12-1999

Effect of Circumferential Edge Constraint on the Transmission Loss of Glass Fiber Materials

J. Stuart Bolton
Purdue University, bolton@purdue.edu

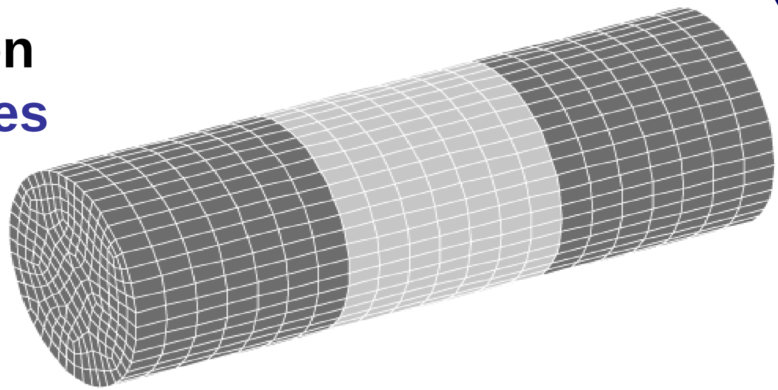
Bryan Song

Yeon June Kang
Seoul National University

Effect of Circumferential Edge Constraint on the Transmission Loss of Glass Fiber Materials

Bryan H. Song and J. Stuart Bolton
Ray W. Herrick Laboratories
Purdue University

Yeon June Kang
Seoul National University



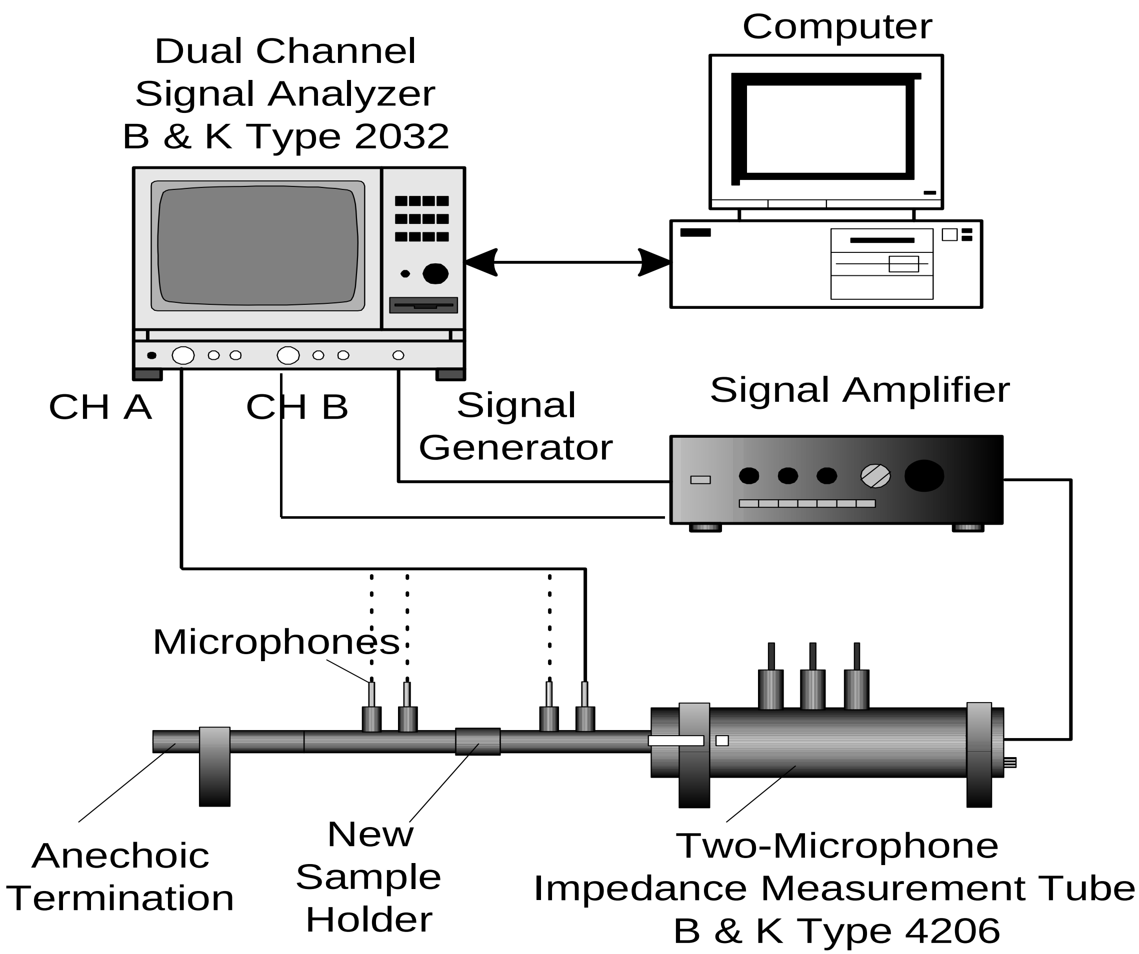
Purdue University Herrick Laboratories

Introduction

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

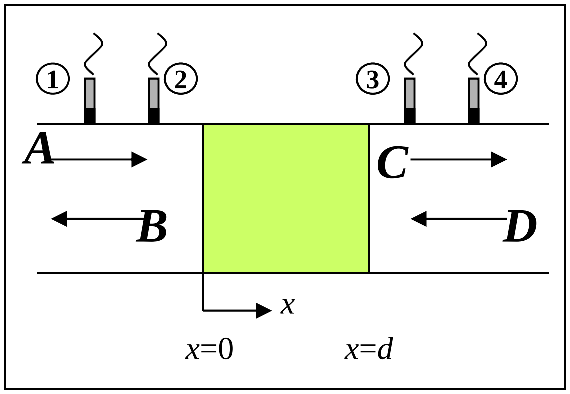
- **How: Comparison of TL and impedance measurements with FEM predicted results using an axisymmetric model COMET / SAFE (Y. J. Kang et al., *JASA* 1999). Demonstration of how the materials' mechanical and physical properties control TL**
- **What: Implications for design of low frequency noise control barriers following from constraint of porous lining materials around their edges.**

Experimental Setup High Frequency Tube



- **2.9 cm diameter samples, 7.5 cm deep**
- **Aviation grade glass fiber, 9.61 Kg/m^3**

