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12-1999

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

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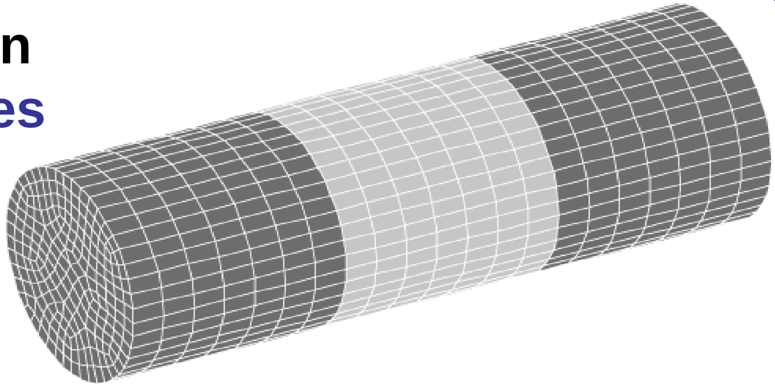
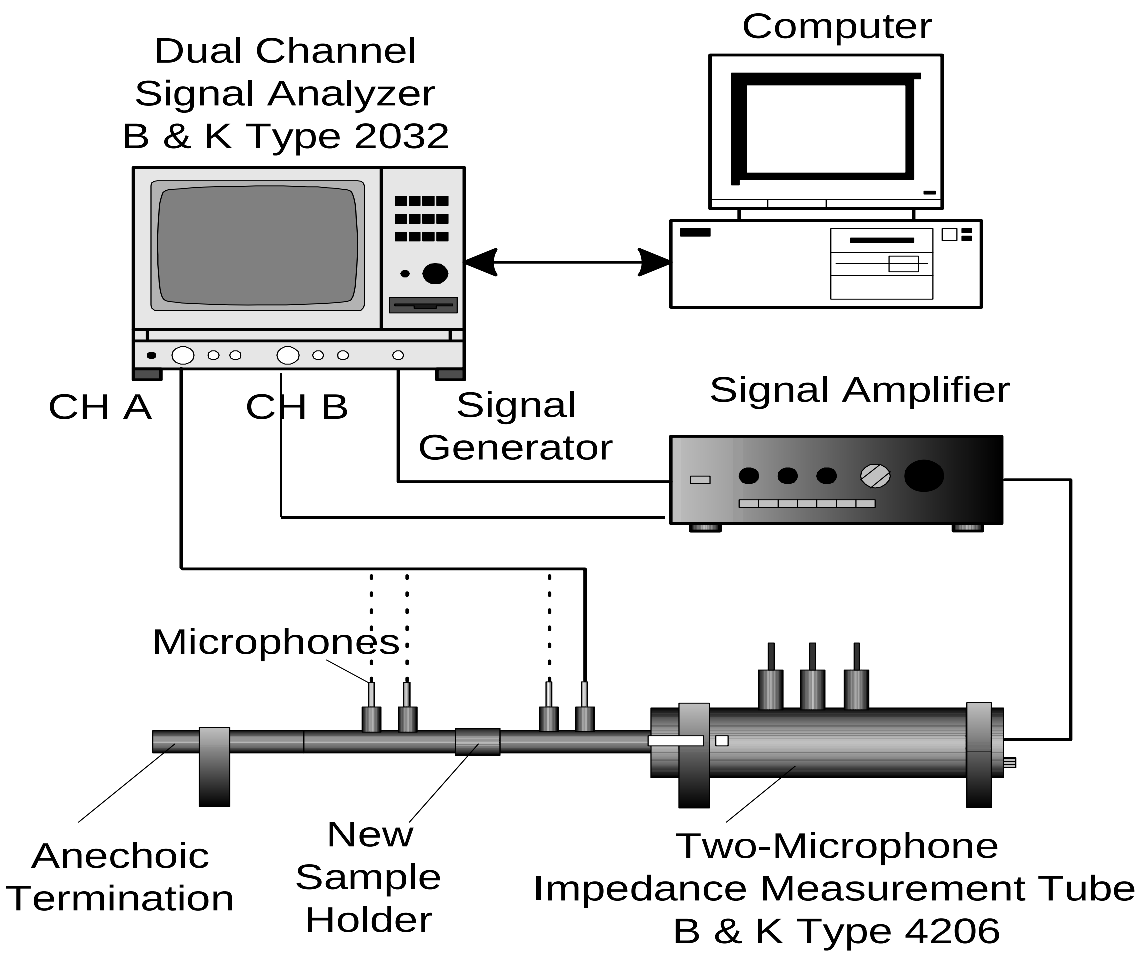


Introduction

- **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).

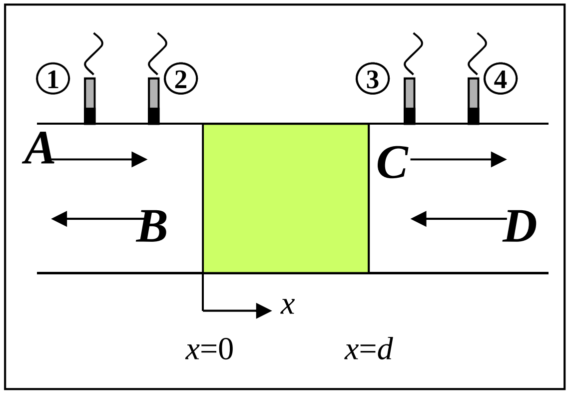
- **How**: Comparison of TL and impedance measurements with FEM predicted results using an axisymmetric model COMET / SAFE (Y. J. Kang et al., *JASA* 1999). Demonstration of how the materials' mechanical and physical properties control TL
- **What**: Implications for design of low frequency noise control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

