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Investigation of the Vibrational Modes of Edge-Constrained Fibrous Samples Placed in a Standing Wave Tube

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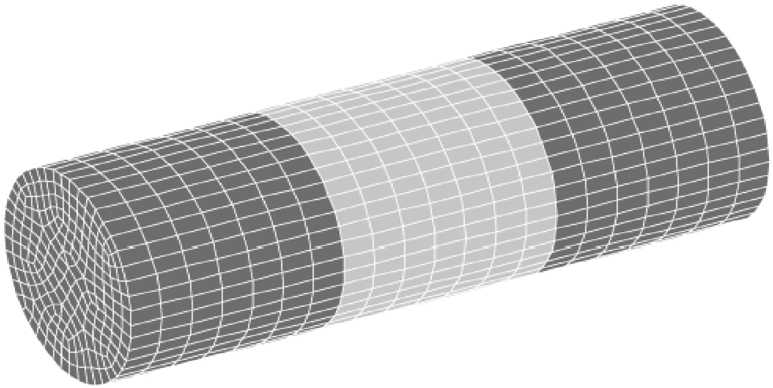


Purdue University **Herrick Laboratories**

Background

- Measurement of the surface normal velocity of vibrating panels or plates [Kruger and Mann (1999) and Muller and Moslehy (1996)]
- Estimation of the mechanical properties (Young’s modulus and Poisson’s ratio) of foam materials by the laser vibration measurement [Mariez et al. (1996) and Dubbelday (1992)]
- **Electromagnetic approach** for measuring the vibrational velocity of the frame of flexible porous materials (Khirnykh and Cummings, 1999)

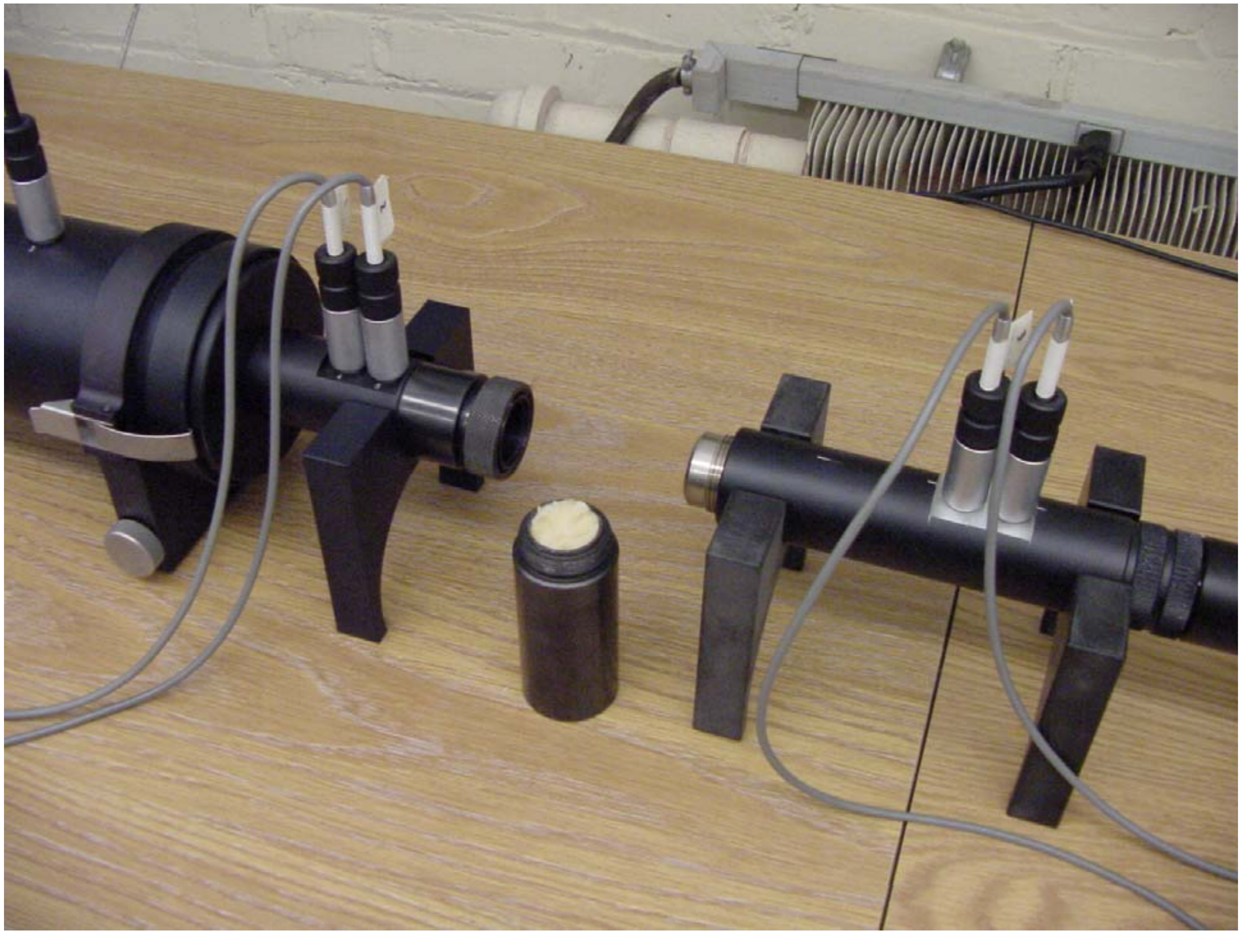
Introduction

- Investigation of edge constraint effect on samples placed in a modified standing wave tube (J. S. Bolton et al., *SAE* 1997; B. H. Song et al., *JASA* 1999).

- Internal constraints may be used to selectively enhance the transmission loss of lining materials at low frequencies (B. H. Song et al., *JASA* 2001).

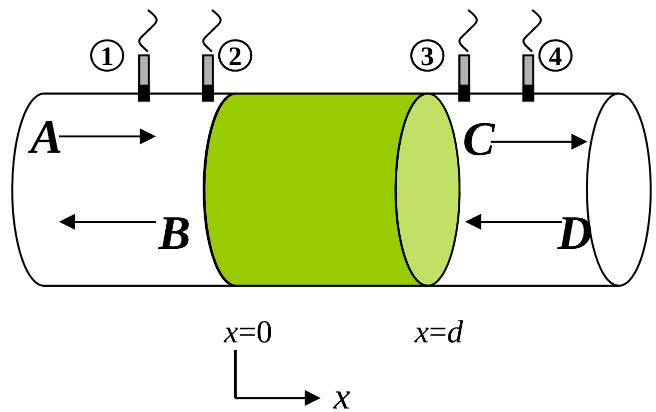
- Implications for design of low frequency noise control barriers following from constraint of porous lining materials around their edges.

