Development of vertical incident sound insulation simulation technology using finite element method

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Self- introduction

First, I took my bachelor's degree in research about street width on old maps of the Edo period by using GIS.
After taking my master's degree in research about historical image analysis of cityscapes,
I worked as a software engineer, and after a period of devotion to raising children,
returned to work as a part-time employee at the Japan Patent Office.
From 2016, I start working on engineering application research of origami structures at Hagiwara Laboratory,
Meiji University (Application of pairing-origami to aluminum cans, Foldable transport boxes for fruits, etc.)

Contents

The calculation of the transmission loss of the sound insulation plate by FEM had to be corrected with the theoretical value, so far.
In this report, we examined a method to obtain the separated input / reflected sound pressures
from the speed condition given to the vibration plate and the sound pressure close to the sound insulation plate.
The validity is confirmed by evaluating the sound insulation characteristics of a flat plate with theoretical values.
Moreover, we consider using it for evaluation of more complicated shapes.

Introduction video about origami engineering

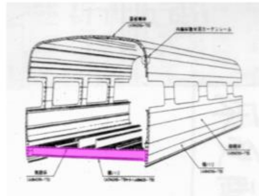
https://youtu.be/Ov3aFNS9VS4

Background

Honeycomb panels for various industrial products as highly rigid and lightweight structures

Building floors
Aircrafts
Trains, etc ...
☞ New origami honeycomb
(Truss score panel, etc.)

Truss score panel

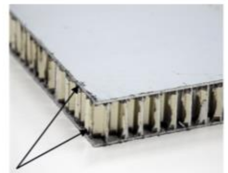


Honeycomb structures used for trains

Solar cell panel

Solar heliostat

Truss core panels are 8 times more rigid than equal weight flat plates.



Enlarged photo of honeycomb panel

Purpose of research

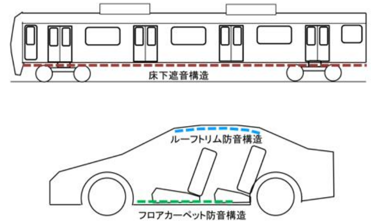
❶ By the invention of origami engineering method
・Possible to manufacture panels with cores with a high aspect ratio.
・New high-efficiency and precision acoustic analysis method
👉 Applying the truss score panel to train's floors as sound insulation walls

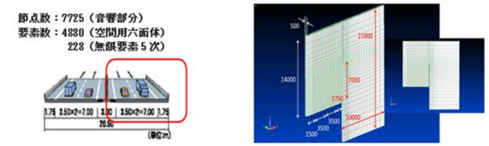
❷ Increasing demand for sound reduction in the manufacturing industry
👉 Attention to unprecedented acoustic metamaterials
Topological optimization analysis system is effective for development
Aiming to develop new metamaterials

❸ Highly efficient and highly accurate evaluation of acoustic characteristics
👉 Increase versatility by extending sound insulation characteristic analysis to sound absorption characteristic analysis

An example of origami honeycomb core (vertical core)
https://youtu.be/-9uw4ljj84o

Application of origami engineering to railway vehicles and automobiles





有限要素、無限要素による高速道路周辺計算モデル
防音シミュレーション

Various acoustic metamaterials

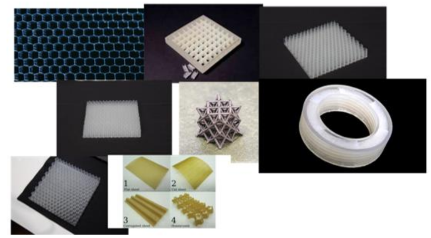
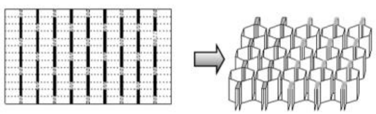
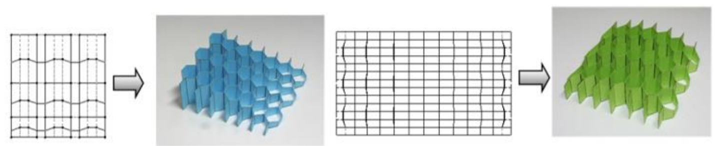