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

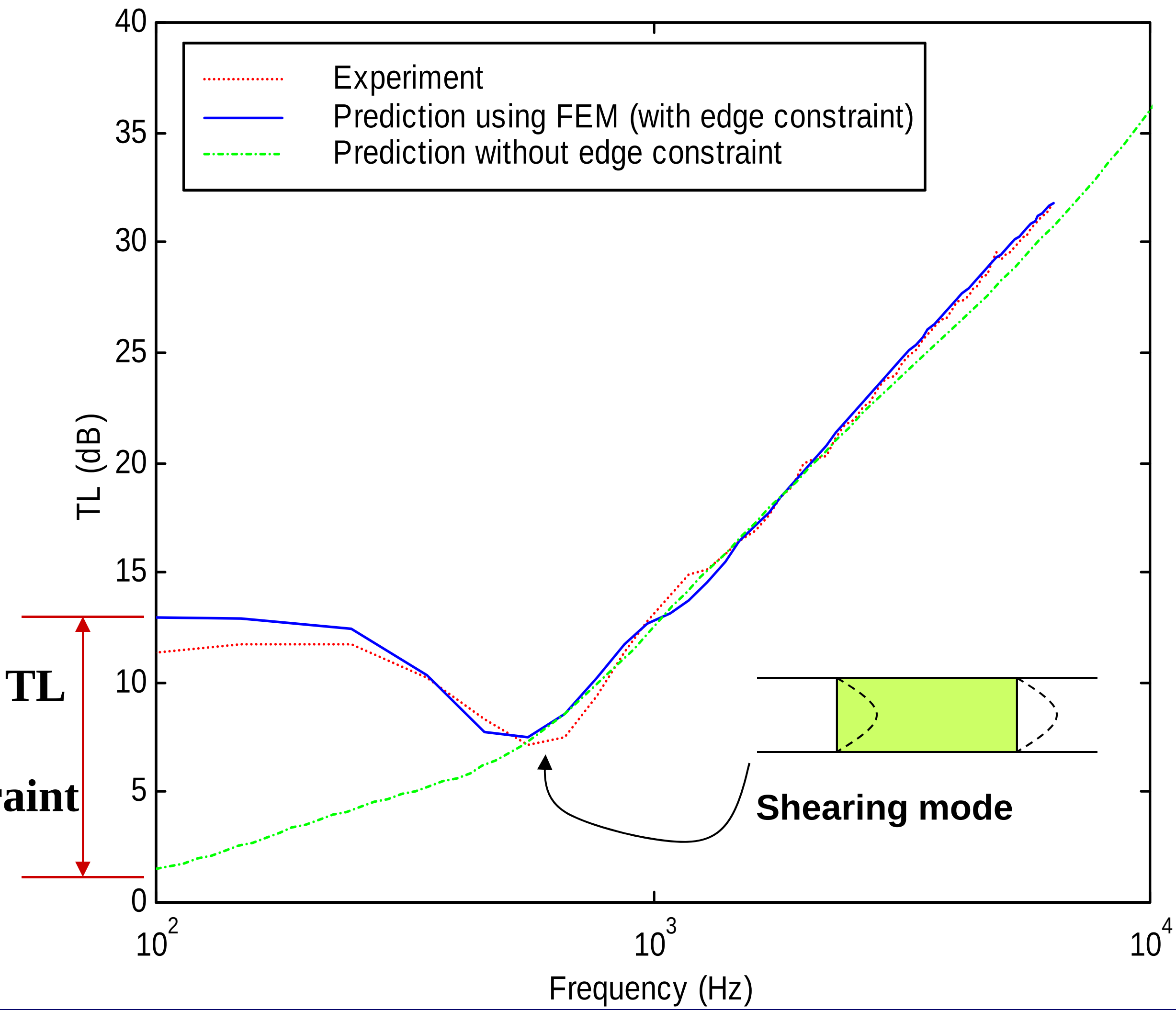
- **Anechoic Reflection Coefficient**

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

- **Anechoic Transmission Coefficient**

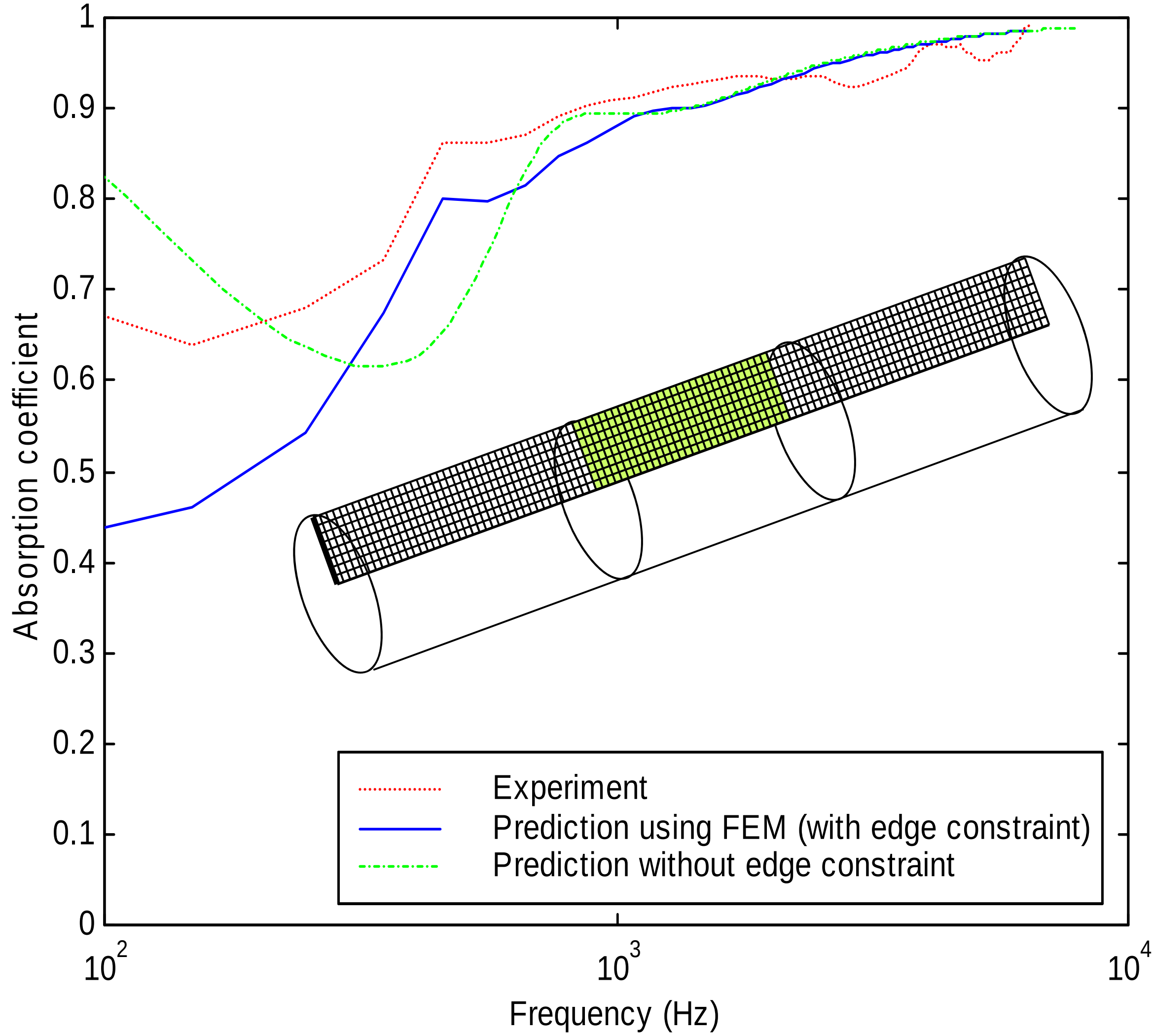
$$T_a = \frac{2 e^{jkd}}{T_{11} + \dfrac{T_{12}}{\rho_0 c} + \rho_0 c T_{21} + T_{22}} \Rightarrow \quad TL = 10 \log(1 / \left| T_a \right|^2)$$