Glass Fiber Material inside of Sample Holder



Four Microphone Measurement

Transfer Matrix Approach I



$$\begin{bmatrix} P \\ V \end{bmatrix}_{x=0} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} P \\ V \end{bmatrix}_{x=d}$$

$T_{11} = T_{22}$ ⇒ **symmetry**

$T_{11}T_{22} - T_{12}T_{21} = 1$ ⇒ **reciprocity**

4 Equations

- **Solve for transfer matrix elements**

Transfer Matrix Approach II

$$\begin{bmatrix} 1 + R_a \\ \dfrac{1 - R_a}{\rho_0 c_0} \end{bmatrix} = \begin{bmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{bmatrix} \begin{bmatrix} T_a e^{-jkd} \\ \dfrac{T_a e^{-jkd}}{\rho_0 c_0} \end{bmatrix}$$

- **Anechoic Reflection Coefficient**

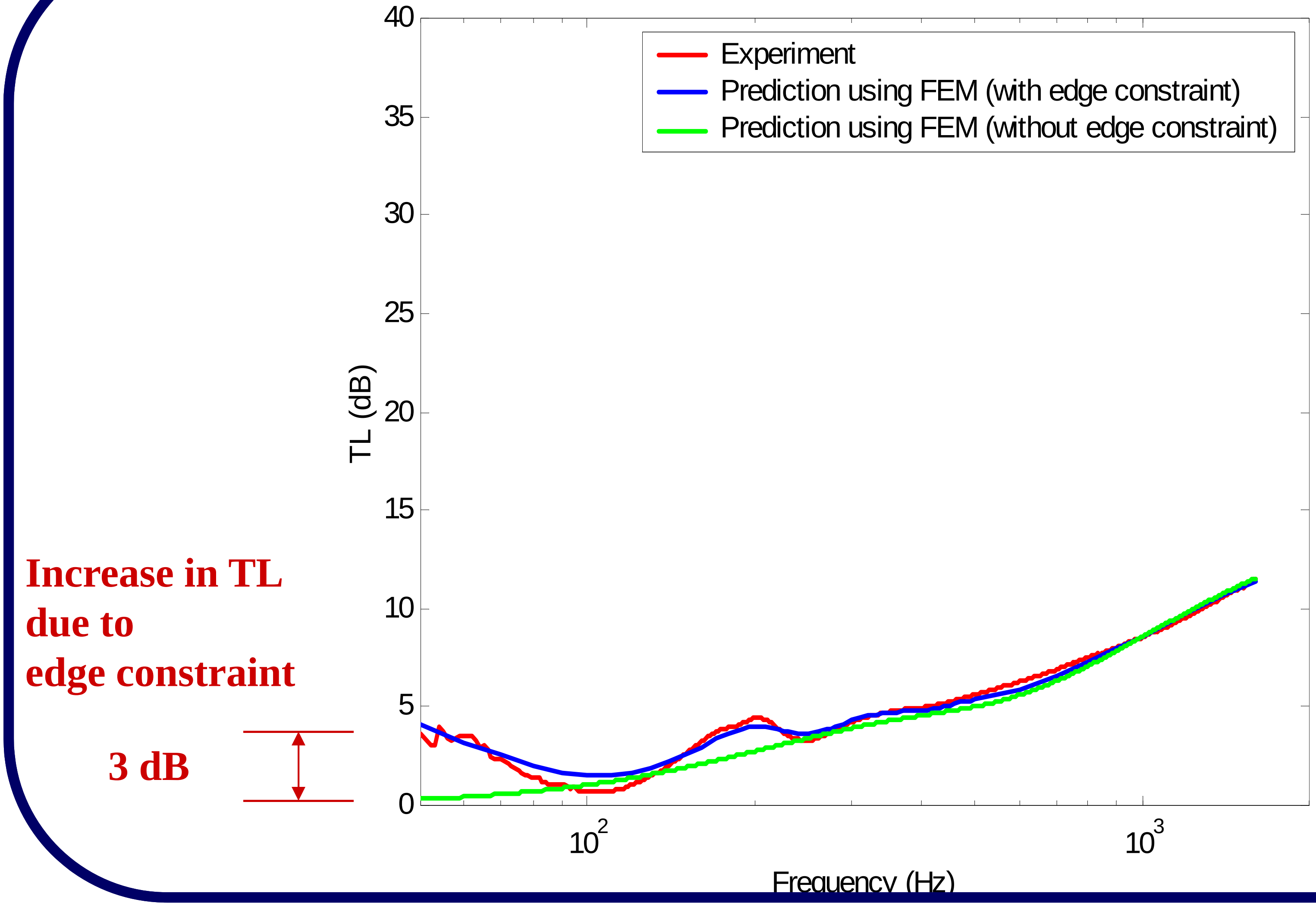
$$R_a = \frac{T_{11} + \dfrac{T_{12}}{\rho_0 c} - \rho_0 c T_{21} - T_{22}}{T_{11} + \dfrac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}} \Rightarrow \quad \alpha = 1 - |R_a|^2, \quad \frac{z_n}{\rho_0 c} = \frac{1 + R_a}{1 - R_a}$$

- **Anechoic Transmission Coefficient**

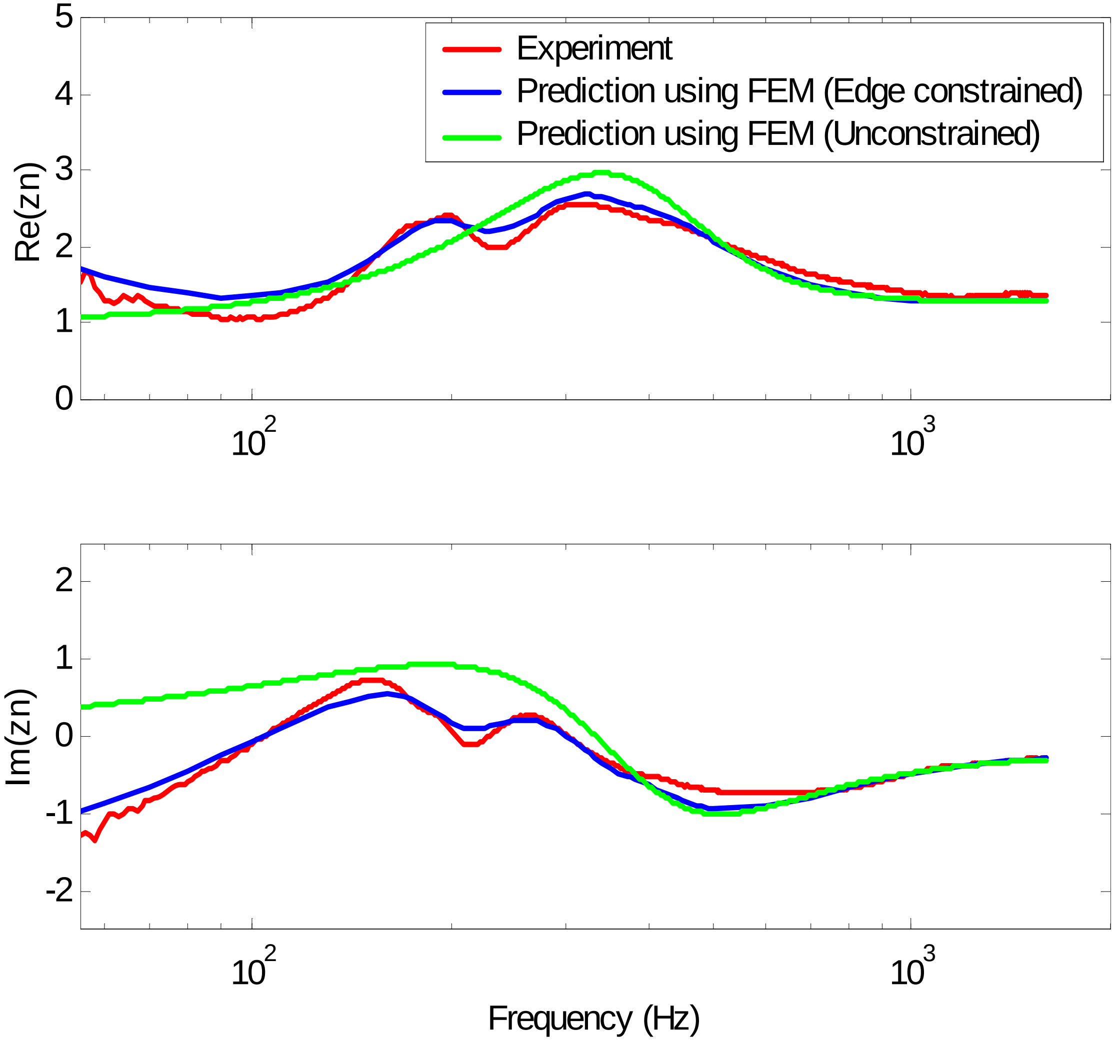
$$T_a = \frac{2 e^{jkd}}{T_{11} + \dfrac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}} \Rightarrow \quad TL = 10 \log(1/|T_a|^2)$$

