Numerical Investigation into Rail-Side Noise Barriers

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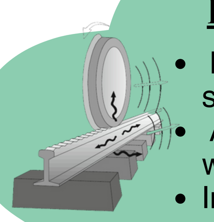
Why it Matters?

- Urban noise pollution is a major environmental issue, causing health problems such as chronic stress and cardiovascular diseases
- Recognised by the World Health Organisation as the second largest environmental threat to public health, after air pollution.
- A major contribution to urban noise pollution is train lines, significantly impacting nearby residential areas.
- Little scope for further noise reduction on the train line themselves as these measures can hinder operations.
- So our research is focused on optimising the materials and compositions for soundproofing walls around train lines.

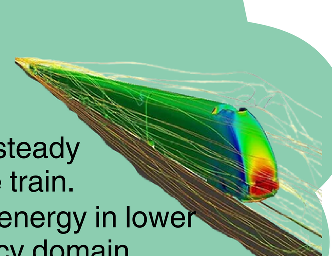
Sources of Sound

Rolling Noise

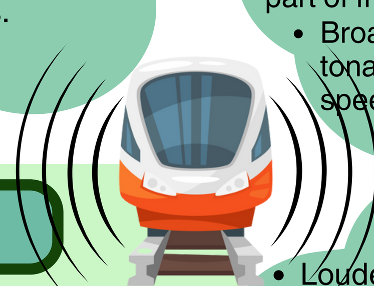


- Dominant source of sound for lower speeds.
- Arises from vibrations of wheels and rails.
- Increases with roughness of surfaces.
- 100 Hz < f < 2kHz
- Broad Band of frequencies.

Aerodynamical Noise



- Dominant source of sound for high speed rail.
  - Arises from unsteady airflow over the train.
  - Most of sound energy in lower part of frequency domain.
    - Broad band of frequencies or tonal noise depending on speed and shape of body.

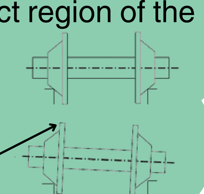


Source Term

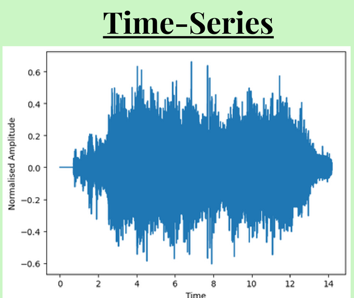
Given the variability involved in simulating train sounds, the source term used in the model is taken from a recording of a train passage. The audio file is converted to a time series of the pressure, normalised to values between -1 and 1. A Fast Fourrier Transform (FFT) is applied to extract the frequency content of the signal. The data is then cleaned by identifying the sources of sound (Rolling, Aerodynamical and Curve Squeal) and removing extra noise from the frequency domain. The inverse FFT is then applied to produce the cleaned signal.

Curve Squeal

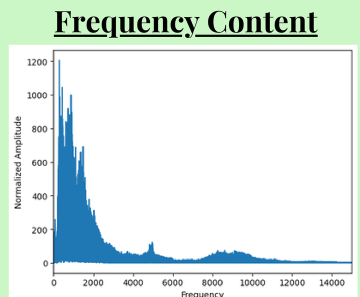
- Loudest, most disturbing noise
- Arises in sharp curves from stick-slip behaviour in the contact region of the wheel and the flange.
  - Strongly tonal



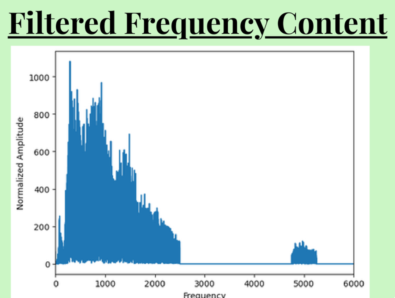
Time-Series



Frequency Content



Filtered Frequency Content



Modelling Sound Propagation

Material Properties

Density, Rho	Alpha	Speed of sound, c
• A combination of strut density and fluid density. • Low for foams	• Absorption Coefficient • Calculated in accordance with the Delany-Bazley Model.	• The speed of sound inside a medium.

