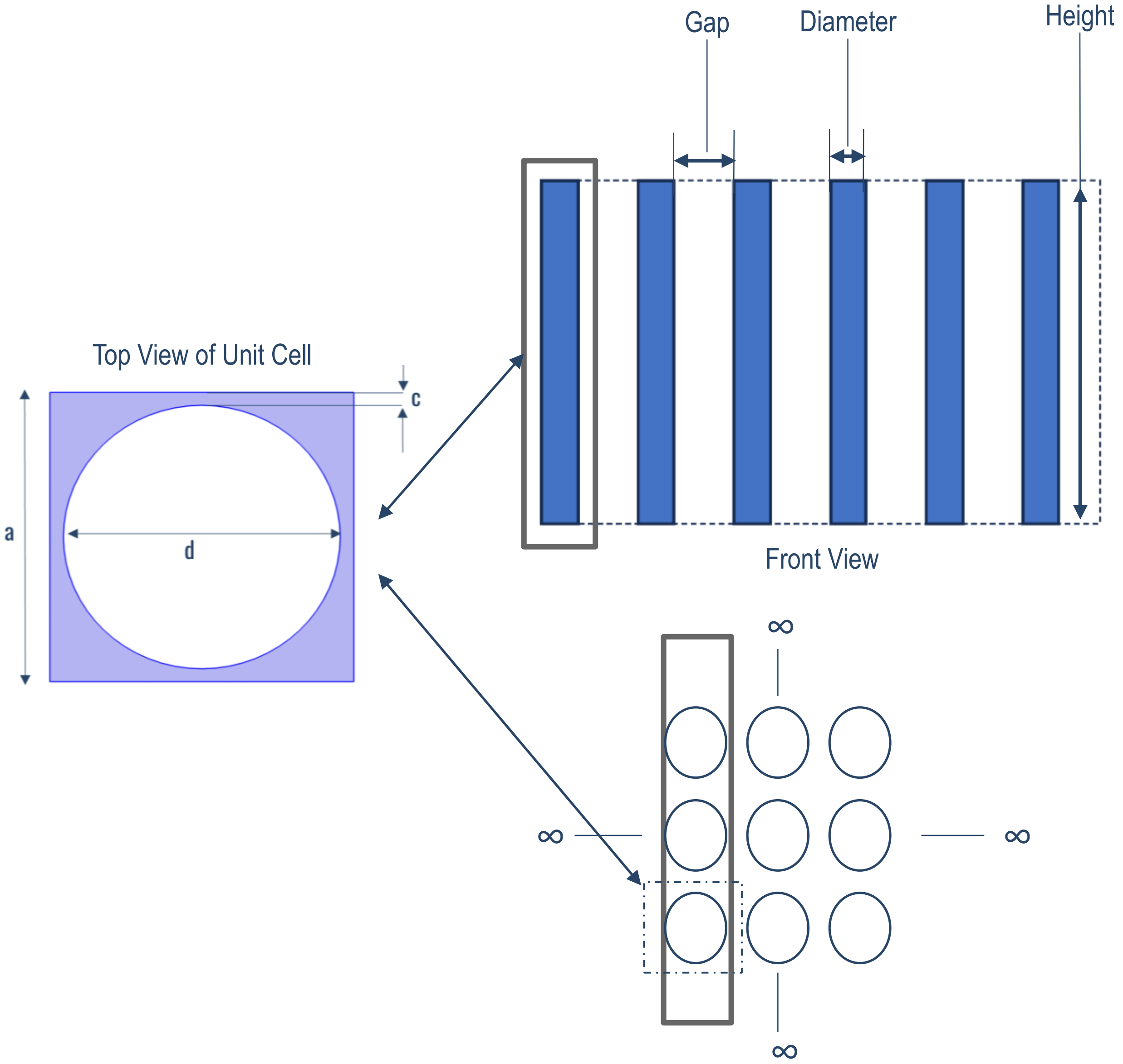
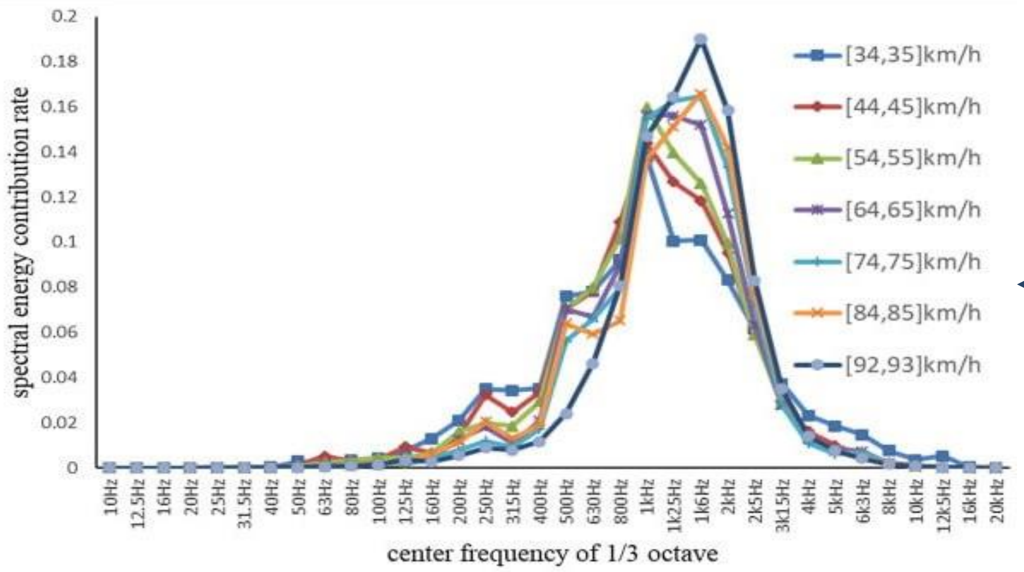
Proposed UC Model and Analyses