Experimental Setup for Low Frequency Tube

Anechoic Transmission Loss
(3” Sample A in a Large Tube)

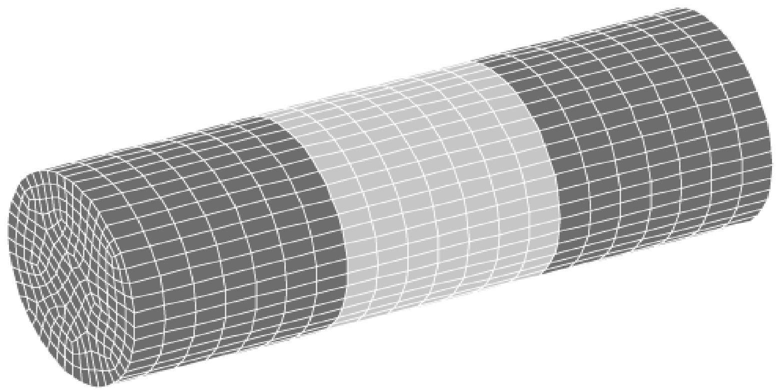


Surface Normal Impedance
(3” Sample A in a Large Tube)

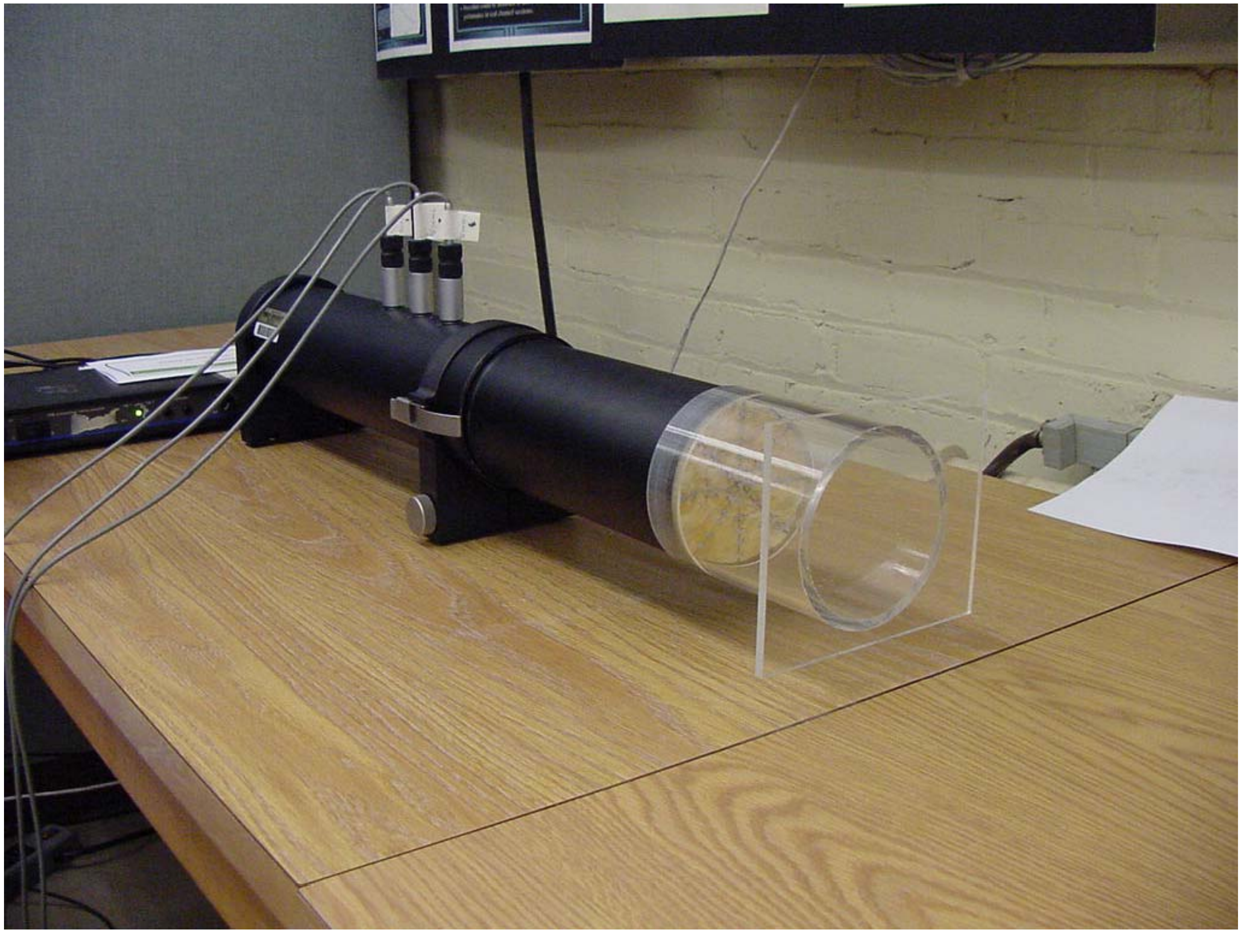


Poroelastic Material Properties used in Calculations

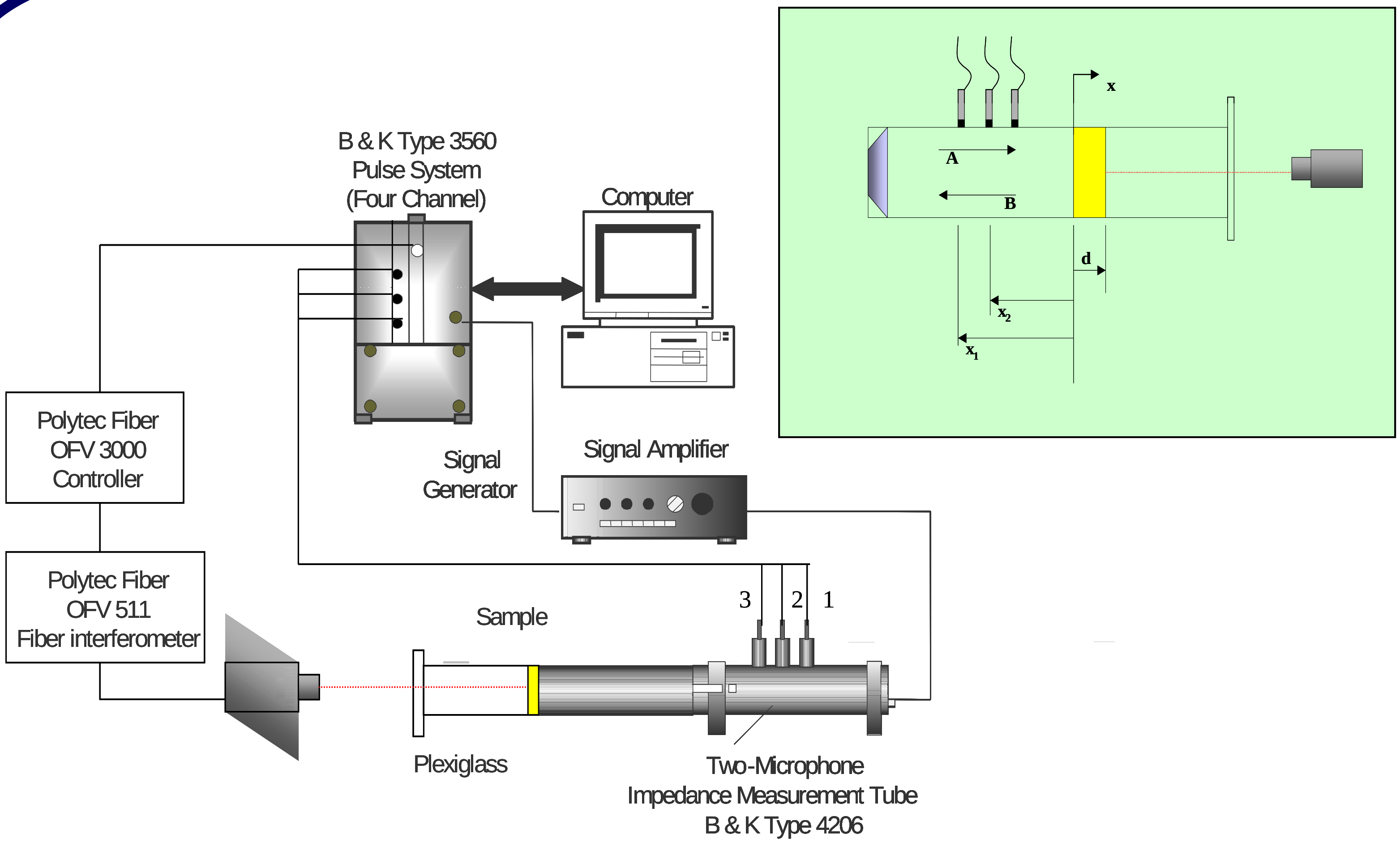