Finite Differences

- Uses central differences to approximate the spatial derivates of pressure and velocity. For the equations of motion of the wave equation. Derived from the Navier-Stokes Equation.

$$\frac{\partial p}{\partial t} = -\rho c^2 \frac{\partial v}{\partial x}$$

$$\frac{\partial v}{\partial t} = -\frac{1}{\rho}\frac{\partial p}{\partial x} - \alpha v$$

Explicit Euler Method

$$p_i^{n+1} = p_i^n + \Delta t \left(-\rho_i c_i^2 \frac{\partial v}{\partial x}_i^n \right)$$

$$v_i^{n+1} = v_i^n + \Delta t \left(-\frac{1}{\rho_i} \frac{\partial p}{\partial x}_i^n - \alpha_i v_i^n \right)$$

- Steps forward in time (n) to predict the next solution (i), velocity and pressure, based on the previous solution.
- First order accurate
- Conditionally stable under the CFL criterion

$$\Delta t \leq \frac{\Delta x}{c \cdot \mathrm{CFL}}$$

Gateway to results

Animations of Wave Propogation

Source Term

$$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2} + S(x = X_S, t)$$

- The train sound is modelled as a point-source at $x = X_S$
- At each time step,the value of $S(x = X_S, t)$ is added to the pressure field.
- The source term has no dependence on x, but the model can handle a source term with x dependence.

Damping

- To reduce reflections on the boundaries.
- So the reflective energy dissipates and does not interfere with the material.
- Enhances Numerical Stability

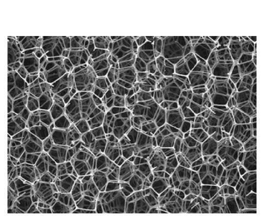
$$v_i^{new} = v_i \cdot (1 - \mu_i)$$

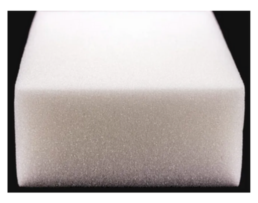
Boundary Conditions

$$p(0,t) = p(L,t) = 0$$
$$v(0,t) = v(L,t) = 0$$

- We applied Dirichlet Boundary conditions
- The value of pressure and velocity is set to 0.
- This means no movement or pressure change is assumed at the boundaries, effectively isolating the simulation domain from external influences.

Results

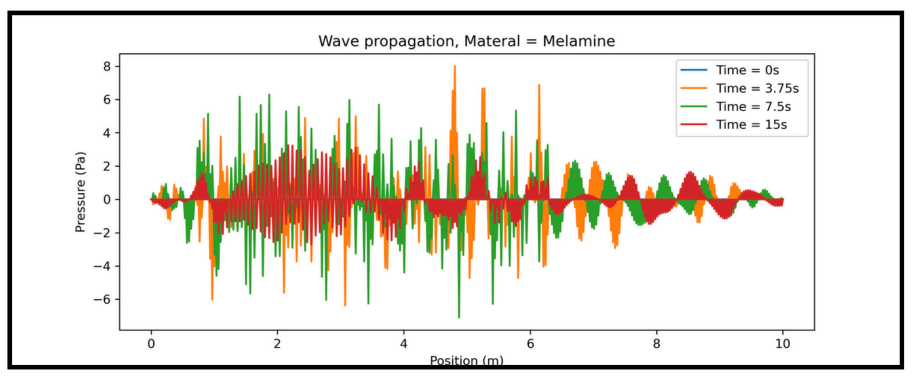


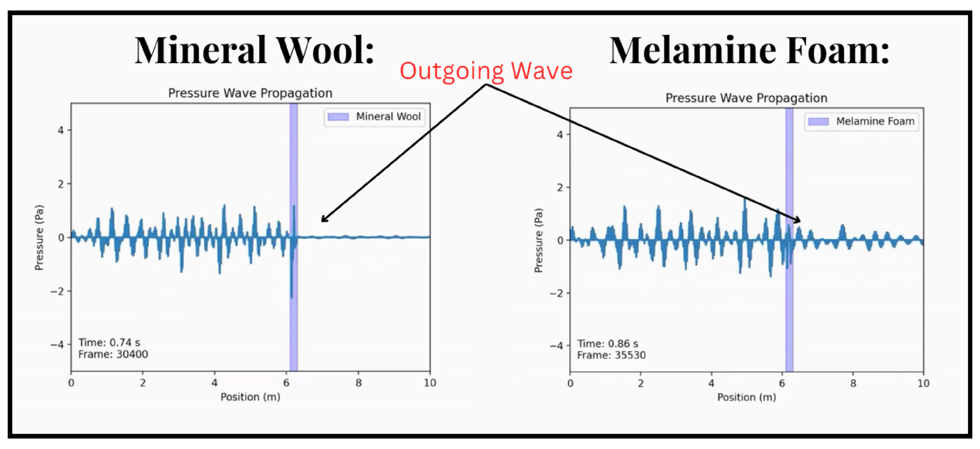


- We tested 5 materials. 3 Foams, 1 Rubber and 1 Wool.
- We calculated the Transmission Loss, measured in decibels, as the primary metric for noise reduction.
- Transmission loss is calculated in relation to the change in Intensity from the initial intensity to the final intensity at the point where the outgoing wave leaves the medium.
- Furthermore, as expected, we observed a positive relationship between the absorption coefficient, alpha, and the Transmission Loss.
- The worst performing material is Melamine, with a transmission loss of 34.9dB
- The best performing material is Mineral Wool, with a transmission loss of 46.5dB.
- So we propose the use of Mineral Wool.