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)**

Four Equations

- **Solve for transfer matrix elements**

Transfer Matrix Approach II

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

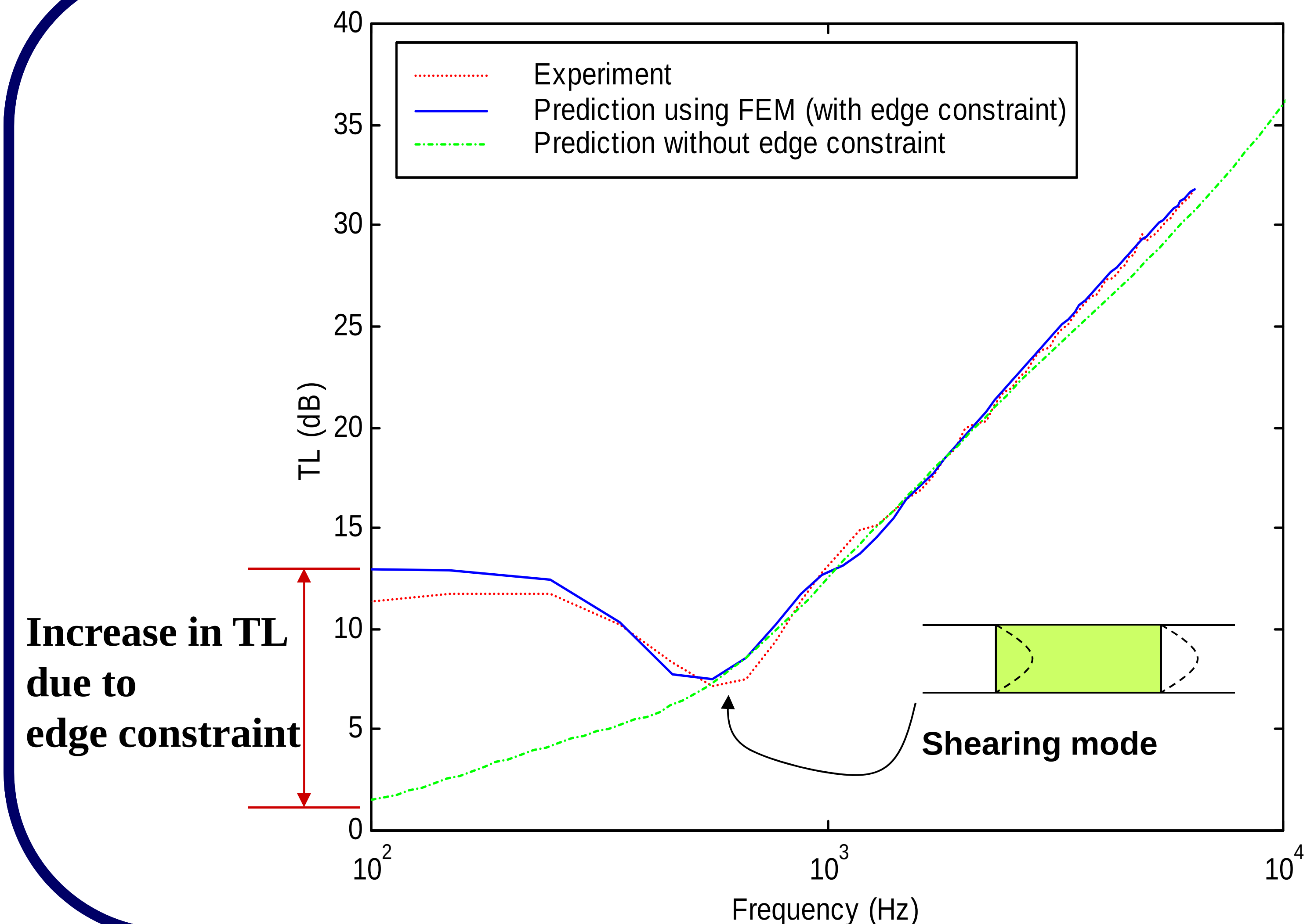
- **Anechoic Reflection Coefficient**

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

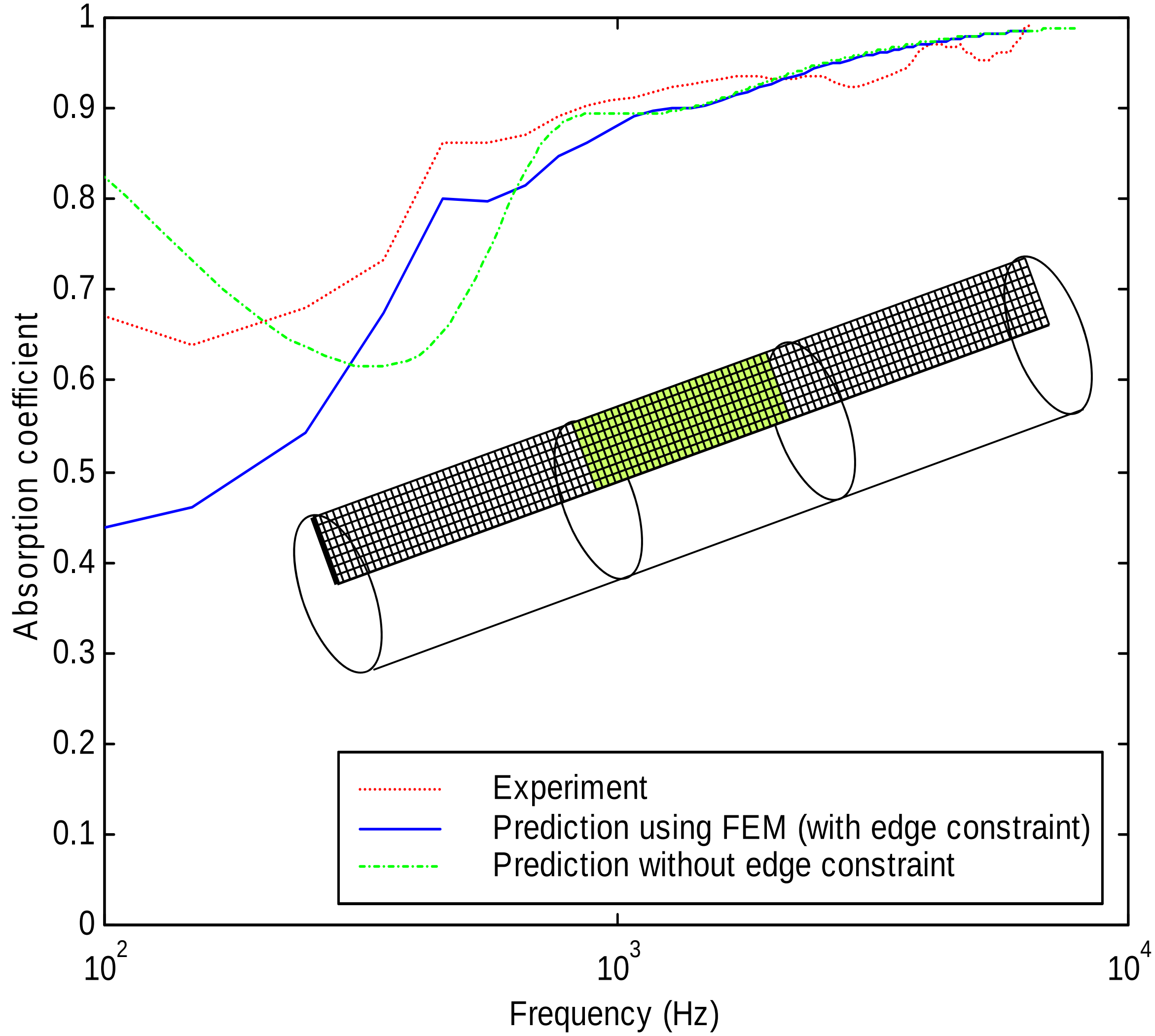
- **Anechoic Transmission Coefficient**

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

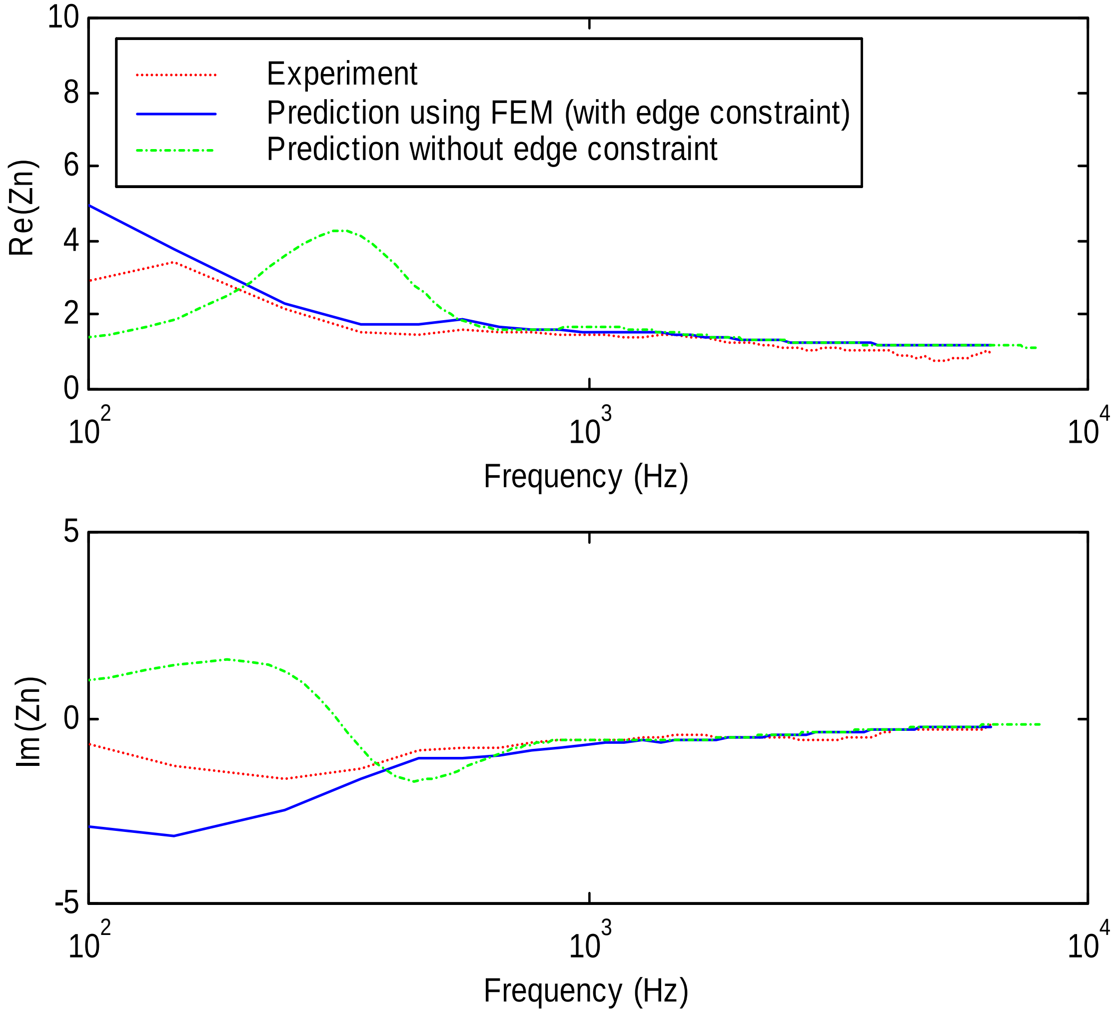