Material	Bulk density (Kg/m^3)	Porosity	Tortuosity	Flow resistivity (MKS Rayls/m)	Shear modulus (Pa)	Loss factor
Sample A	6.73	0.99	1.1	21000	1200	0.35



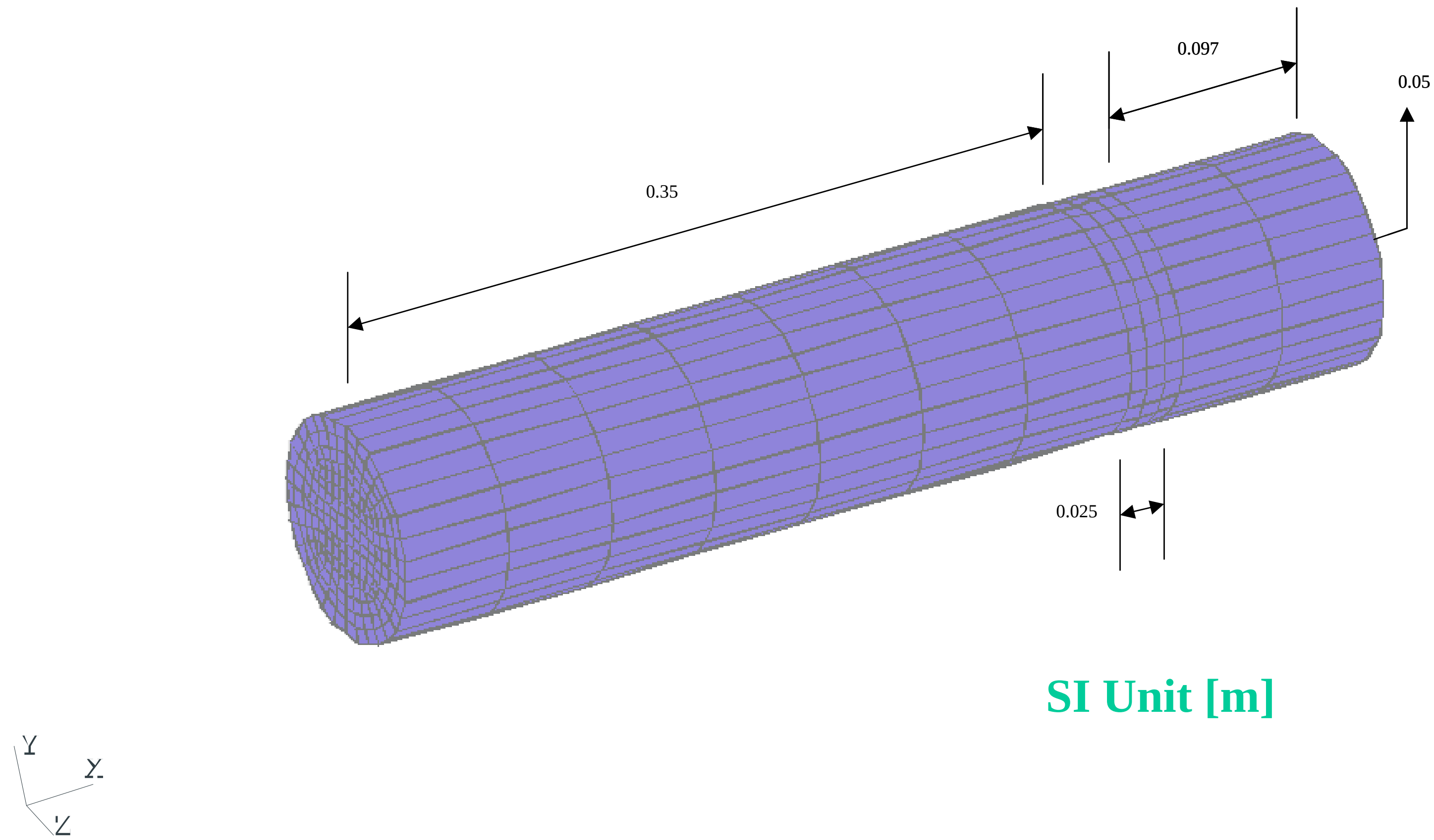
Investigation of Vibrational Modes of Glass Fiber Materials (1" Sample A)



Laser Measurement Setup (Large Tube, 1” Sample A)