Anechoic Transmission Loss

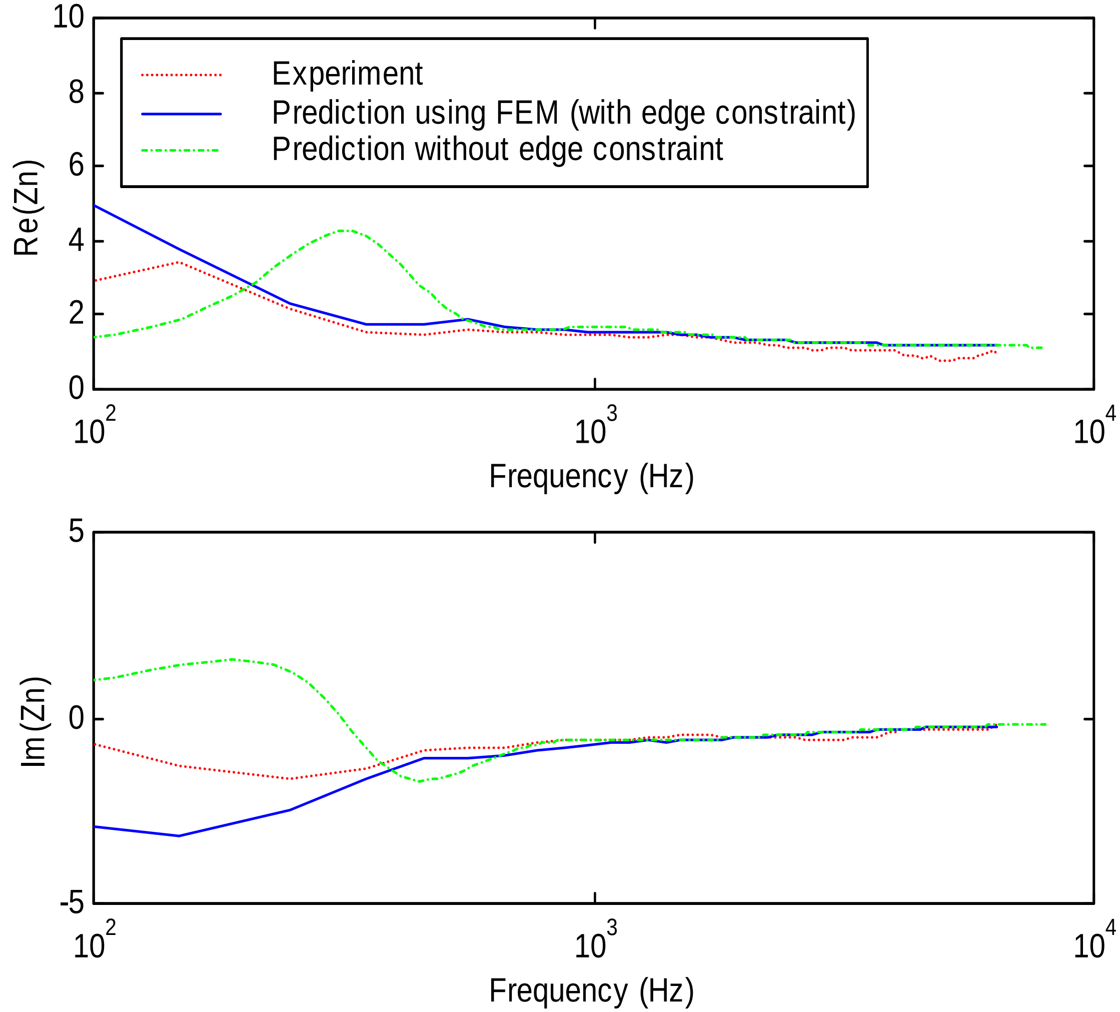


Increase in TL due to edge constraint

Anechoic Absorption Coefficient



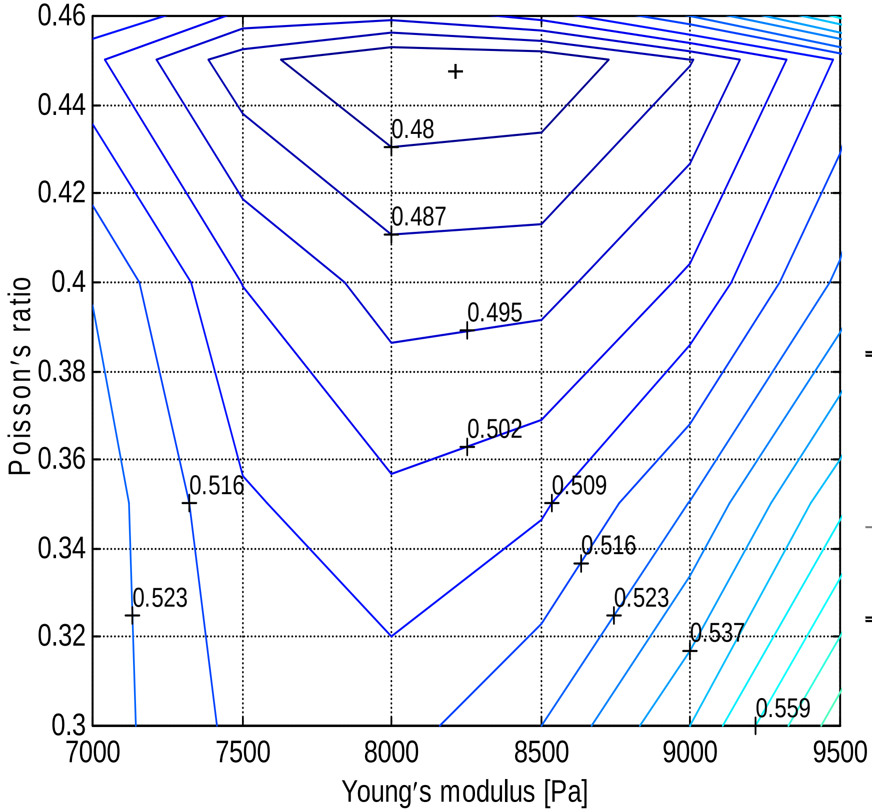
Surface Normal Impedance



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

Estimation of Material Mechanical Properties

• **Error surface**



+ **Minimum location**

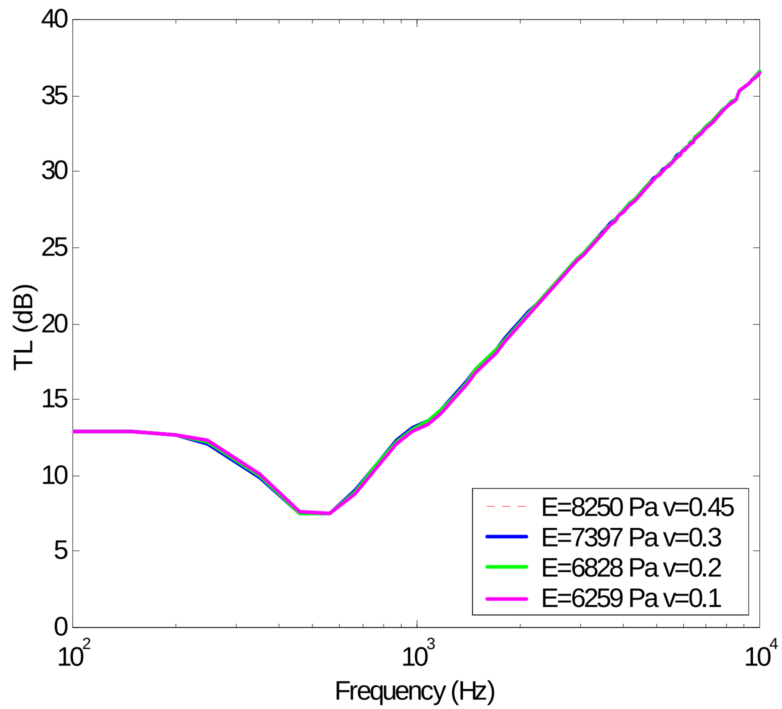