Anechoic Transmission Loss



Anechoic Absorption Coefficient



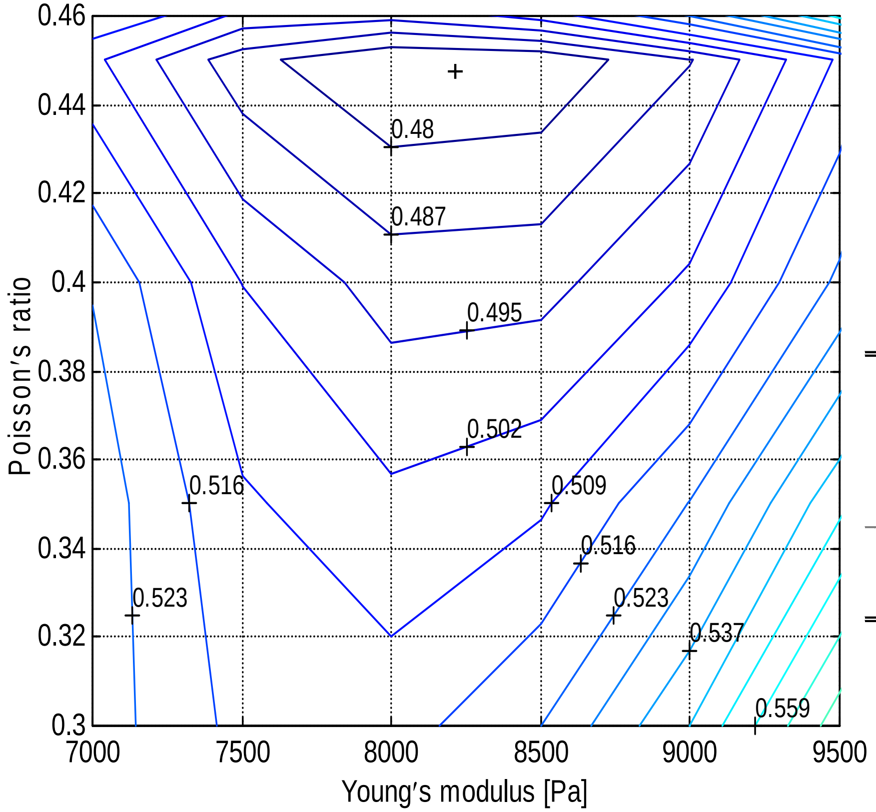
Surface Normal Impedance



- **Change from mass-like reactance to stiffness reactance**

Estimation of Material Mechanical Properties

• **Error surface**



+ **Minimum location**

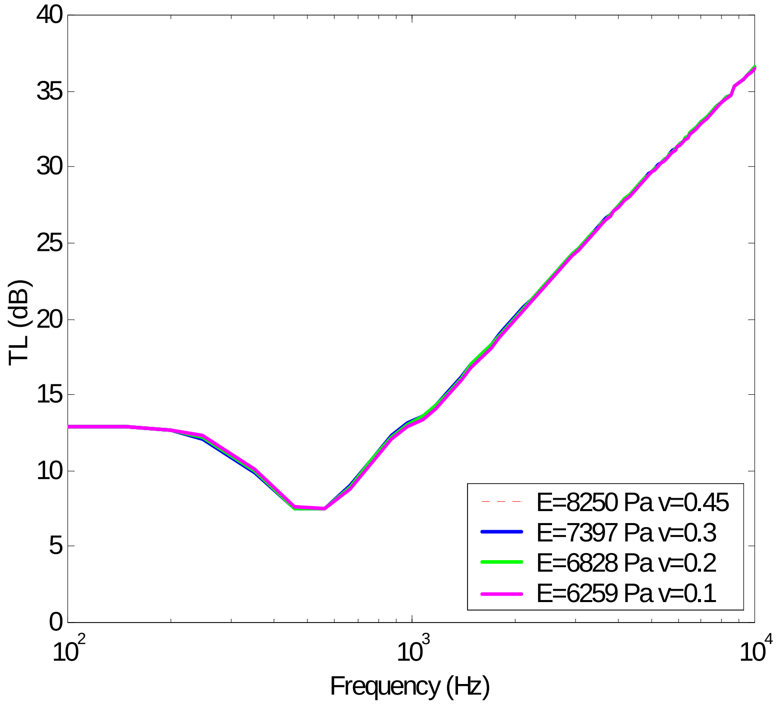
• **Objective Function**

$$J = \sum_i \frac{|\alpha_{m_i} - \alpha_{\mathrm{FEM}_i}|^2}{\alpha_{m_i}{}^2} + \sum_i \frac{|\mathrm{TL}_{m_i} - \mathrm{TL}_{\mathrm{FEM}_i}|^2}{\mathrm{TL}_{m_i}{}^2}$$