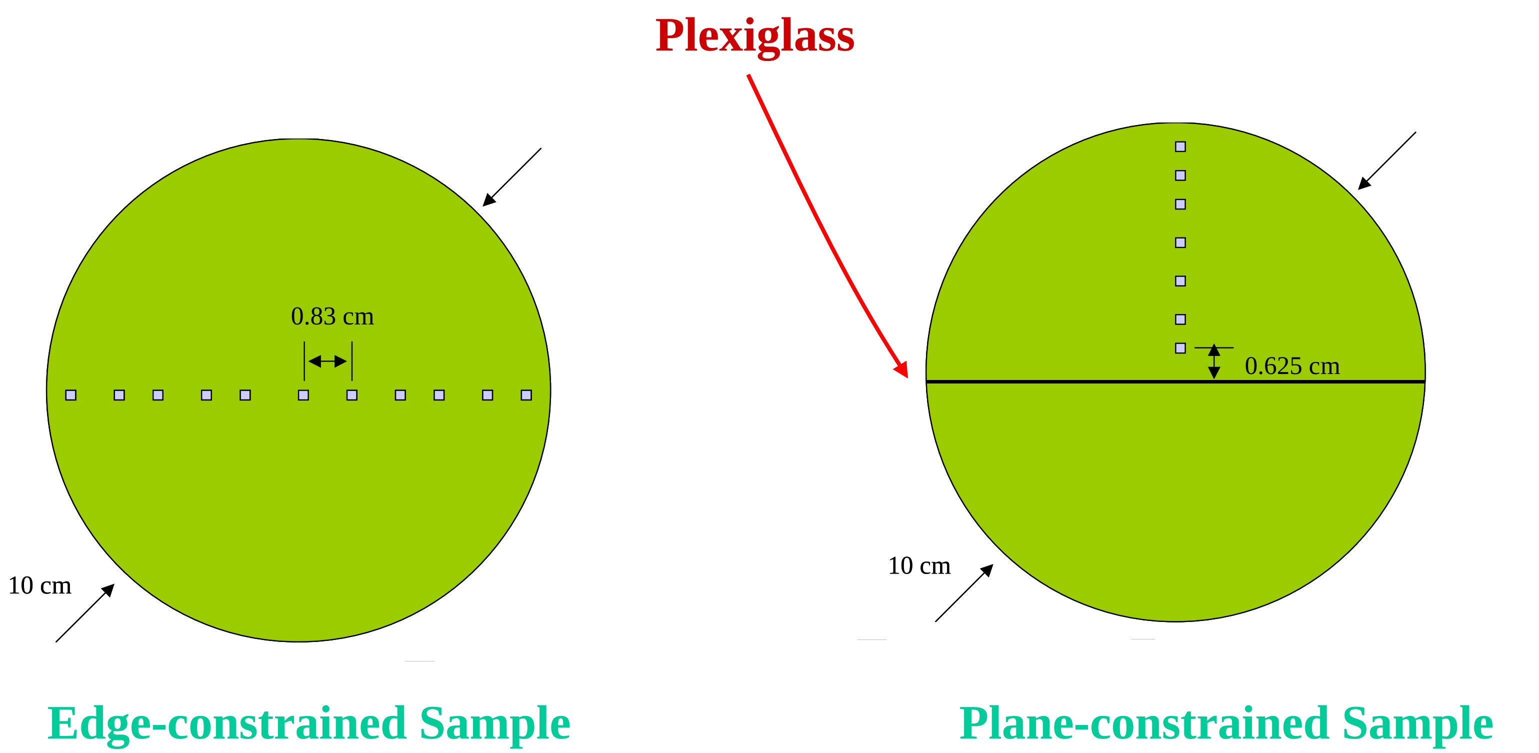


Three-Dimensional Finite Element Model



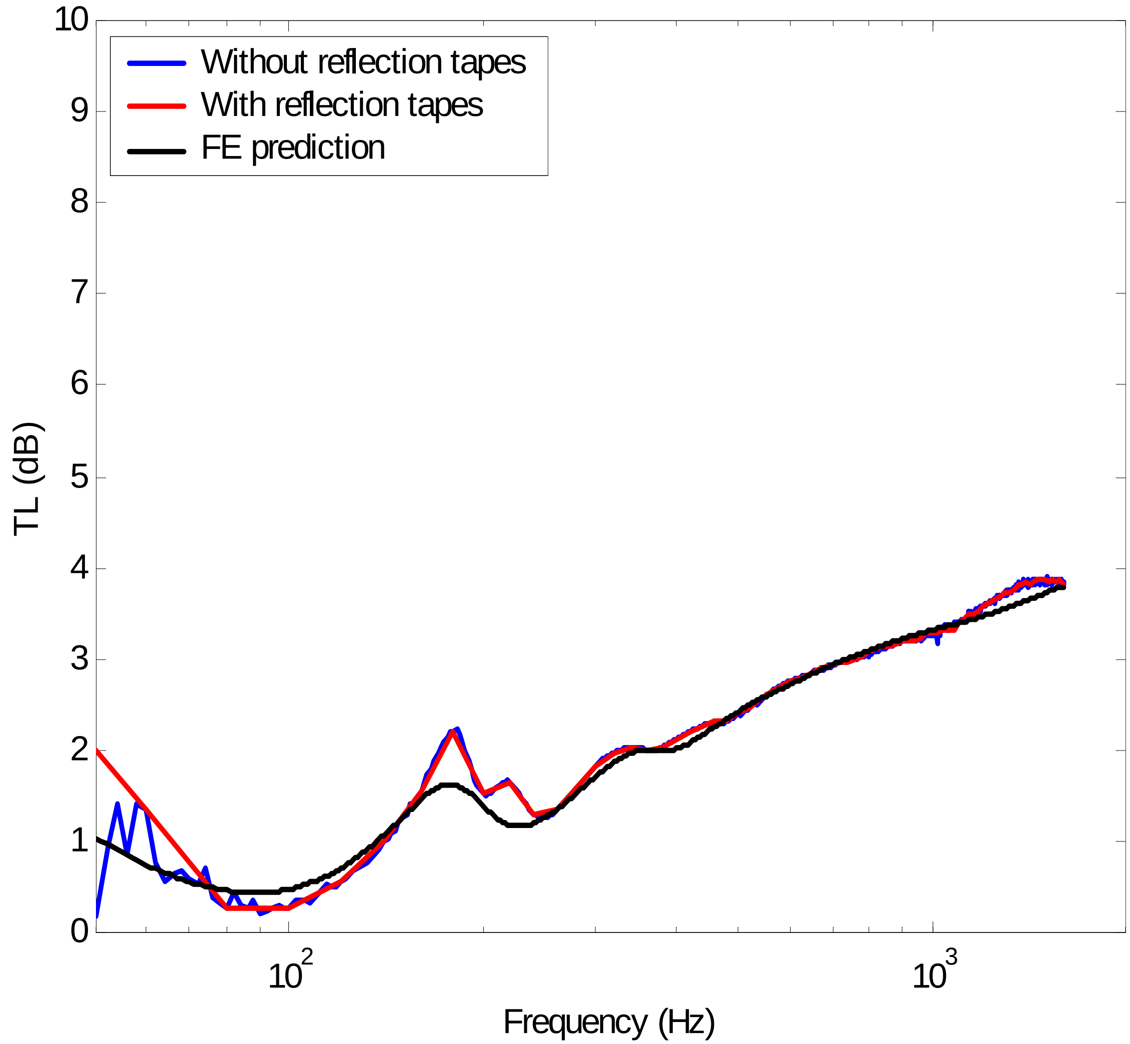
SI Unit [m]