• **Objective Function**

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

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

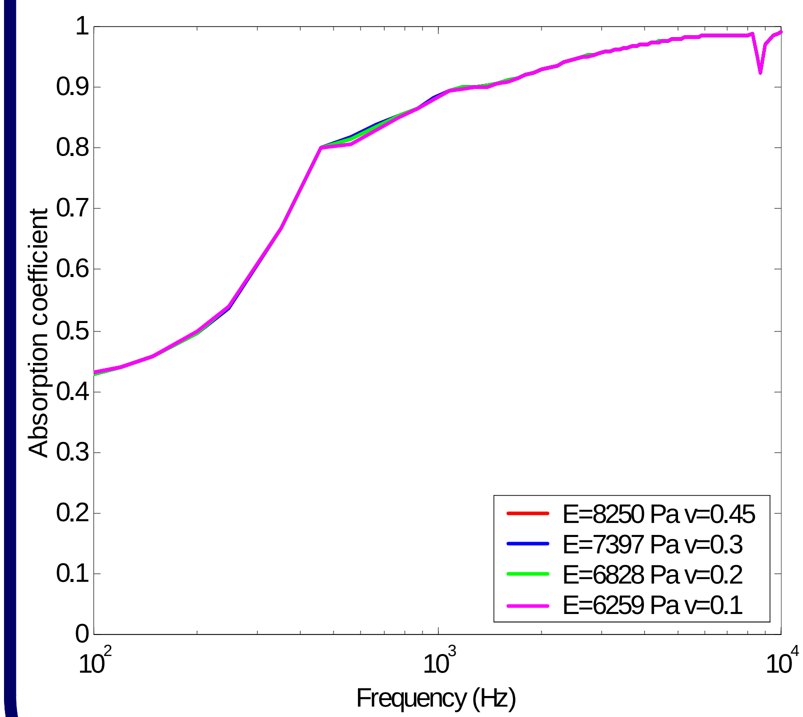
Transmission Loss

- **<u>Shear modulus</u> controls minimum location in TL curve**



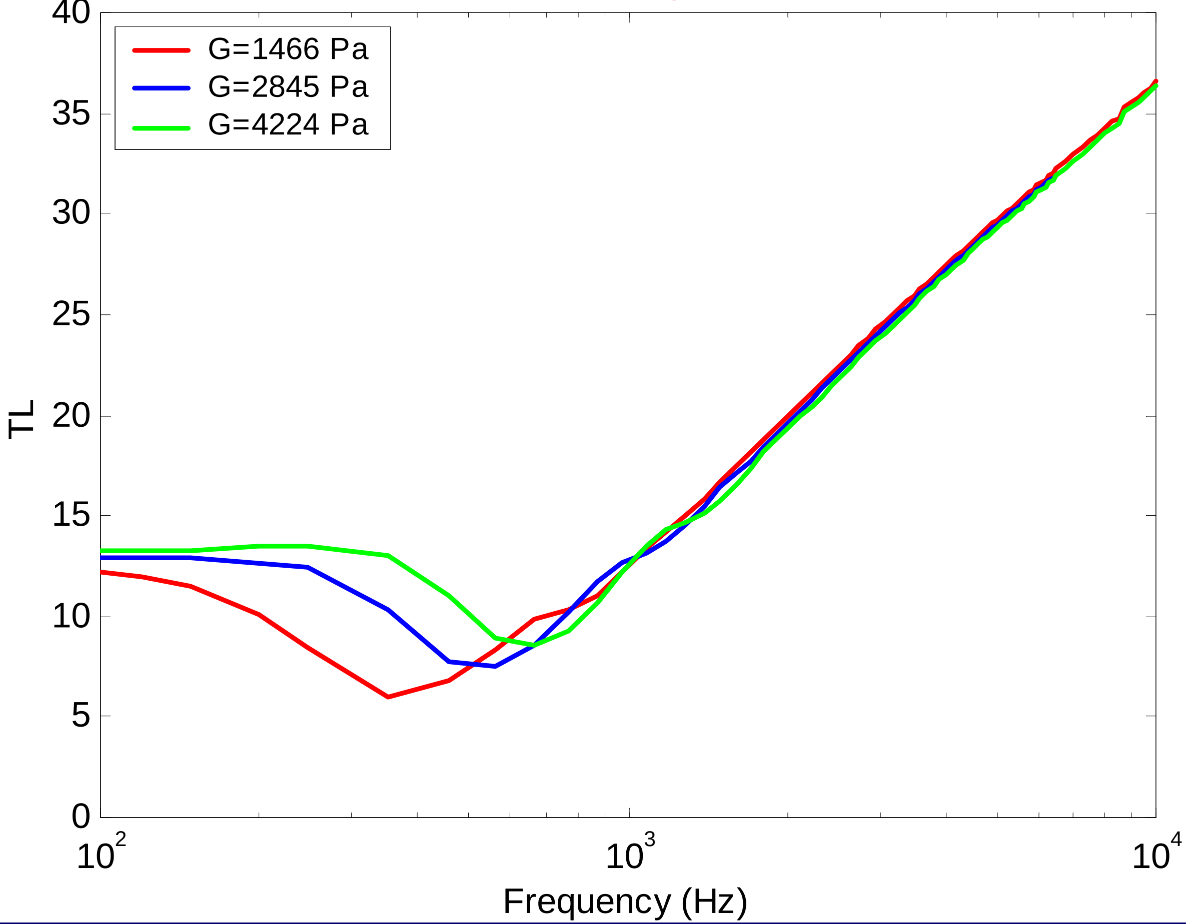
Absorption Coefficient

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