- Unit Cell design proposed for barrier representation
- Model integrates pressure acoustics and narrow region acoustics
- Considered thermo-viscous losses
- Model sound wave-barrier interaction, considering geometry and periodicity
- Analysis conducted to assess unit cell performance and validate model:
    - Stopband Analysis of Unit Cell
    - Parametric Analysis for spacing order of Unit Cells
    - Parametric analysis for geometric variations
    - Infinite Unit Cell Modeling (Idealised Conditions)
    - Finite Unit Cell Modeling (in-situ Conditions)

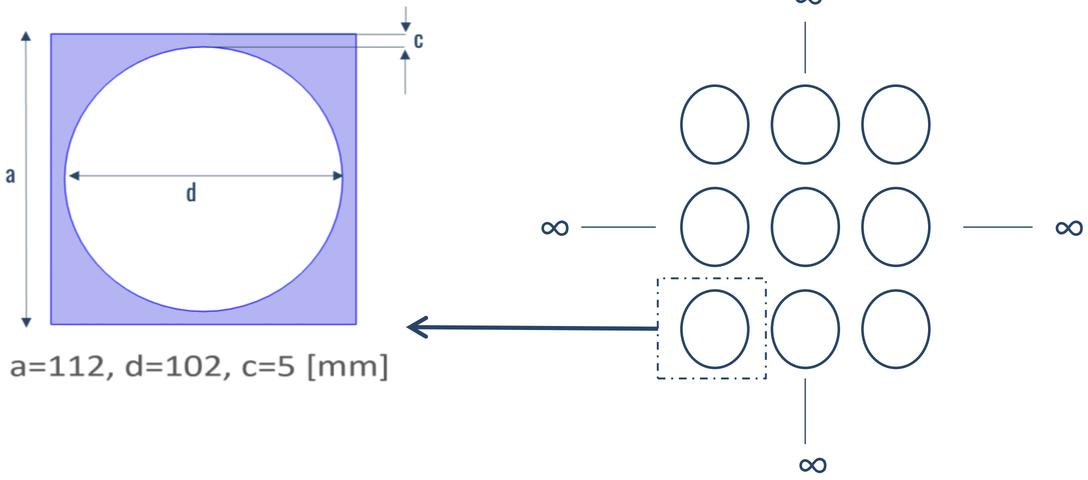


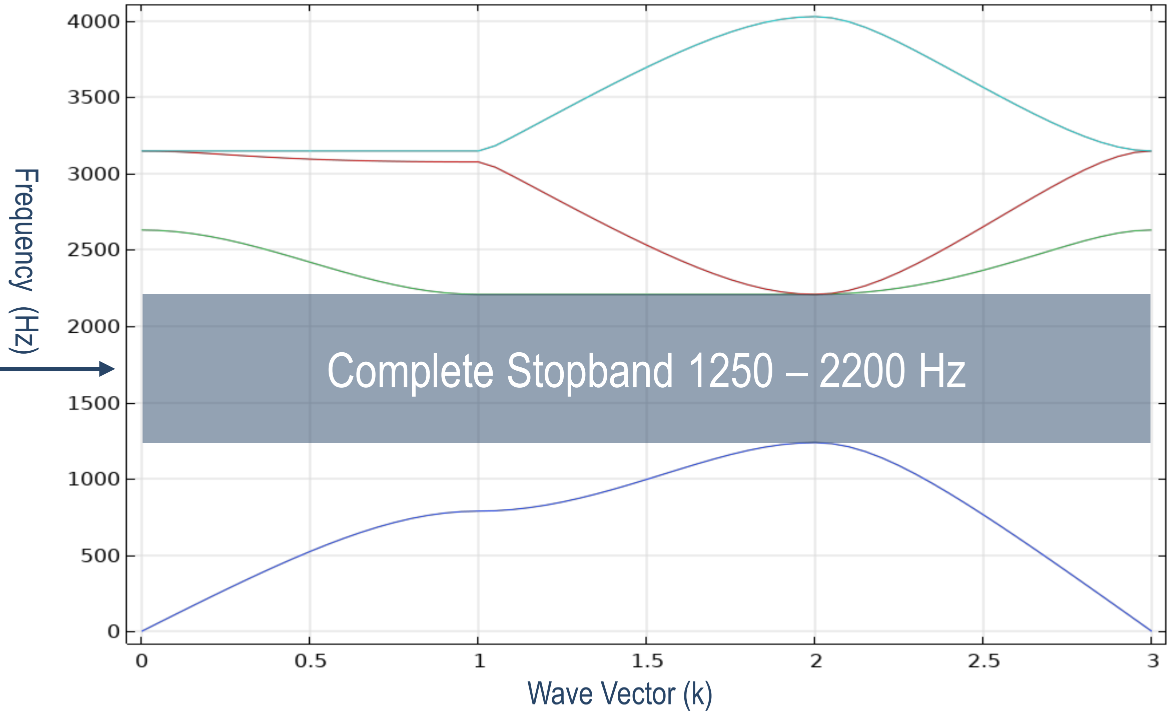
Stopband Analysis of Unit Cell

- The stopband frequency range of 1250-2200 Hz
- Corresponds closely to the frequencies of the traffic noise spectrum
- By targeting this frequency range, the barrier can efficiently attenuate the most noise sources.



Road traffic Noise Spectrum [2]





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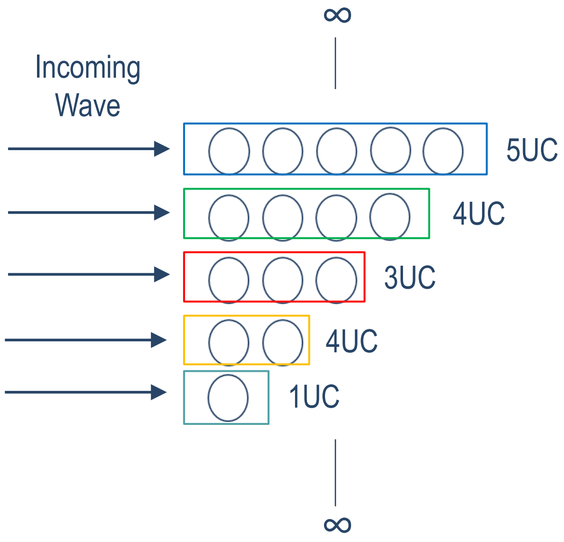
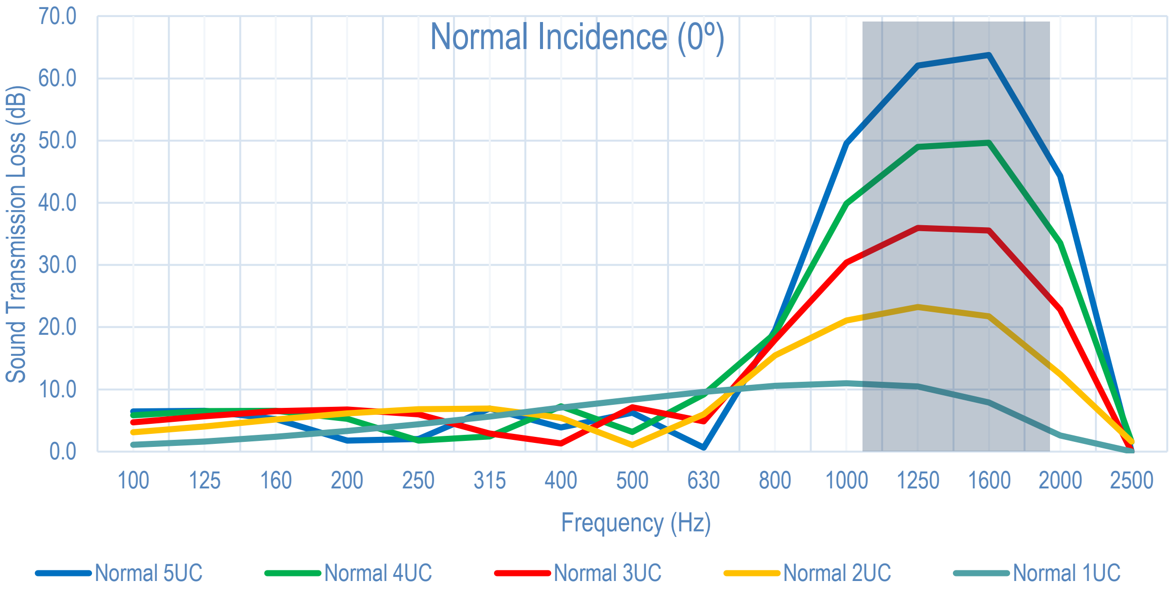
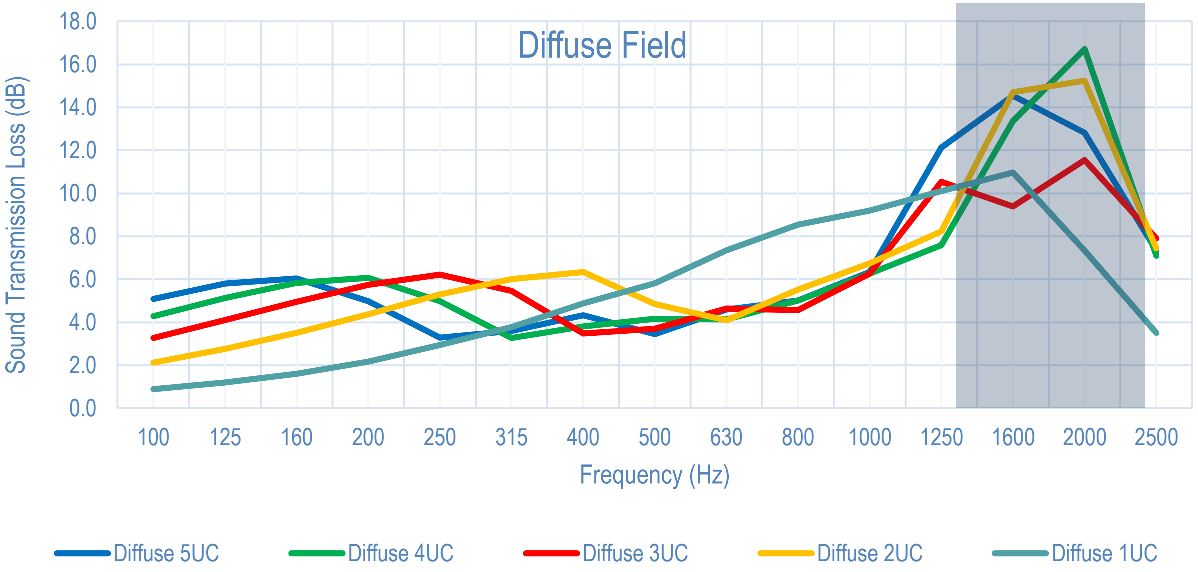
Sensitivity Analysis: Number of Unit Cells