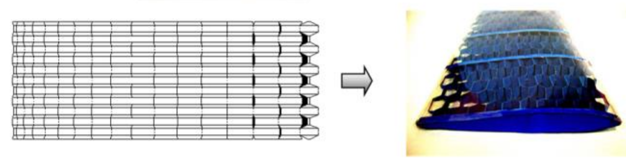
Image of topological optimization analysis

Reproduce the acoustic metamaterial with original method of origami honeycomb core



Honeycomb with changing cross-sectional shape can be folded from one flat plate.



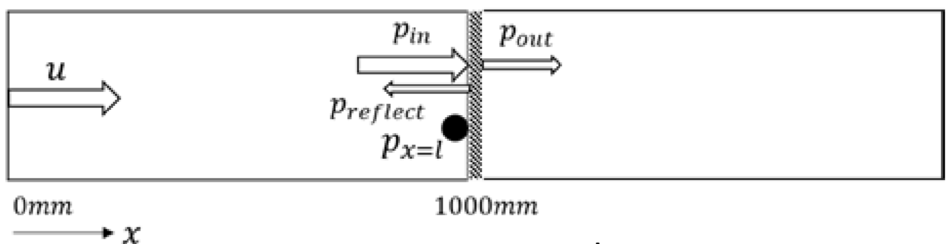


❶ Definition of transmission loss

$P_{in} \neq P_{x=l}$

$$TL = 10log_{10}\left(\frac{|p_{in}|^2}{|p_{out}|^2}\right) = 20log_{10}\frac{|p_{in}|}{|p_{out}|}$$

In the sound source room (the left side),
Sound pressure value is combined with the theoretical solution of the wave equation.
Separated into traveling wave pressure p_{in} and backward wave pressure $p_{reflect}$.



With Helmholtz's wave equation

$$\frac{\partial^2 u}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 u}{\partial t^2}$$

Traveling wave | Backward wave

$$u(t,x) = \frac{u_0 e^{j2kl} - De^{jkl}}{e^{j2kl}-1} e^{j(\omega t - kx)} + \frac{De^{jkl} - u_0}{e^{j2kl}-1} e^{j(\omega t + kx)}$$

Sound pressure = density * speed of sound * particle velocity

$$p = \rho c u$$

Amplitude of excitation plate velocity

$$D = \frac{2u_0 e^{jkl}}{1+e^{j2kl}} + p_{x=l} \cdot \frac{1-e^{j2kl}}{\rho c(1+e^{j2kl})}$$