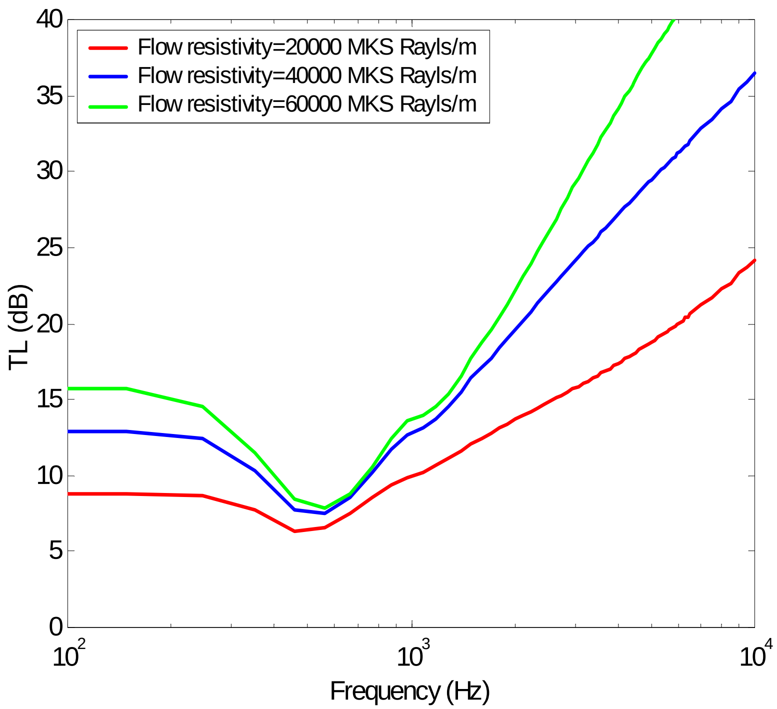
Variation of Shear Modulus

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



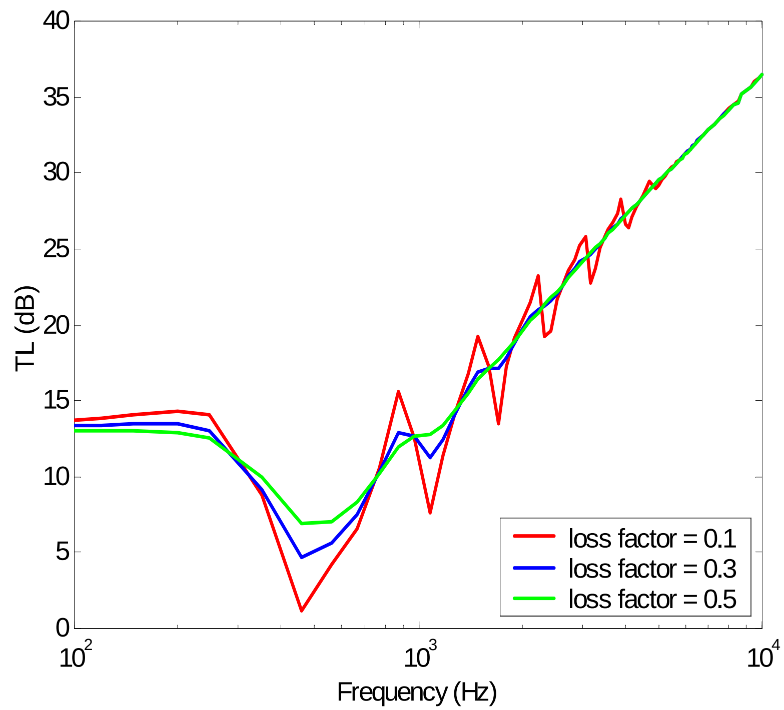
Flow Resistivity

• Flow resistivity controls TL in **low and high frequency limit**



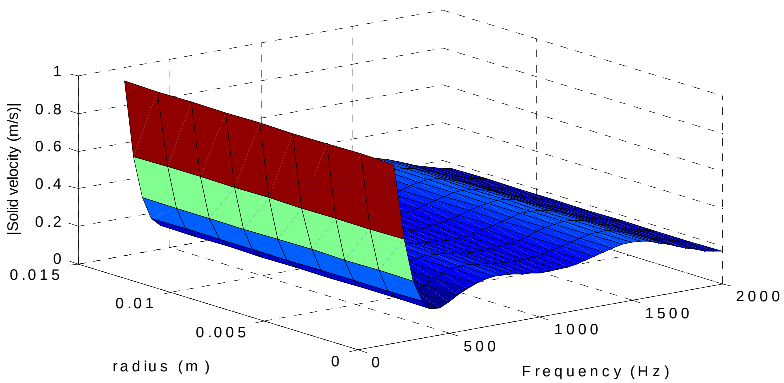
Loss Factor

• Loss factor controls depth of TL minimum

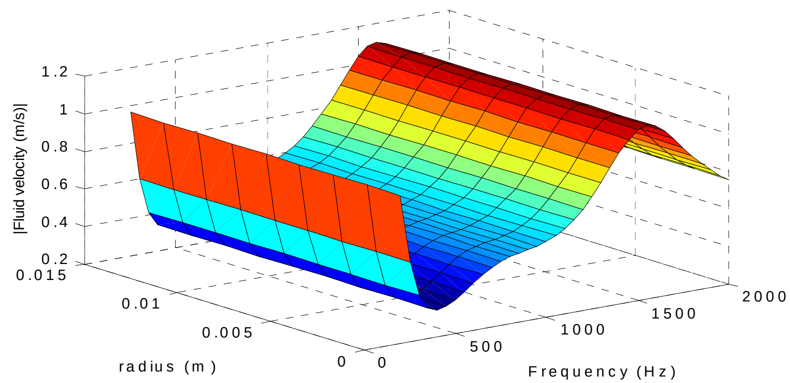