Schematic of Edge- and Plane-Constrained Sample with Reflecting Tapes

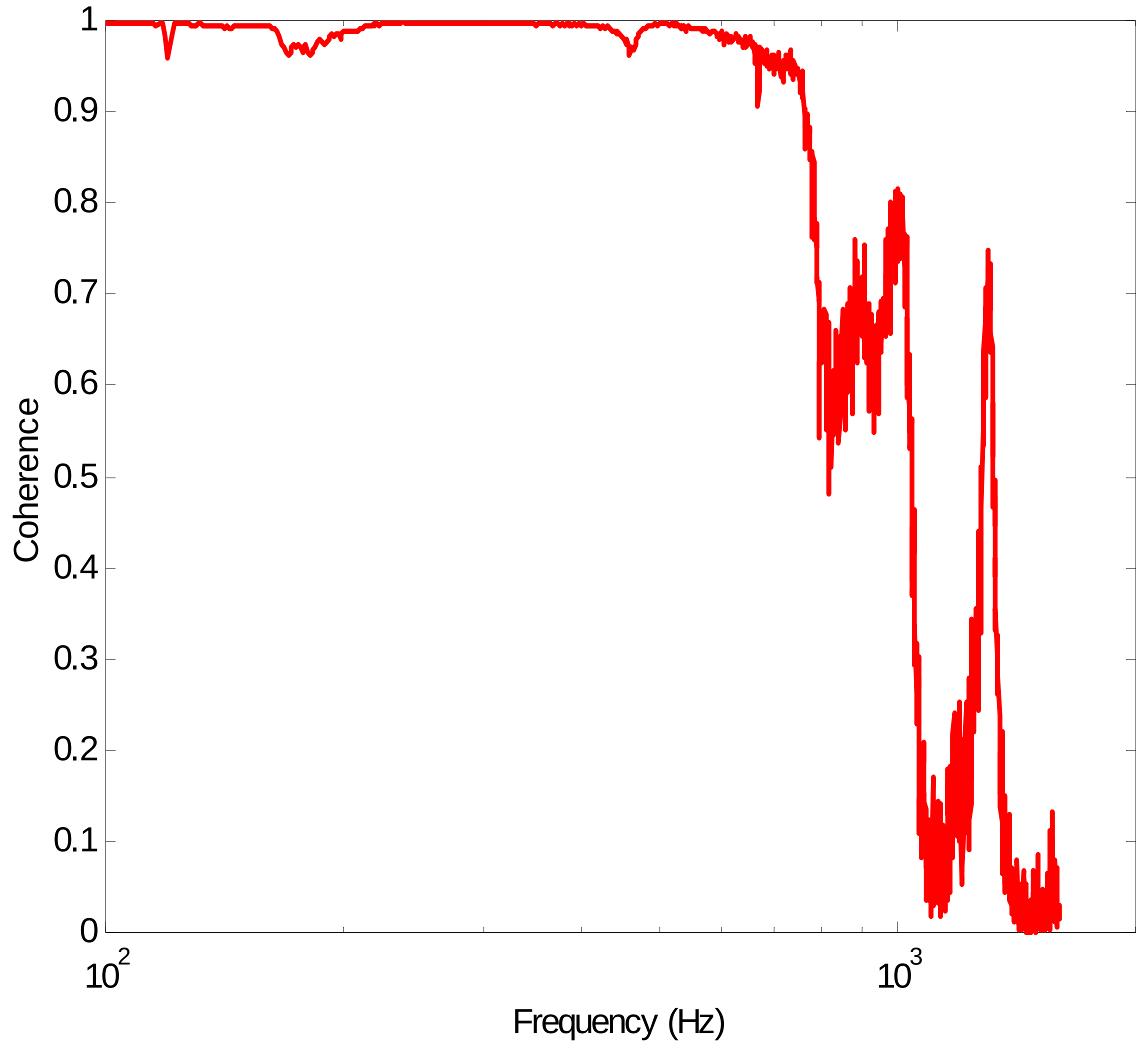


Glass Fiber Materials with Reflecting Tape

Effect of Reflecting Tape on TL (1” Sample A)