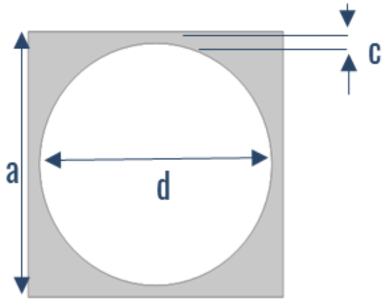
Different
Scales

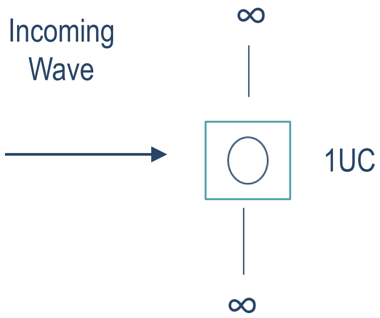




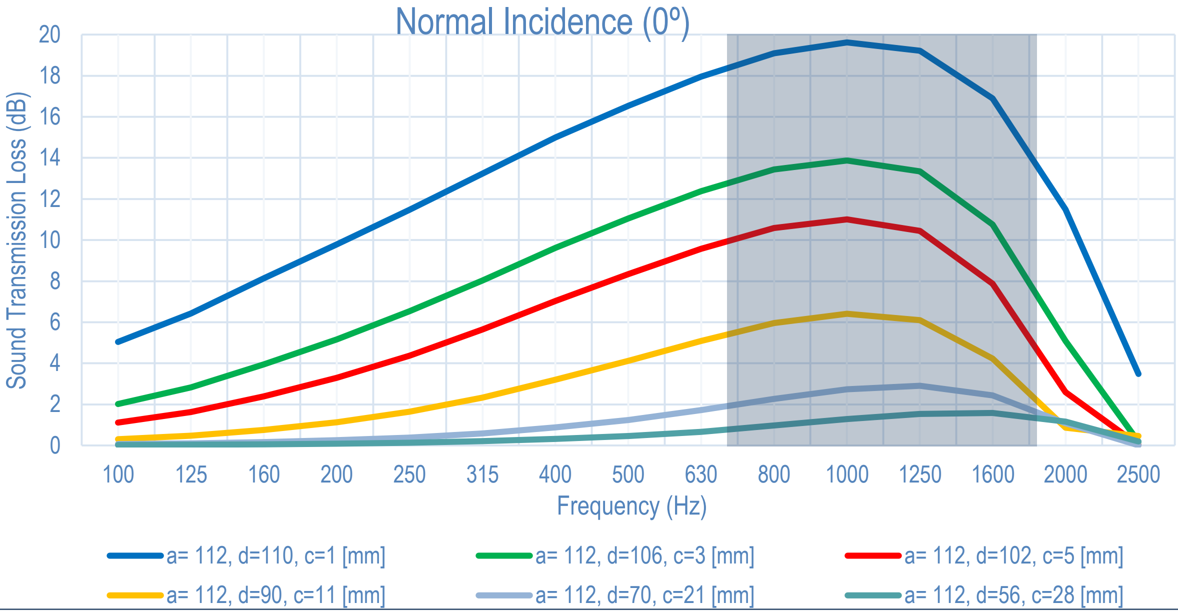
- Barriers extend infinitely vertically and perpendicular to wave propagation
- Evaluated the effect of varying unit cell numbers along wave direction
- Reduction of unit cells impact sound attenuation due to less scattering.
- Spacing order coincidence with wavelength affects frequency shift and creates conditions for constructive interference (Braggs Effect).