Axial Particle Velocity at the Front of Sample

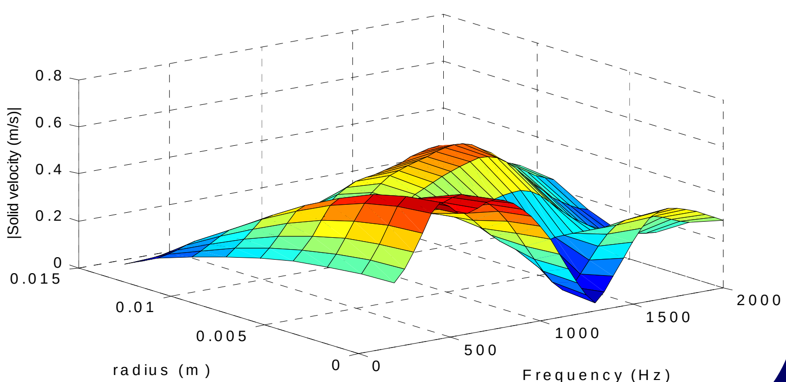
- **Solid phase (unconstrained)**



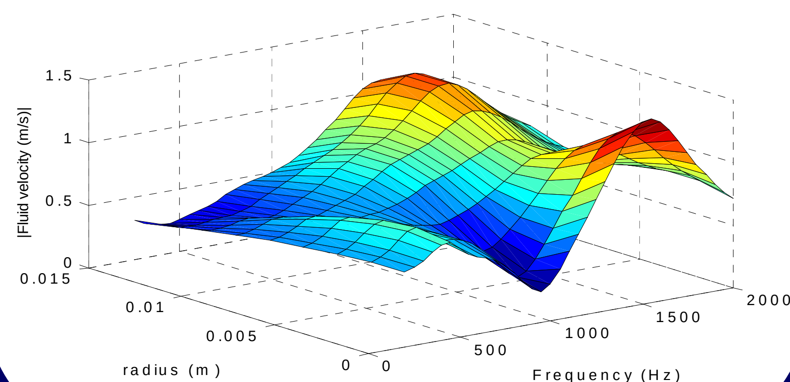
- **Fluid phase (unconstrained)**



- **Solid phase (constrained)**

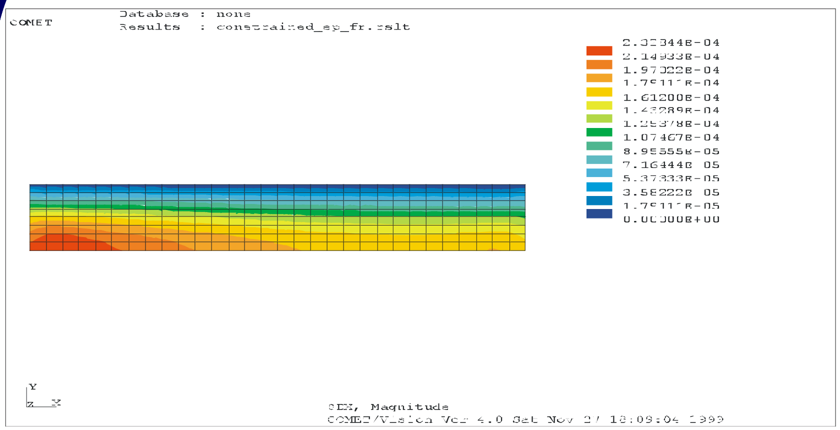


- **Fluid phase (constrained)**

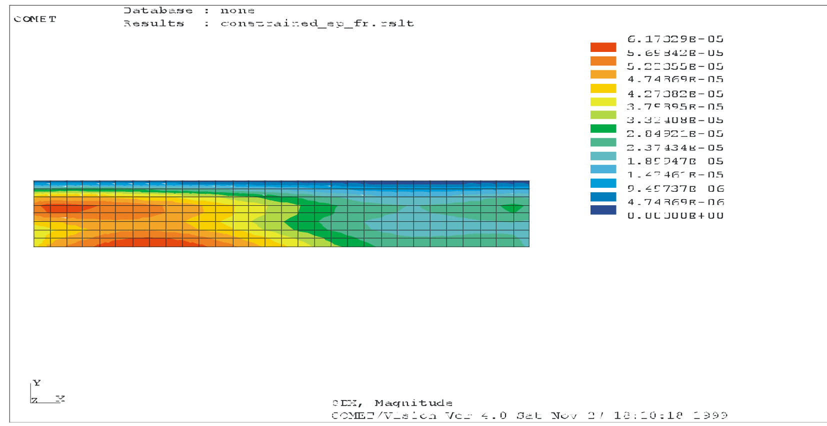


Solid Phase of Constrained Sample (SDX)