Bulk density (kg/m^3)	Measured / Predicted Flow resistivity (MKS Rayls/m)	Porosity	Tortuosity	Young's modulus (Pa)	Loss factor	Poisson ratio
9.61	24400 / 40000	0.99	1.1	8250	0.5	0.45

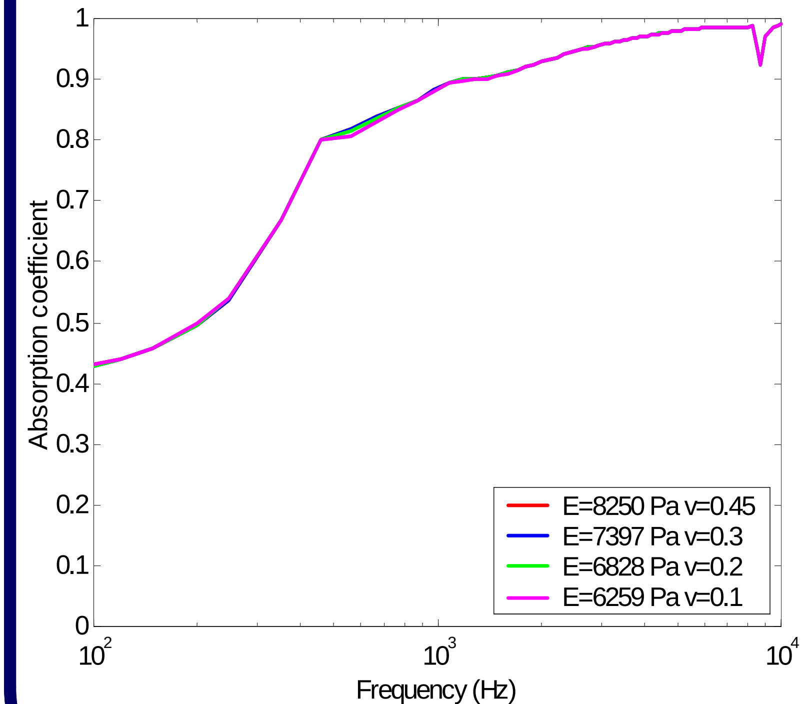
Transmission Loss

- **Shear modulus controls minimum location in TL curve**



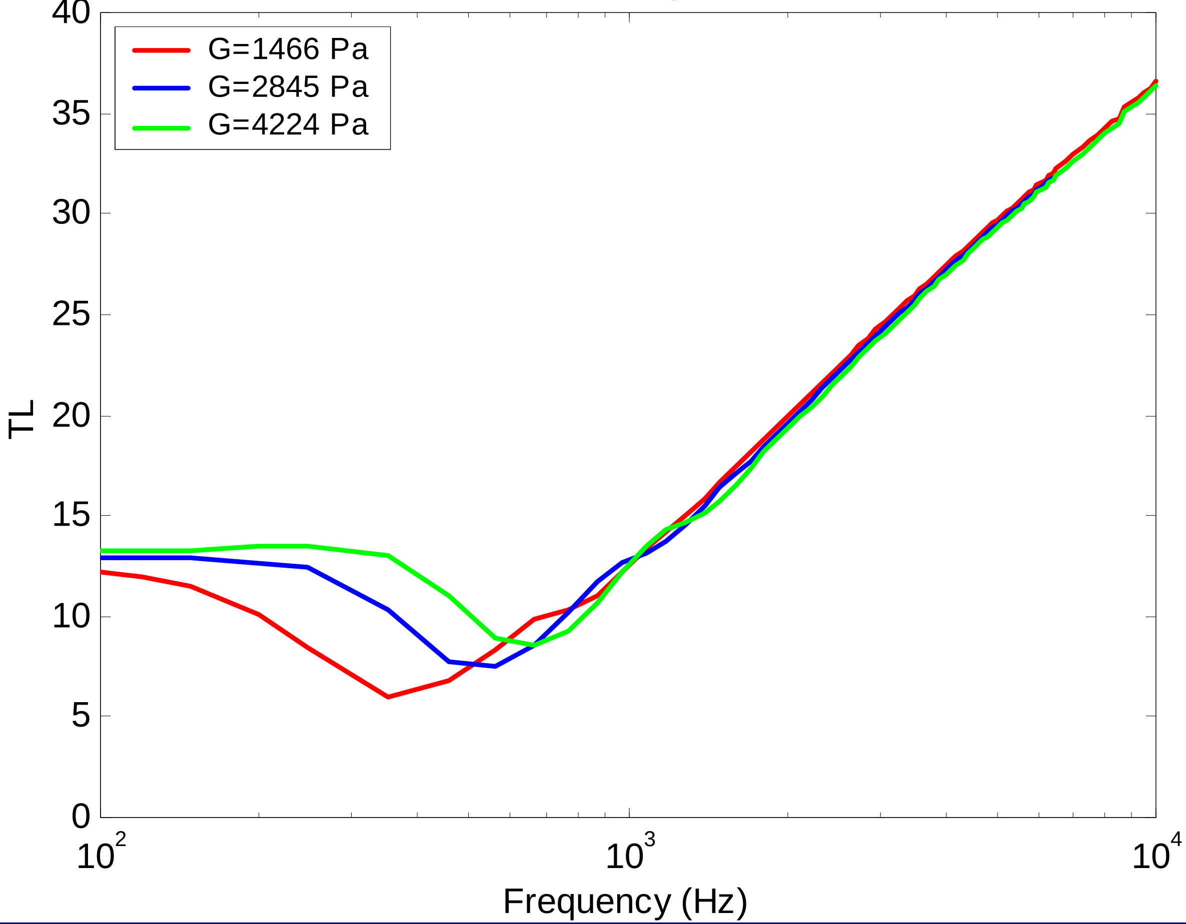
Absorption Coefficient

- **G = E/2(1+v) = 2845 Pa**



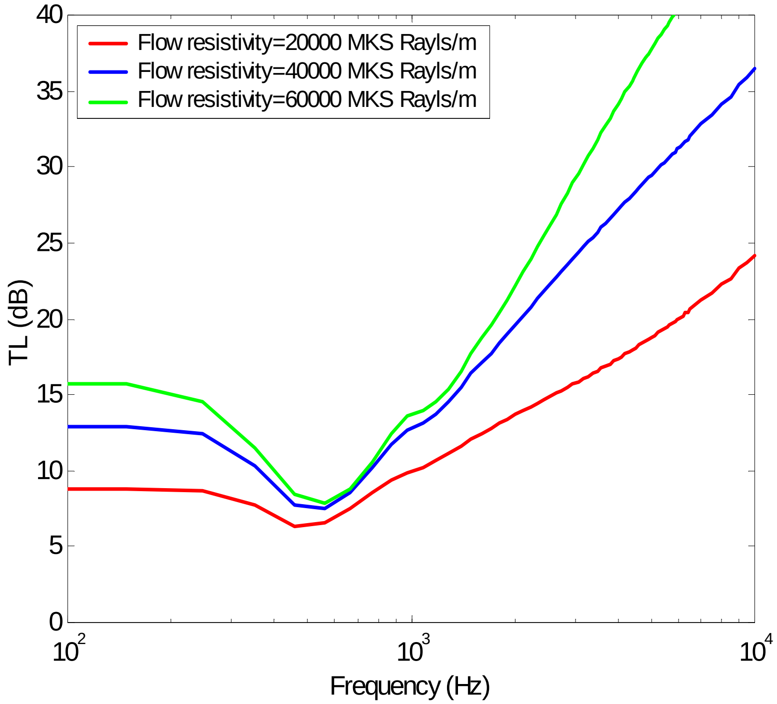
Variation of Shear Modulus

- **As shear modulus increases, the minimum location moves to higher frequencies**