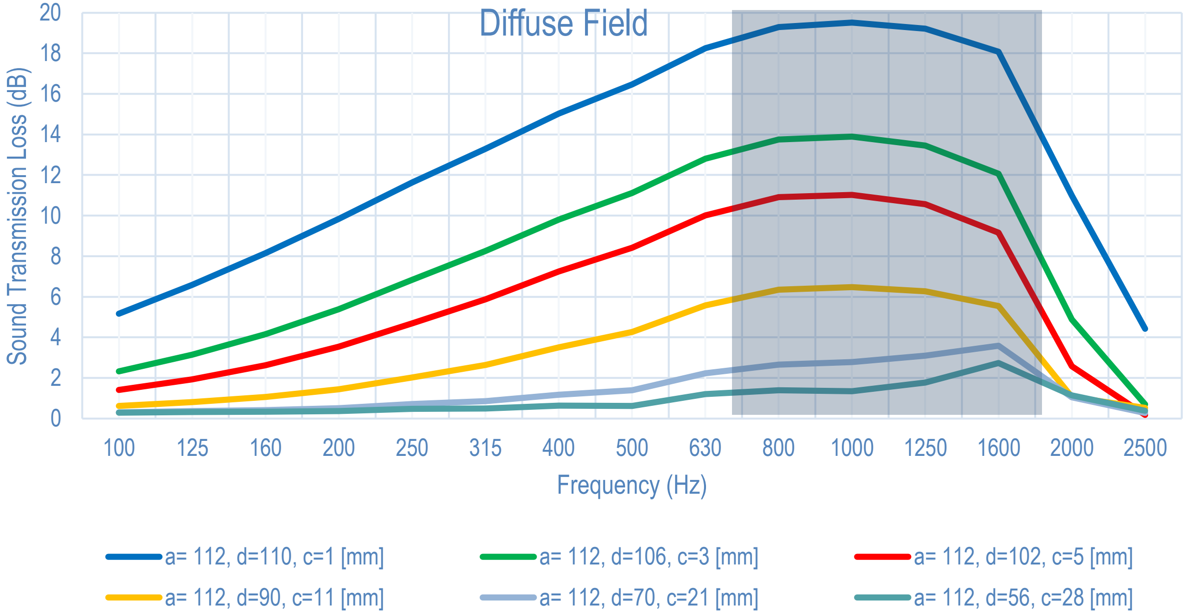
Geometric Analysis of Unit Cell





- Parametric analysis varies gap (c) and barrier diameter (d) for STL influence.
- Increasing unit cell diameter enhances STL but reduces ventilation.
- Wider gaps compromise noise mitigation but improve ventilation.
- Sensitivity analysis explores barrier diameter and gap effects on stopband.
- This relationship validates the barrier's ability to block specific frequencies.
- Despite STL values, getting a peak within the same stopband frequency range.
- Identify design configurations that maximize noise reduction effectiveness.
- Unit Cell Symmetry and Homogeneity