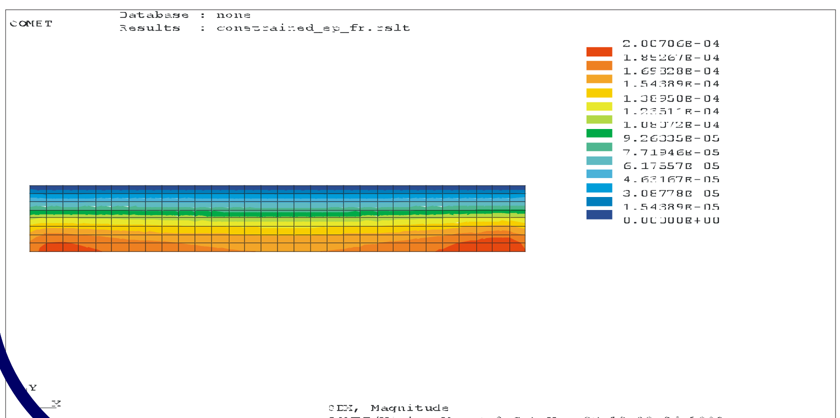
- 200 Hz



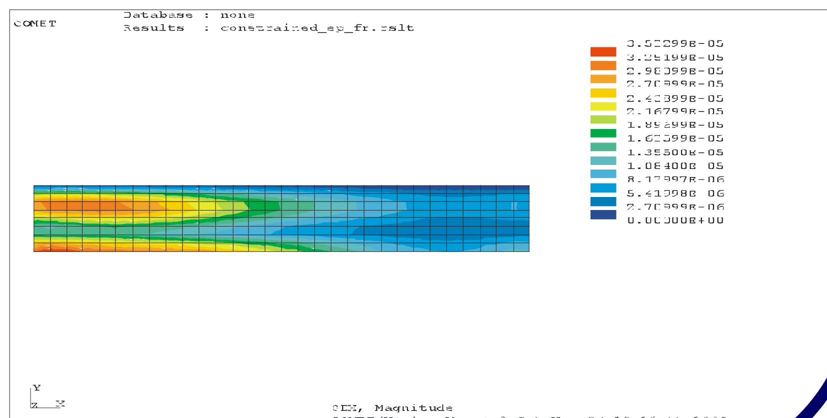
- 1100 Hz



- 500 Hz

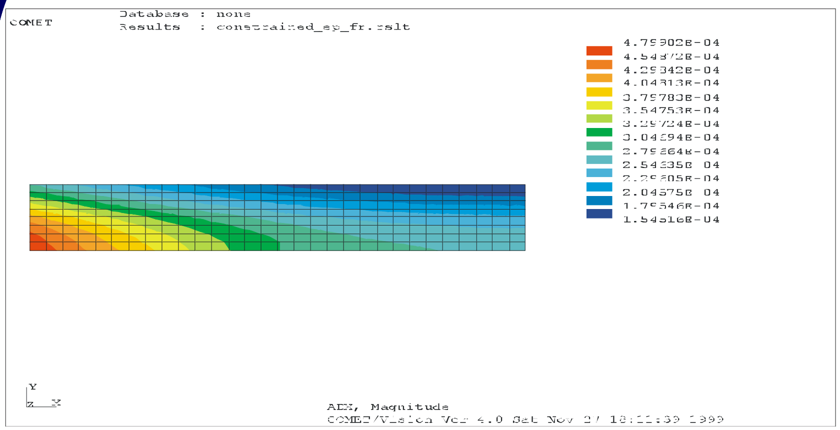


- 1800 Hz

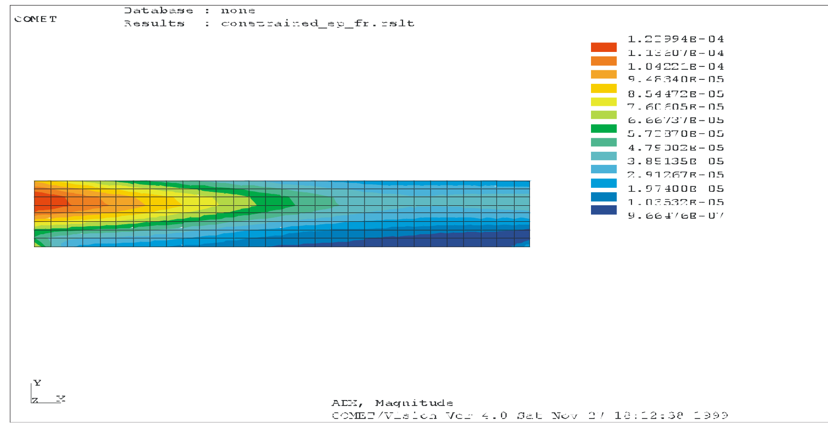


Fluid Phase of Constrained Sample (ADX)