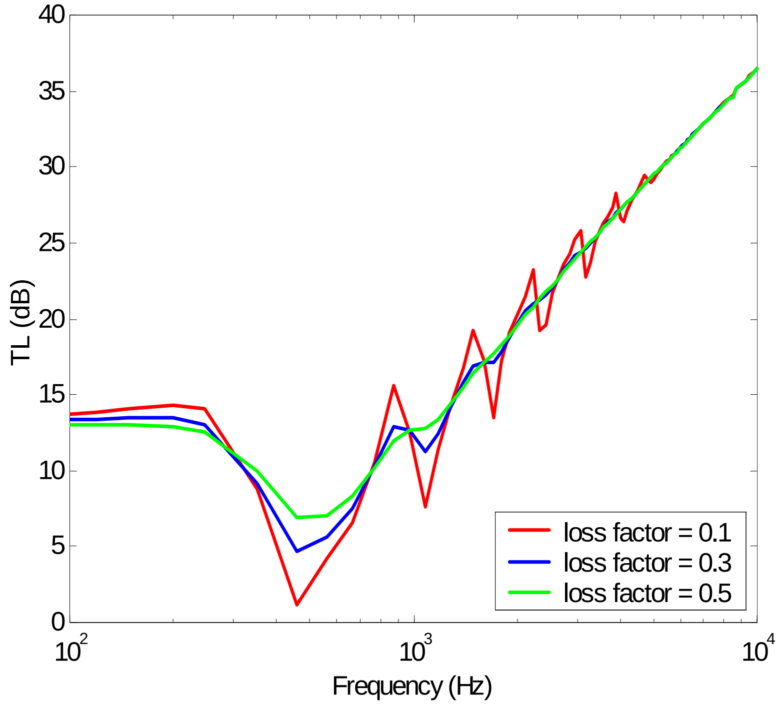
Flow Resistivity

- Flow resistivity controls TL in <u>low and high frequency limit</u>



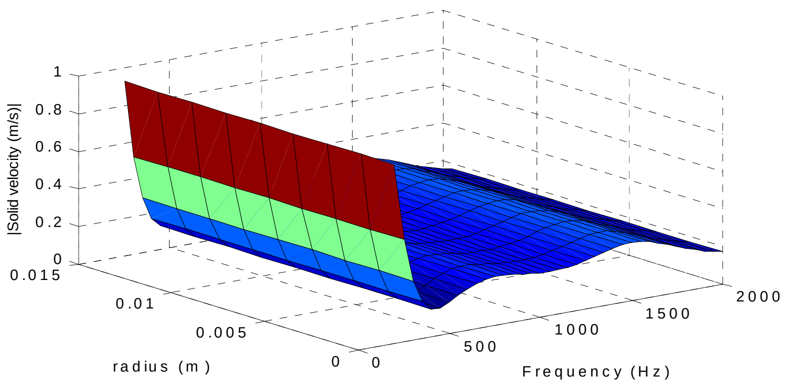
Loss Factor

- Loss factor controls depth of TL minimum

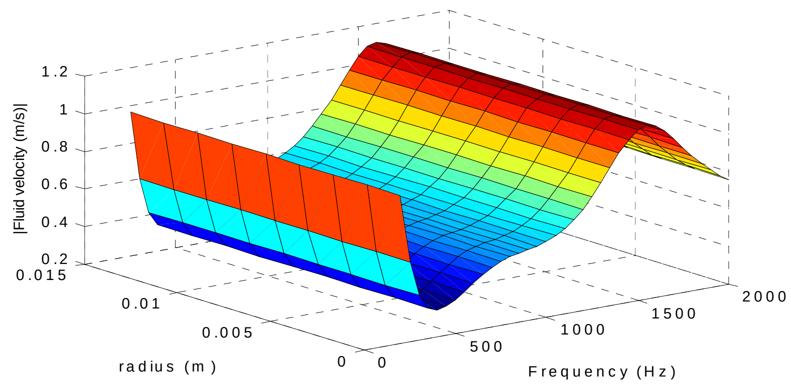


Axial Particle Velocity at the Front of Sample

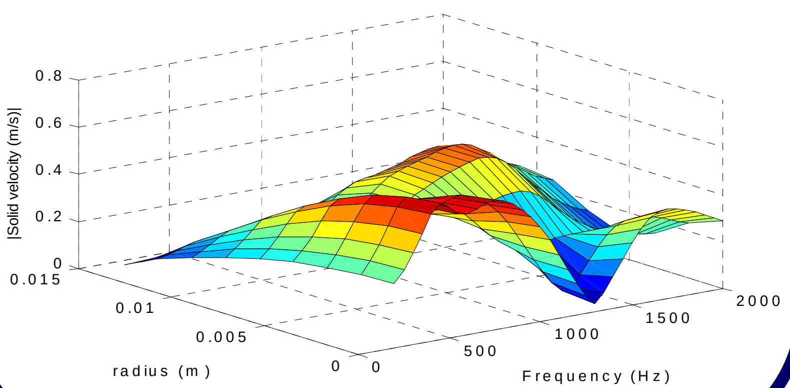
- **Solid phase (unconstrained)**



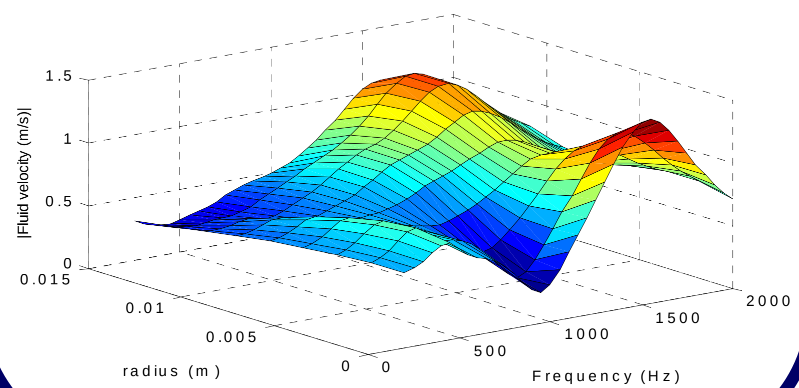
- **Fluid phase (unconstrained)**