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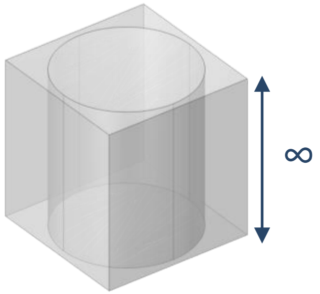
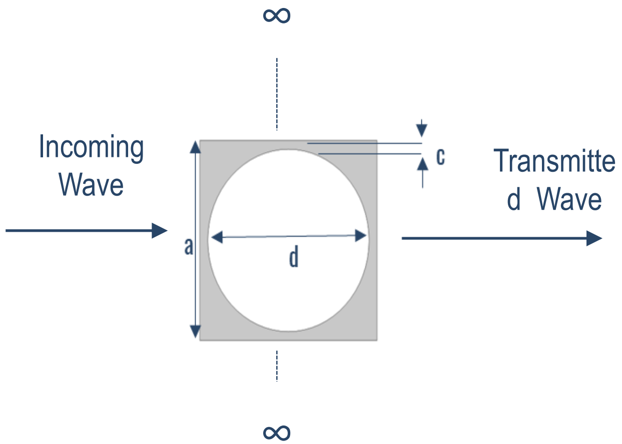
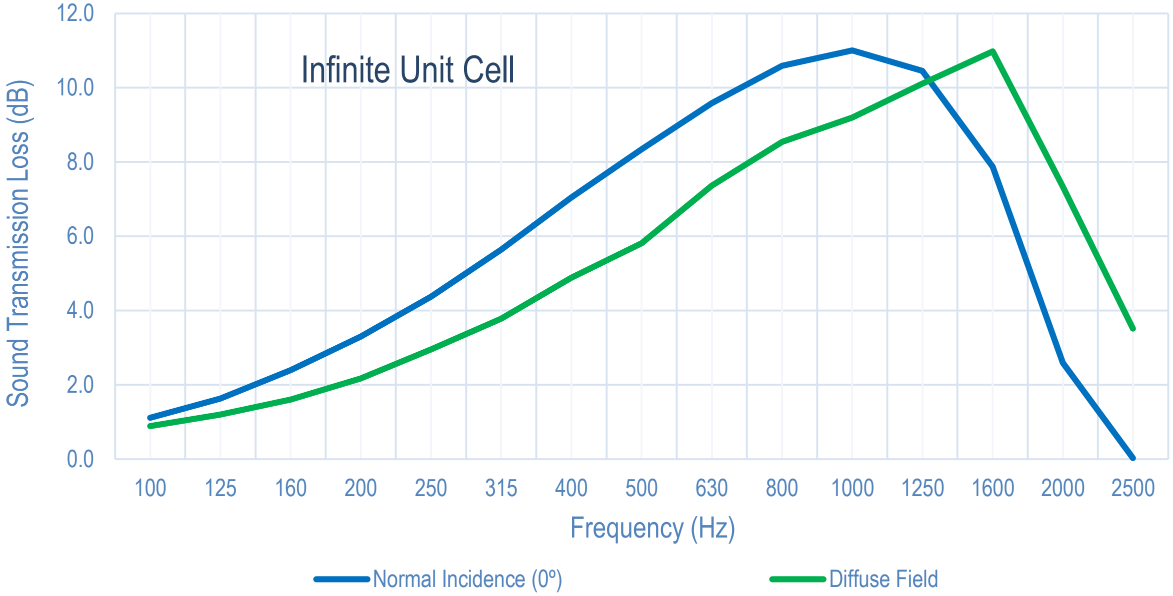
Semi-Infinite and Finite Unit Cell Modeling

Infinite Unit Cell

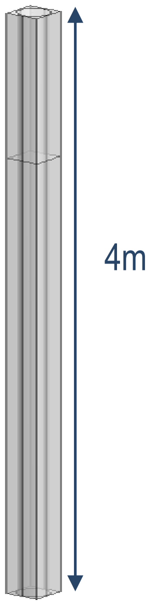


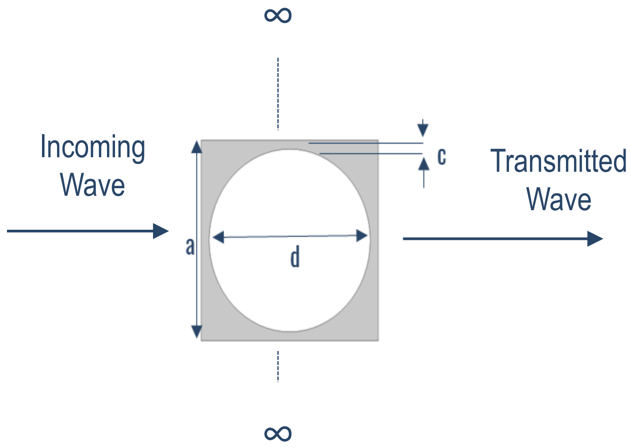


a=112, d=102, c=5 [mm]