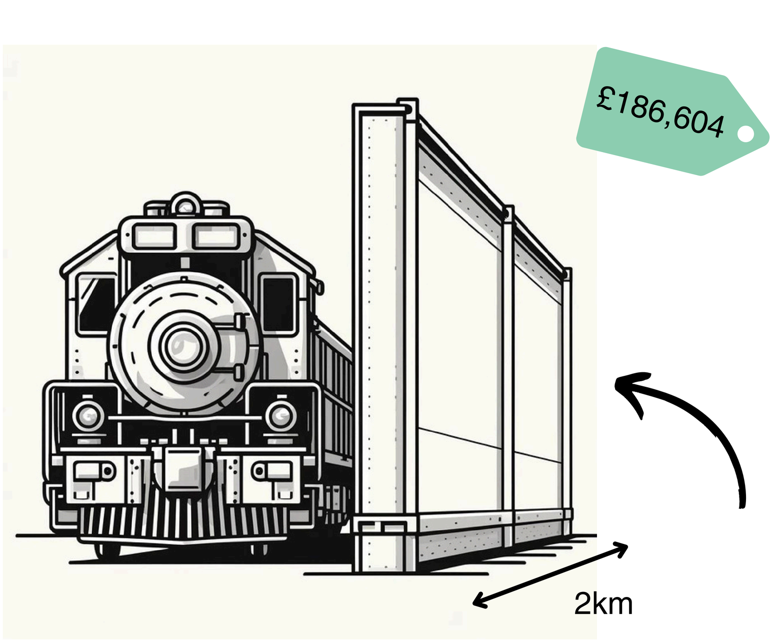
Materials Thickness: 20cm	Alpha	Change in Intensity	Transmission Loss (dB)
Polyurethane Open-cell Foam	0.92047	13.840	37.021
Melamine Foam	0.74317	13.838	34.858
Nitrile Rubber	0.96659	13.842	41.941
Polyimide	0.96659	13.842	41.531
Mineral Wool	0.97338	13.843	46.509

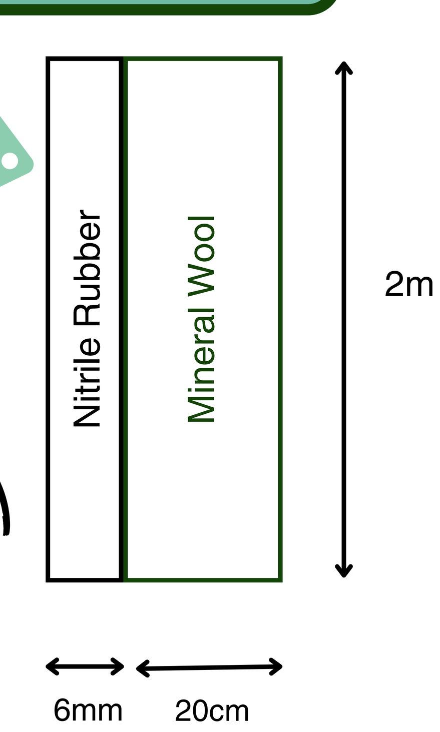
- Numerical dispersion is observed as the spread of the amplitudes





Proposal/Conclusion





Limitations:

- The model is created in one dimension so does not nessassarily reflect the reality.
- The dampaning on the boundaries reduces reflections but does not negate them.
- The wall materials proposed will not be structurally robust so will require further supports to be able to implement them as a barrier.

References

[1] https://www.who.int/europe/news-room/fact-sheets/item/noise

[2] https://www.eea.europa.eu/en/topics/in-depth/noise#:~:text=The%20impacts%20of%20railway%20noise,Noise%20pollution%20also%20affects%20wildlife.

[3] THOMPSON, David, Railway noise and vibration: mechanisms, modelling and means of control. Elsevier, 2008.

[4] REITER, Paul, WEHR, Reinhard, and ZIEGELWANGER, Harald. Simulation and measurement of noise barrier sound-reflection properties. Applied Acoustics, 2017, vol. 123,