- **Solid phase (constrained)**

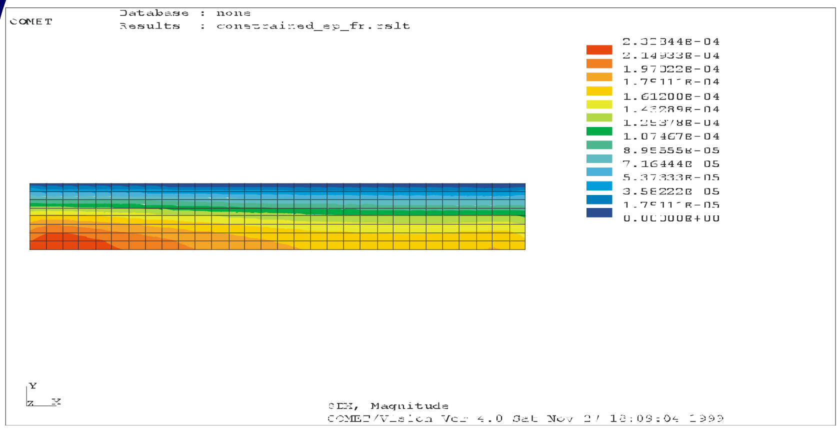


- **Fluid phase (constrained)**

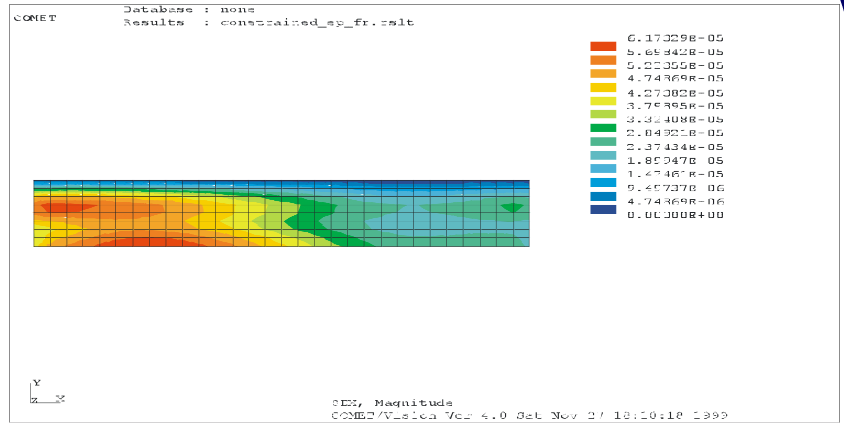


Solid Phase of Constrained Sample (SDX)

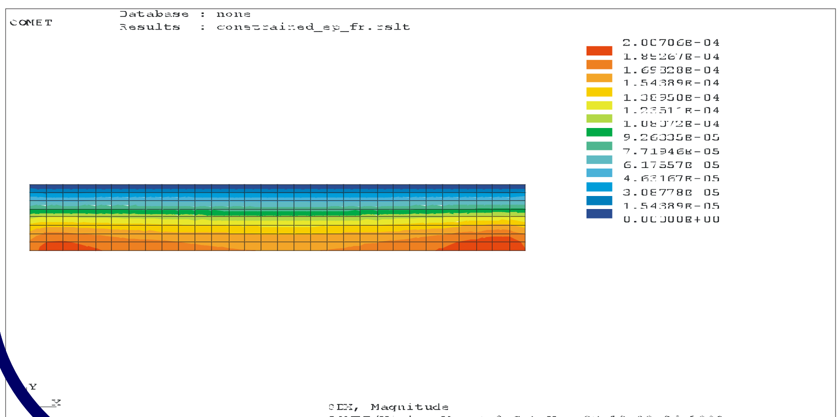
- **200 Hz**



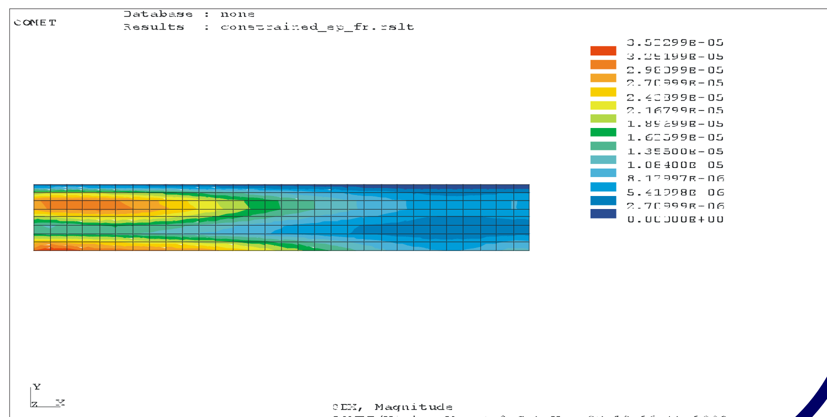
- **1100 Hz**



- **500 Hz**

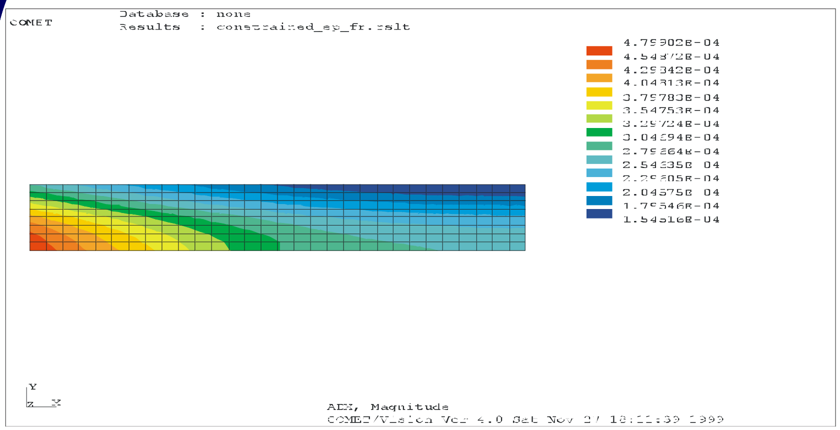


- **1800 Hz**

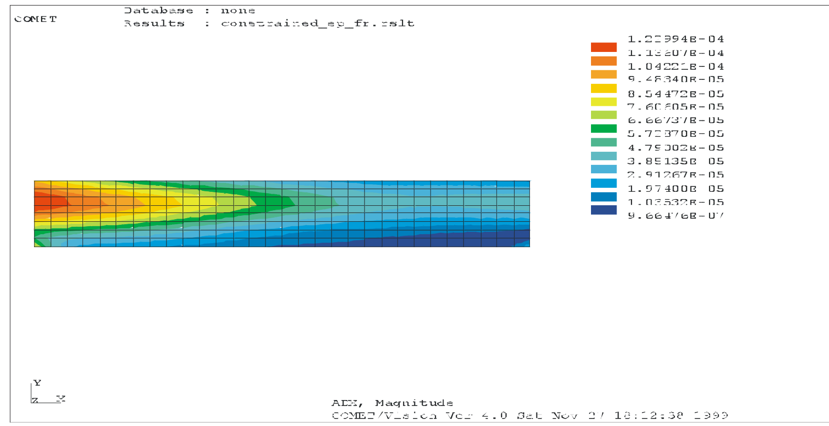


Fluid Phase of Constrained Sample (ADX)