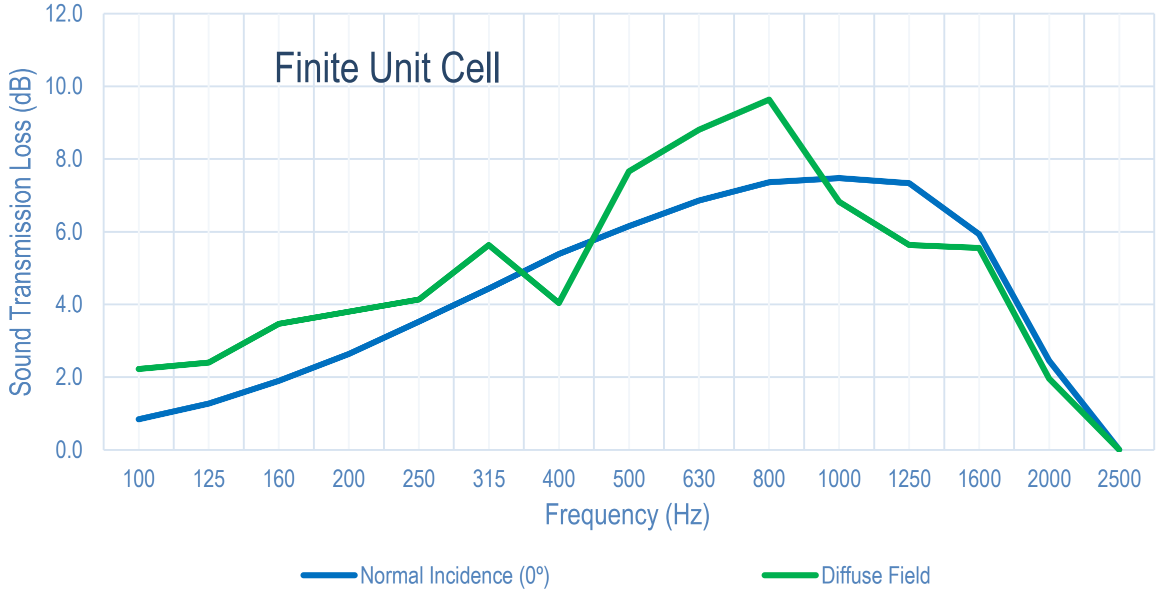


Finite height Unit Cel





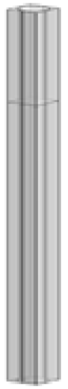
a=112, d=102, c=5 [mm]