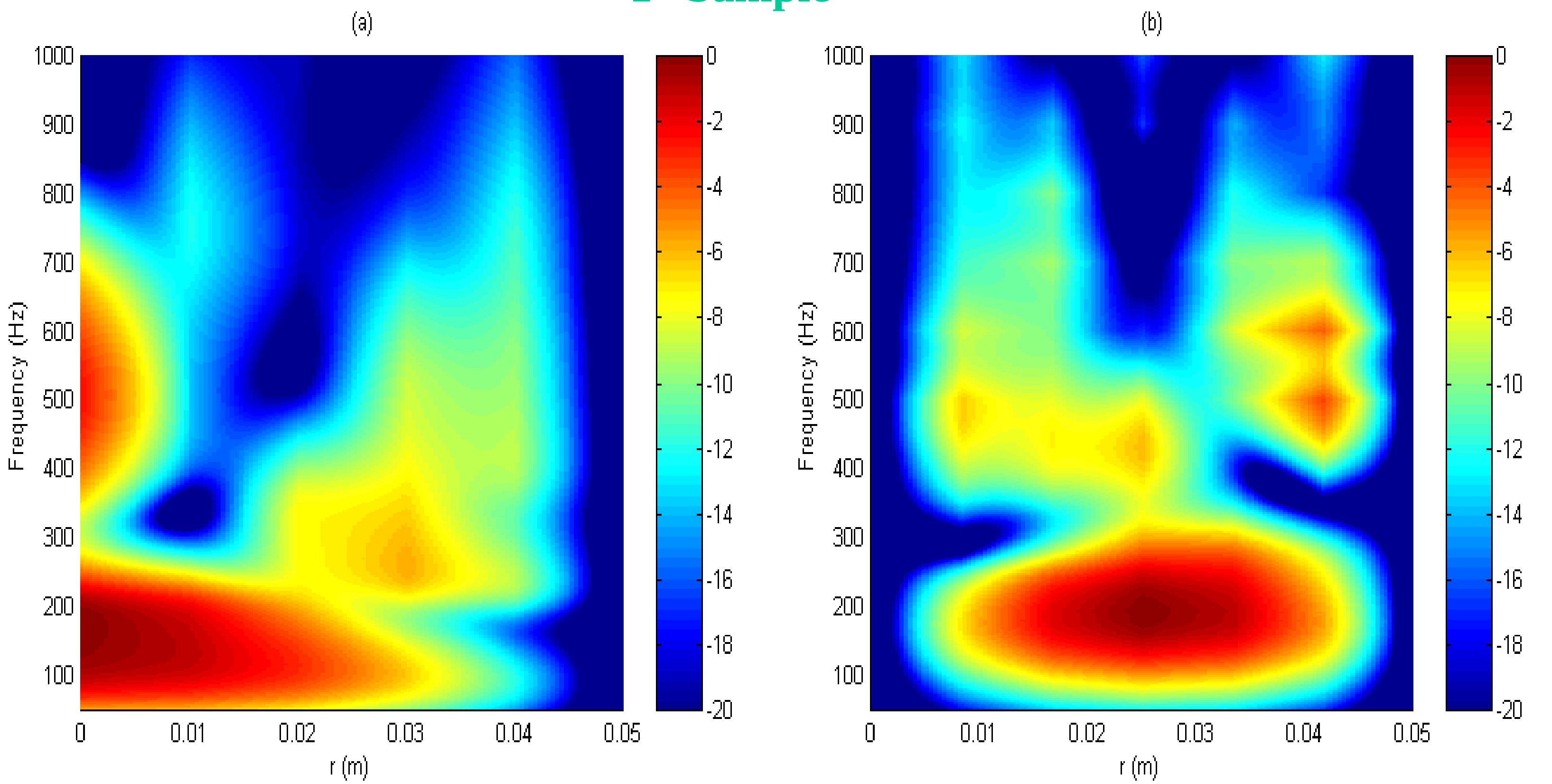


Coherence Between Reference Microphone and the Laser Velocity Signal (1” Sample A)



FEM-Predicted Normalized Frame Velocity in Large Tube, Anechoic Termination Case (1”)

1” Sample

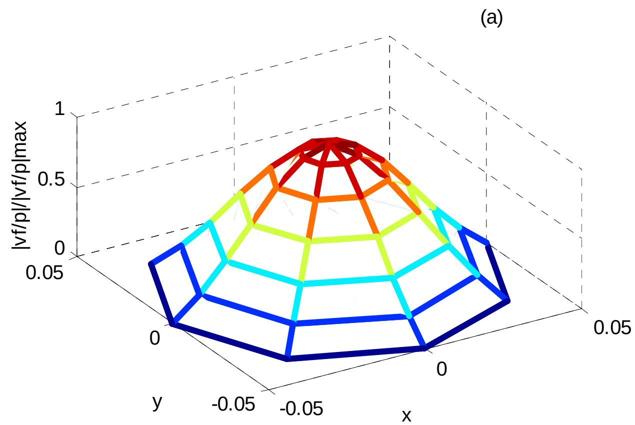


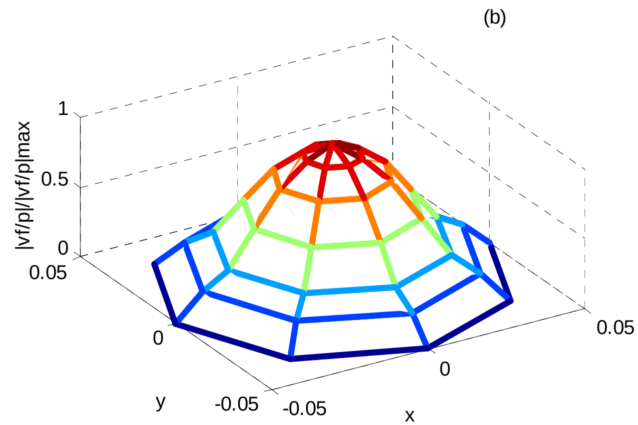
Edge-constrained Sample **Plane-constrained Sample**

The 1st and 2nd Mode Shapes of the Edge-constrained Sample (1”)