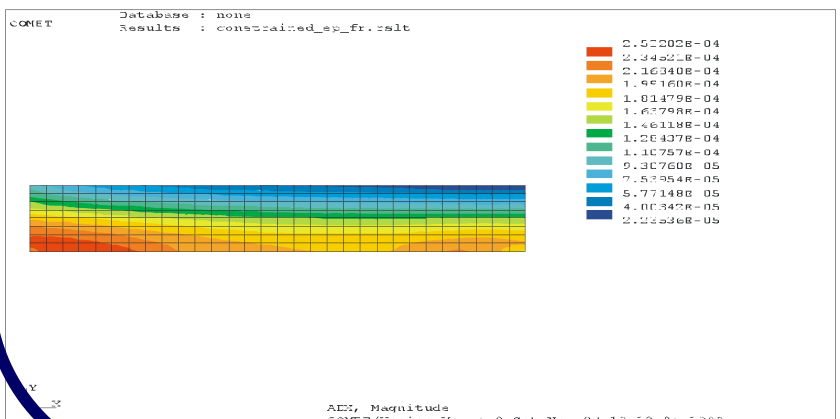
- **200 Hz**



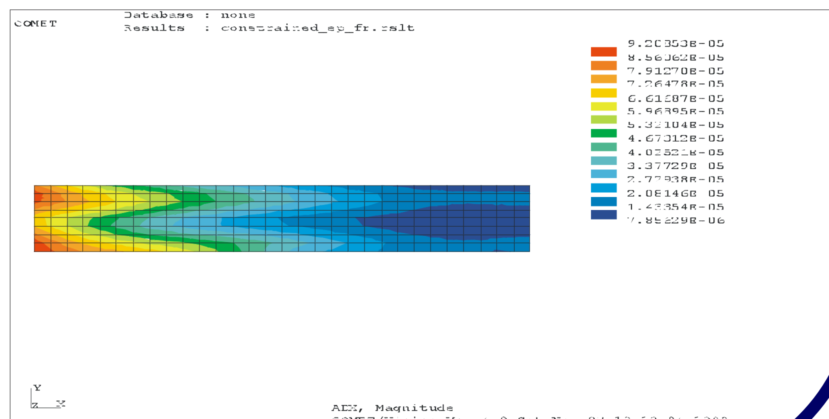
- **1100 Hz**



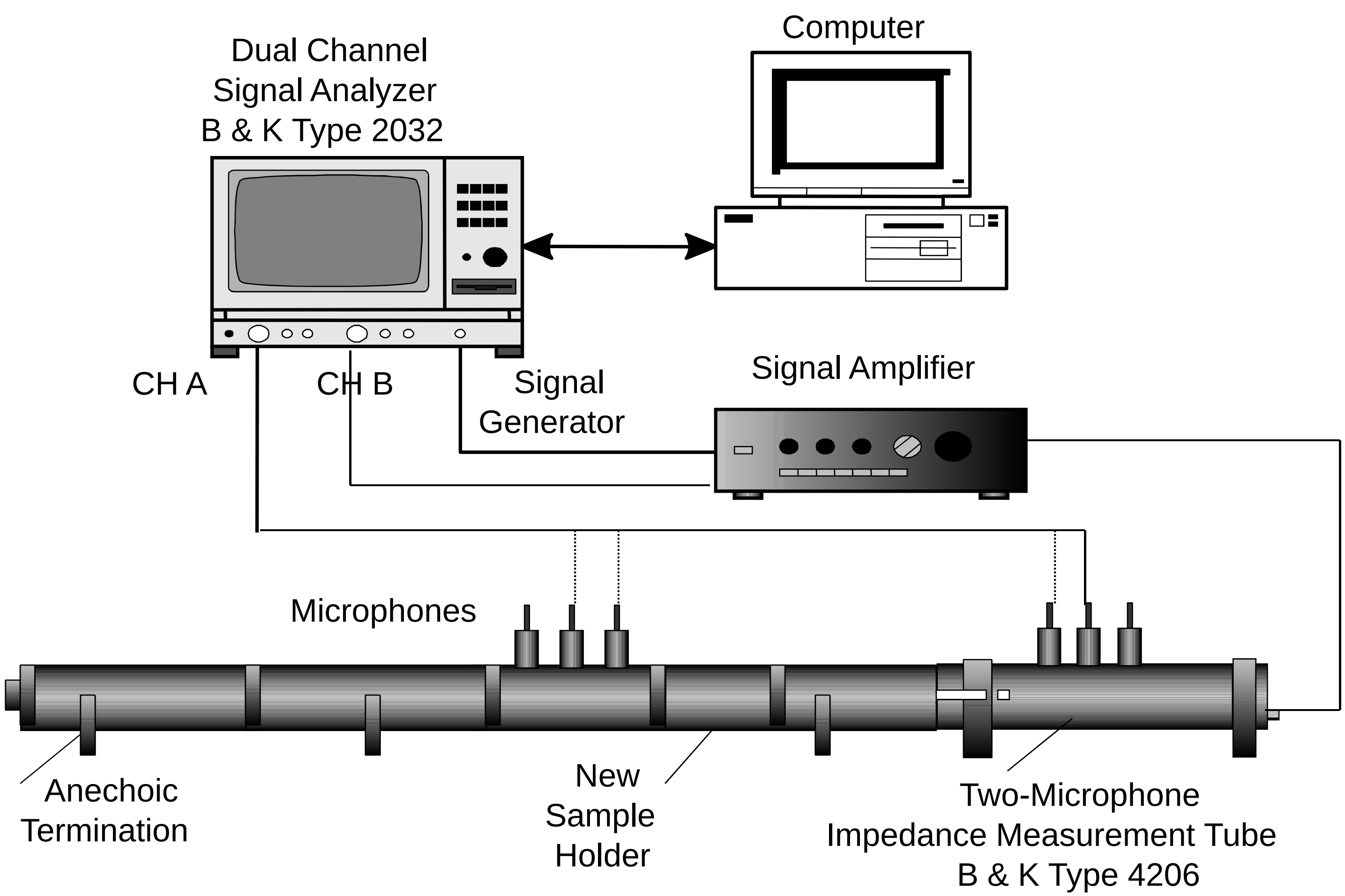
- **500 Hz**



- **1800 Hz**

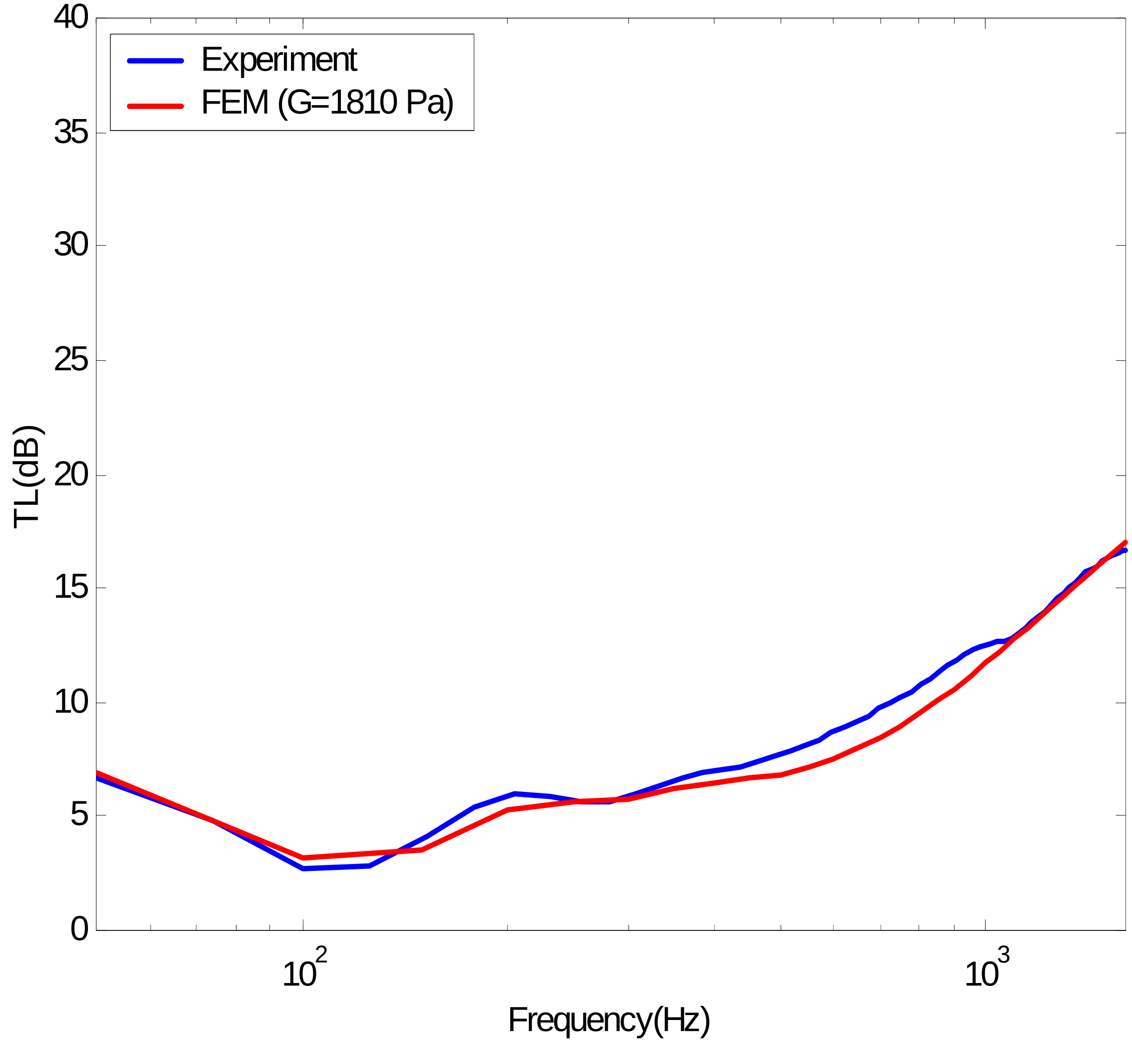


Effect of Sample Size
Experimental Setup for Low Frequency Tube

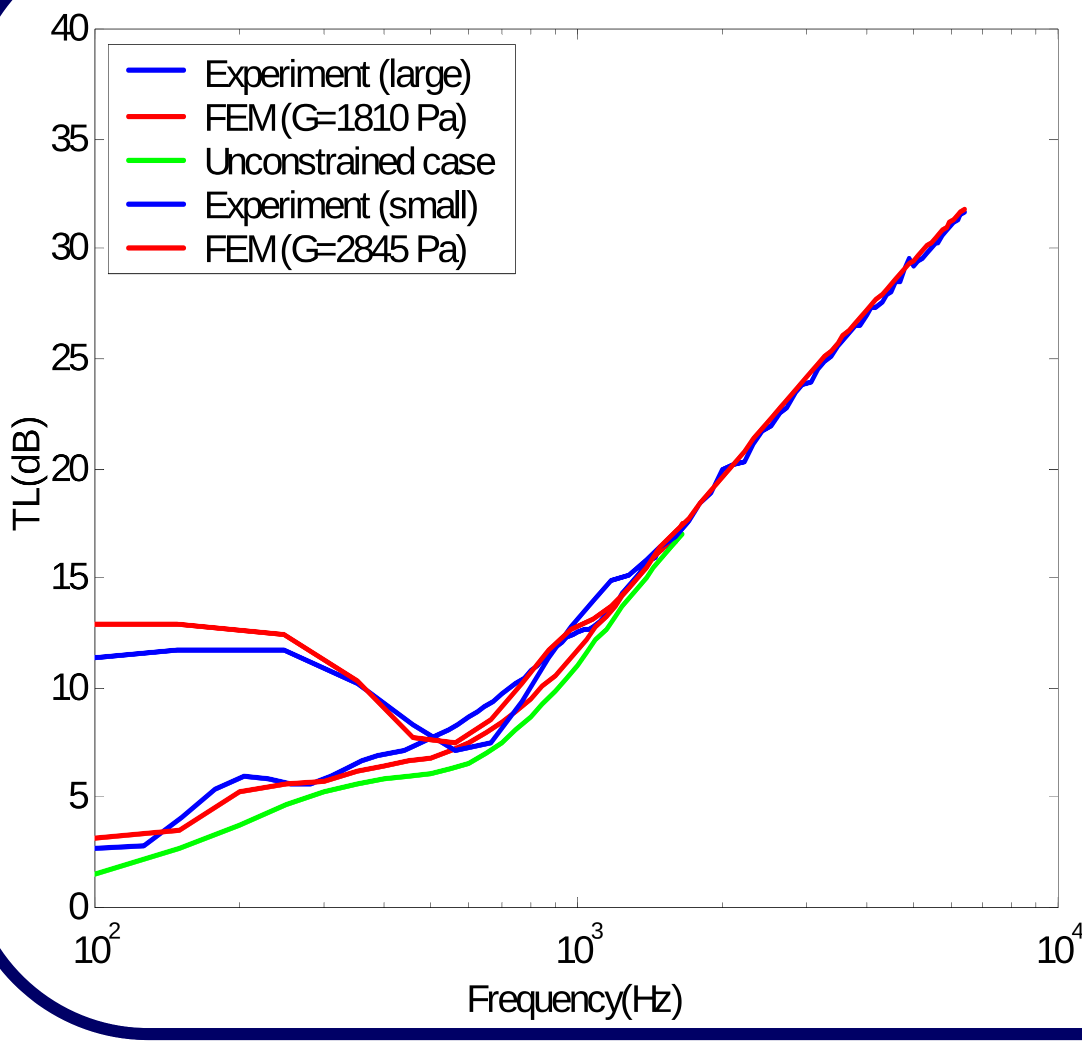


- **10 cm diameter samples, 7.5 cm deep**
- **Aviation grade glass fiber, 9.61 Kg/m^3**

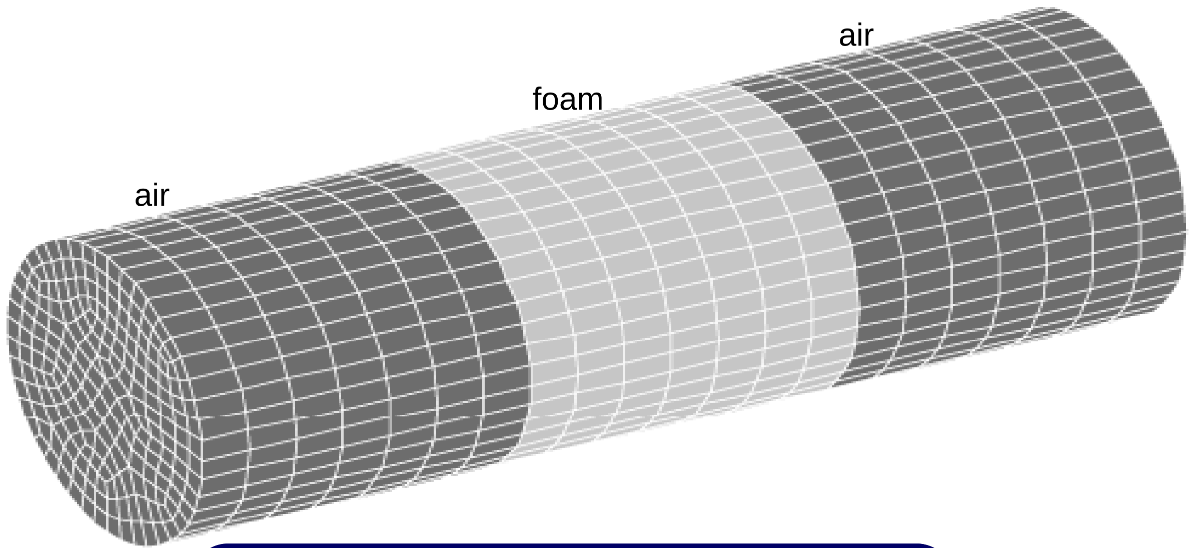
Transmission Loss (50 Hz - 1600 Hz)



Transmission Loss (100 Hz - 6400 Hz)



- **10 cm samples very nearly approximates <u>unconstrained case</u>**



Conclusions

- **Acoustical performances of fibrous layers such as transmission loss and absorption coefficient are affected by constraint on the boundary of the samples.**
- **The edge constraint effect is well predicted by using poroelastic FEM model (COMET/SAFE).**
- **<u>Light and stiff fibrous materials</u> combined with edge constraint mechanisms may enable us to design, light, high performance low frequency noise control barriers.**