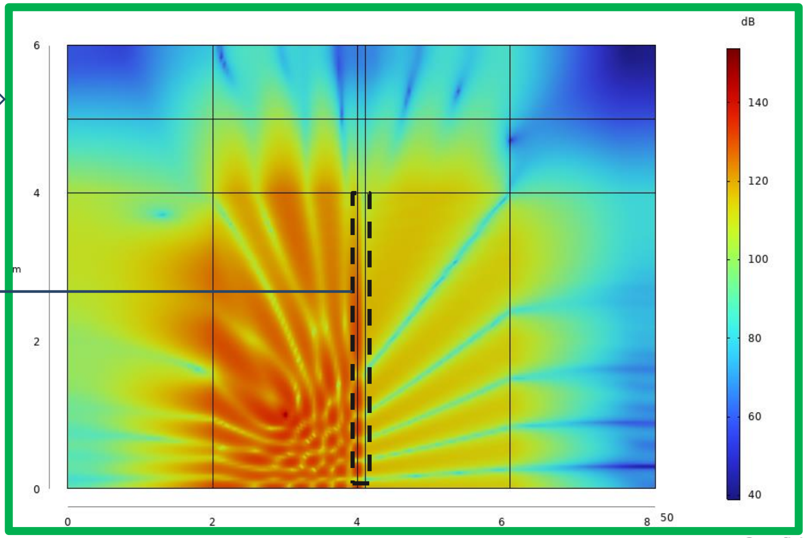


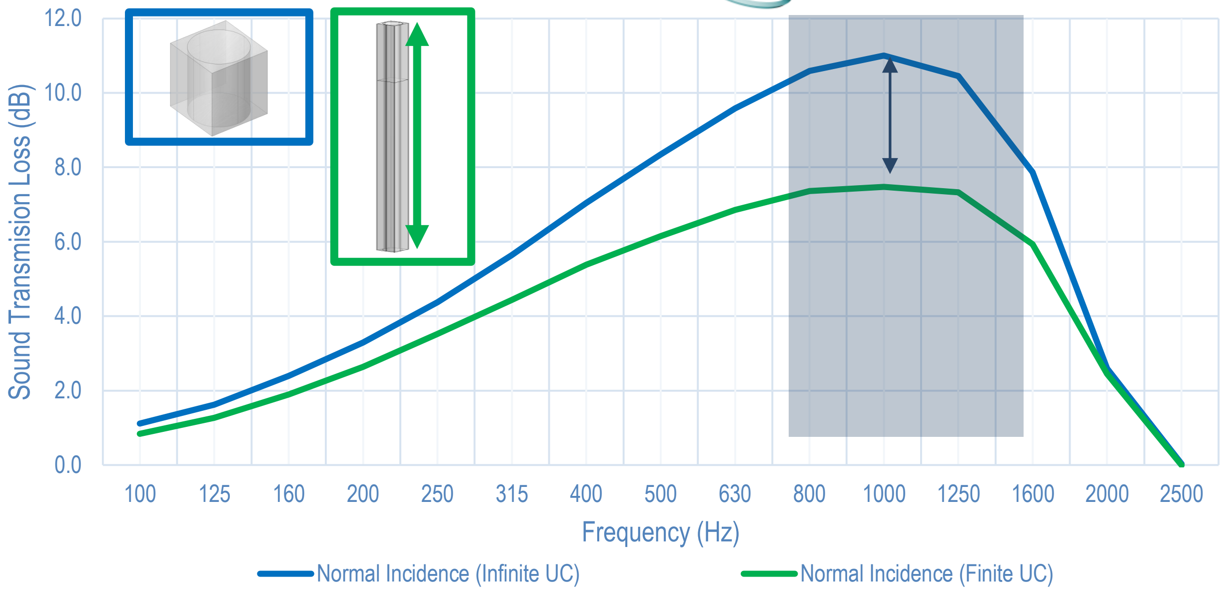
Results Comparison

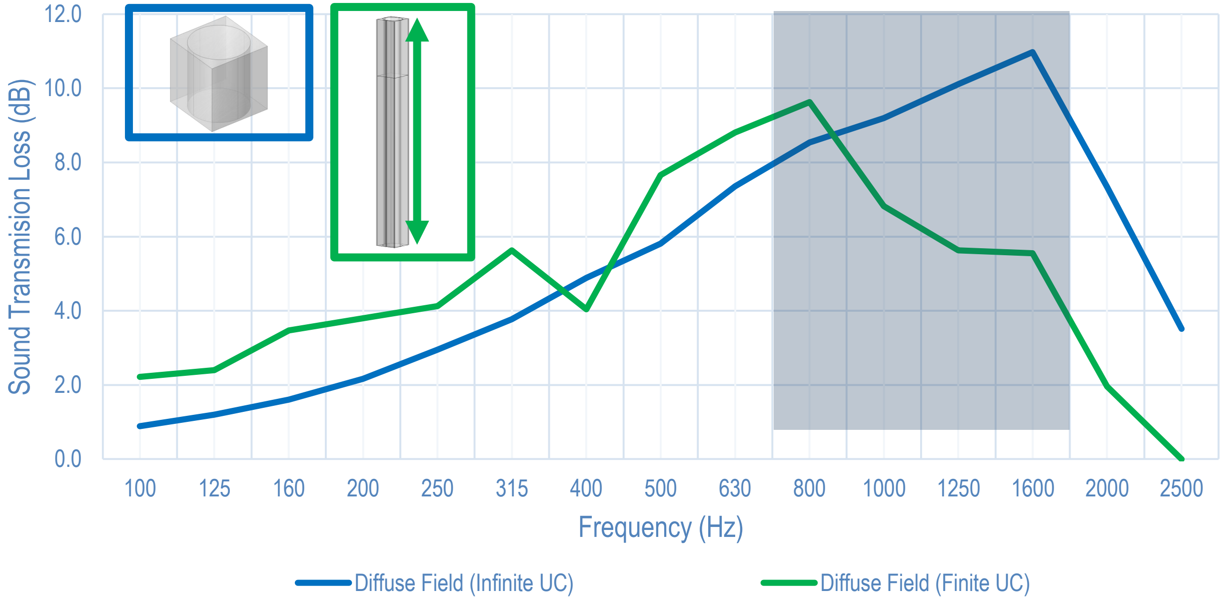
- In plane-wave behavior, finite barrier height influences acoustic behavior, and STL decreases.
- Idealized conditions provide maximum potential for noise attenuation.
- In the diffuse field, infinite UC got STL Peak at 1600 Hz and finite Unit Cell at 800 Hz.
- Wave Bypassing and Diffraction around finite height barrier cause STL reduction.
- These results give theoretical and practical insights into noise barrier effectiveness evaluation.

Sound Pressure Level at 1000 Hz









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Summary and Next Steps

- In this work, our research attention was focused on:
    - Preliminary design baseline of a Ventilated Barrier
    - Mitigating mid-range frequency traffic noises in 1000–2500 Hz
    - Providing numerical guidelines to assess sound insulation of noise barriers
- Model shows the behavior of unit cells under different boundary conditions
- STL computed for both idealized conditions and in-situ and results validating the model.
- Will investigate adjustments to the unit cell design to target broader or more specific frequency ranges.
- Will analyze airflow and ventilation effectiveness to strike the best balance between noise reduction and air circulation.
- Will extend to model sandwiched barriers, Helmholtz structures, Helmholtz resonators, or square and rectangular shape barriers.

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Thank you.

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