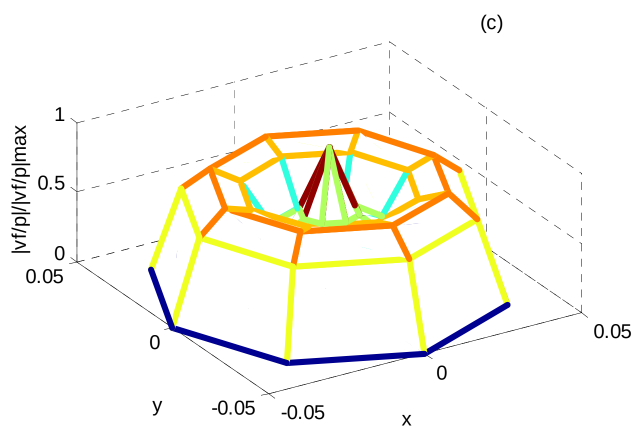
FEM | **Experiment**

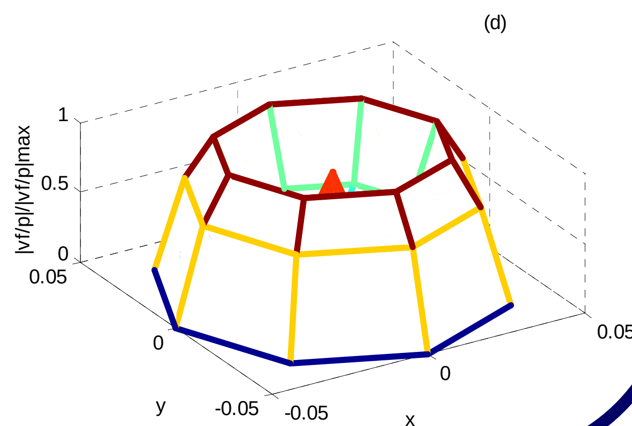
1st Mode at 100 Hz





2nd Mode at 350 Hz



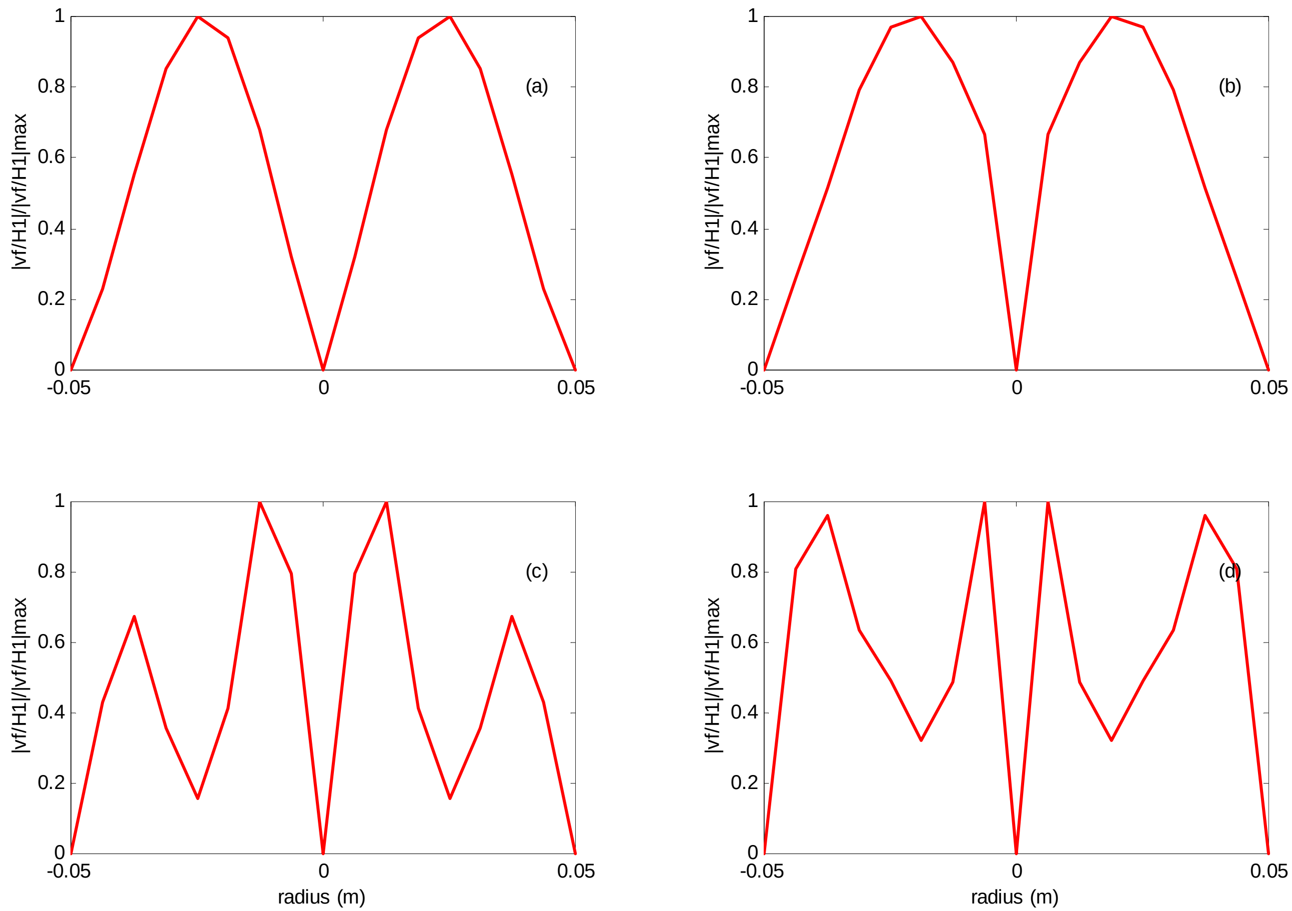


The 1st and 2nd Mode Shapes of the Plane-constrained Sample (1")

FEM | **Experiment**

1st Mode at 200 Hz

2nd Mode at 500 Hz

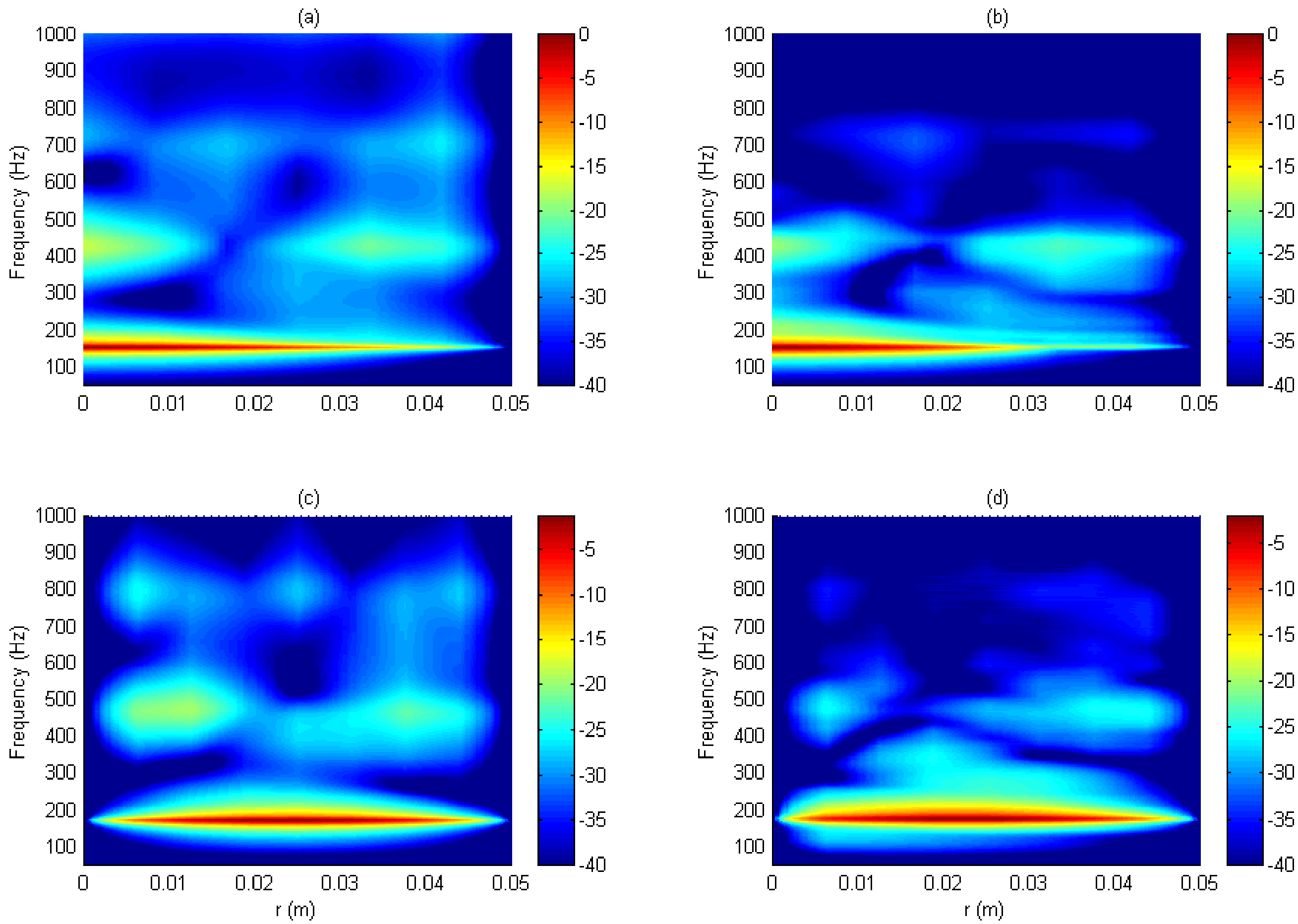


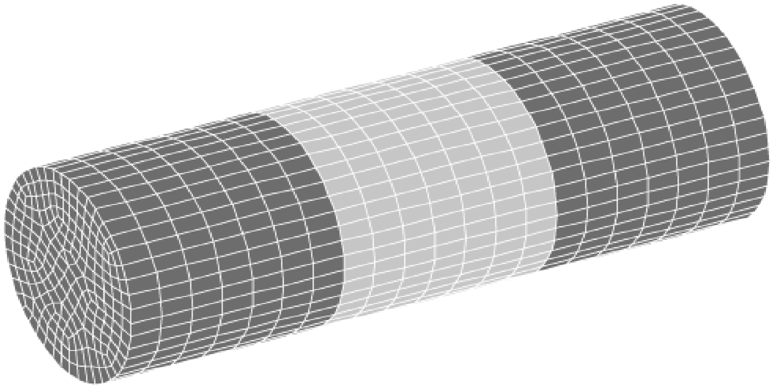
Normalized Frame Velocity of Sample in Large Tube, Hard Termination Case (1”)

FEM | Experiment

Edge-constrained

Plane-constrained





Conclusions

- Direct measurements show the vibrational velocity of the solid skeleton of fibrous sample placed in a standing wave tube.
- The vibrational characteristics are well predicted by using poroelastic FE model (COMET/SAFE).
- Vibrational modes of edge- and plane-constrained fibrous layers have been verified using a laser vibrometer measurement.