Sound pressure calculation value by FEM

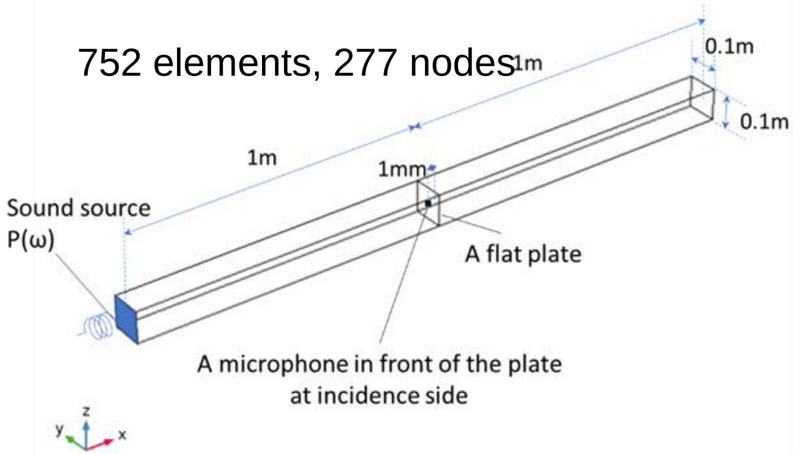
Traveling wave pressure

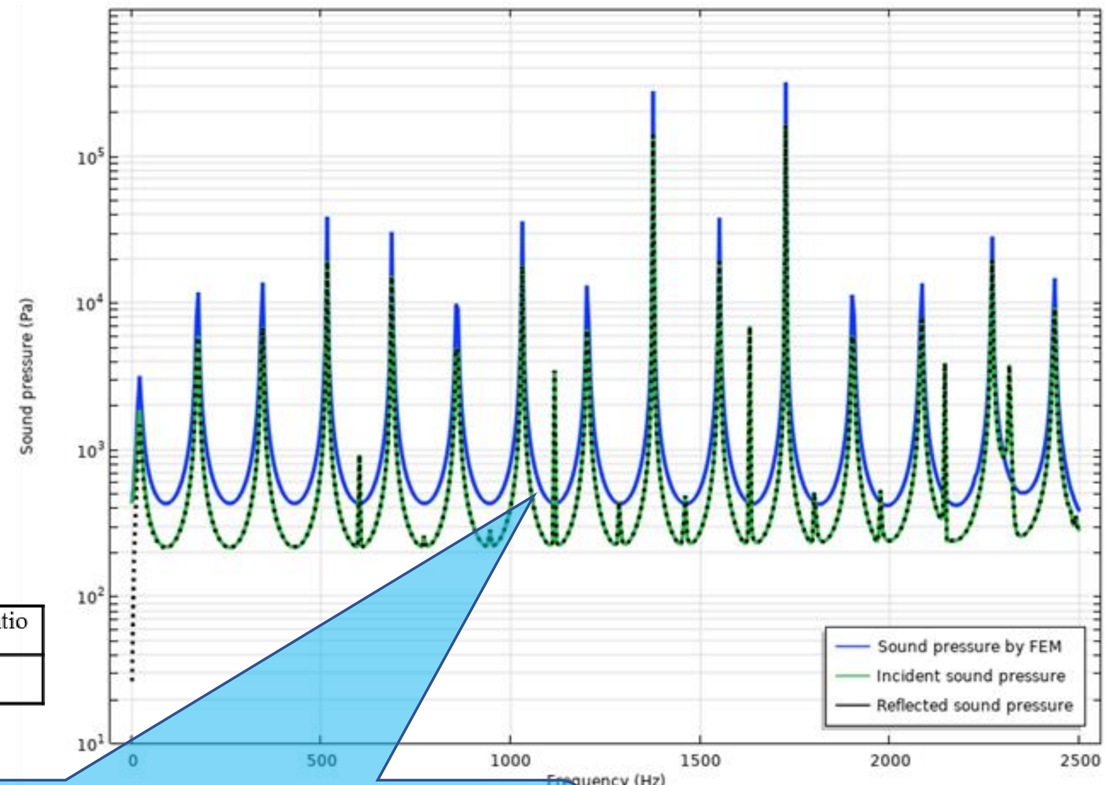
$$p_{in}|_{x=l} = u(t,l) = \rho c \cdot \frac{u_0 e^{jkl} - D}{e^{j2kl}-1} e^{j\omega t}$$

❷ Separation verification of incident wave and reflected wave

FEM calculation using COMSOL Multiphysics ®
Same conditions as previous research
The right end of the acoustic tube is non-reflective
The sound pressure observation point is 1 mm in front of the plate in the x-axis direction.

752 elements, 277 nodes





Specification of material of the plate

Material	Young's modulus [N/m²]	Density [kg/m³]	Poisson ratio
Steel	2.05×10^{11}	7.85×10^{3}	0.28

SP by FEM = incident SP + reflected SP
Incident SP = reflected SP

❸ Comparison of TL with equal mass on 3 different core heights