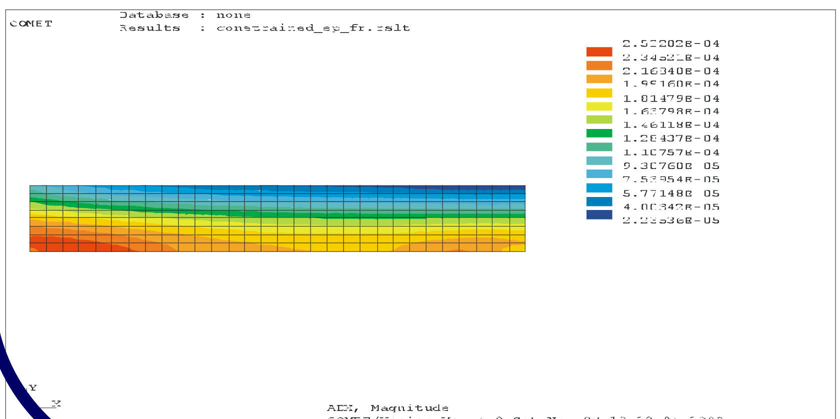
- **200 Hz**



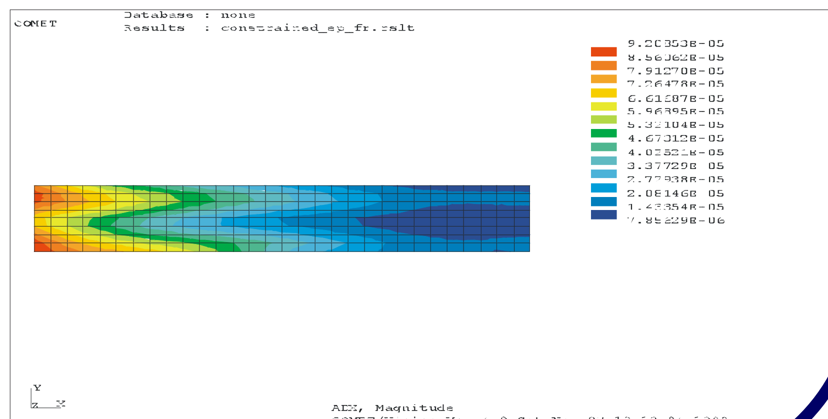
- **1100 Hz**



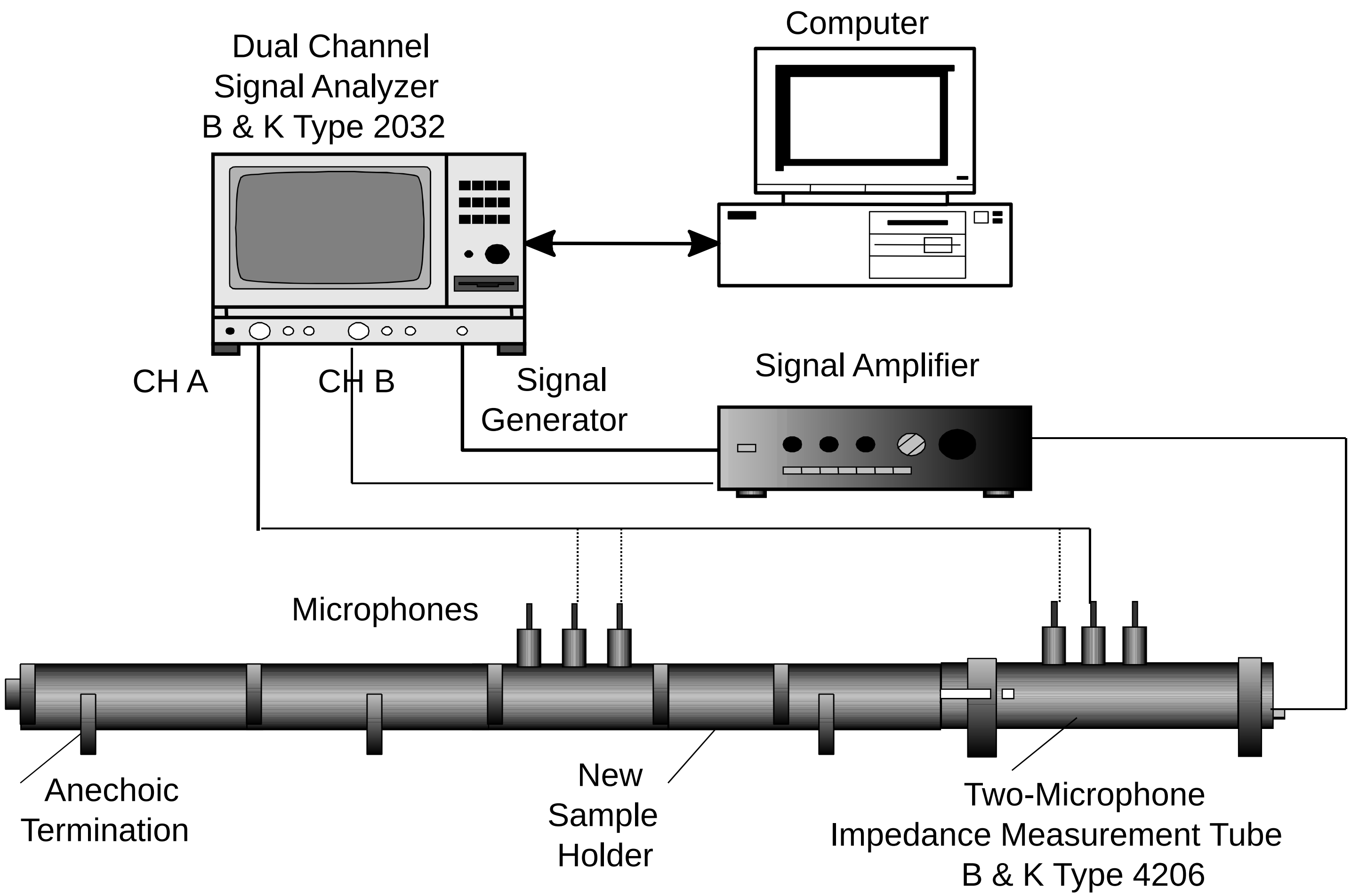
- **500 Hz**



- **1800 Hz**

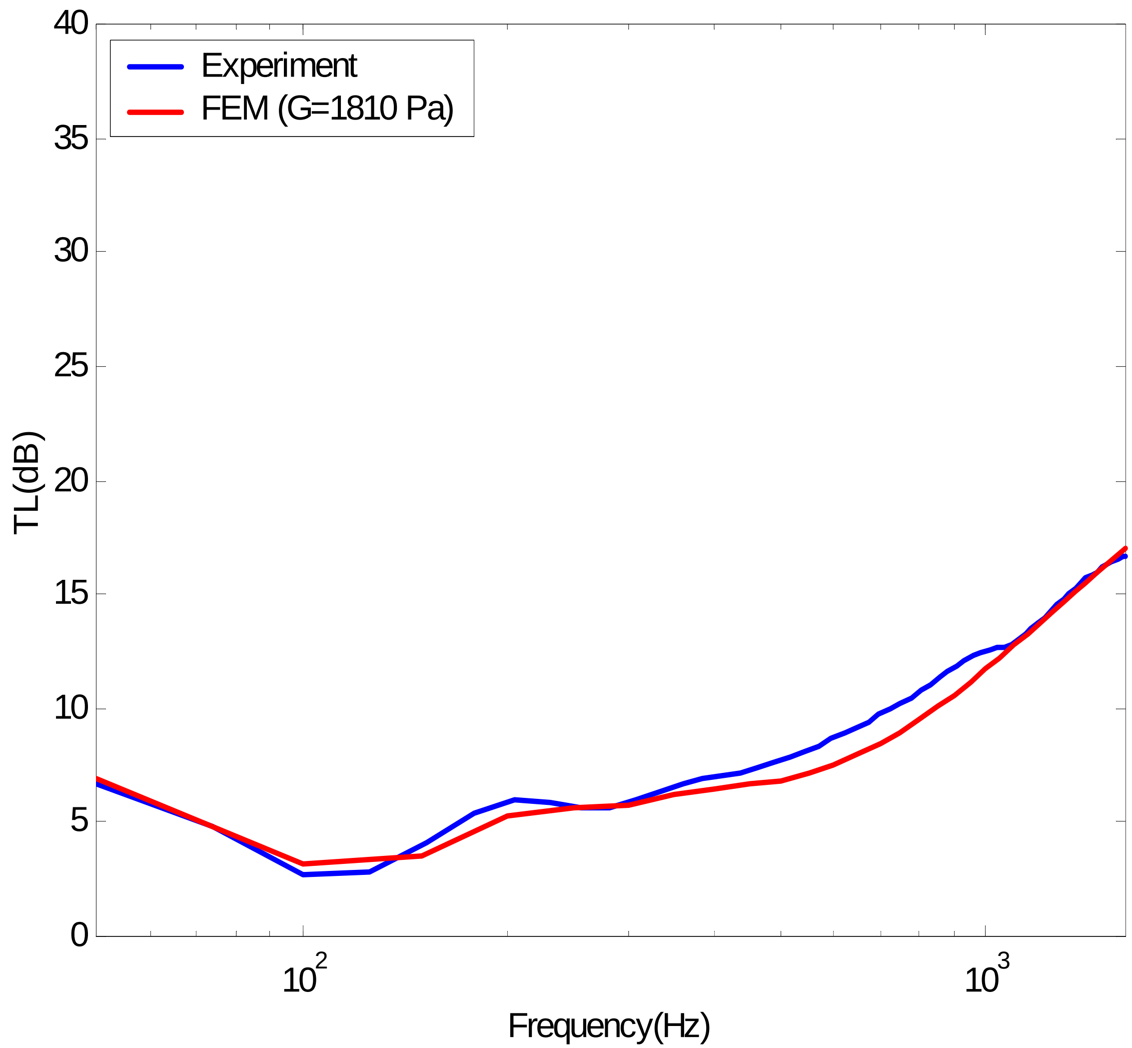


Effect of Sample Size
Experimental Setup for Low Frequency Tube

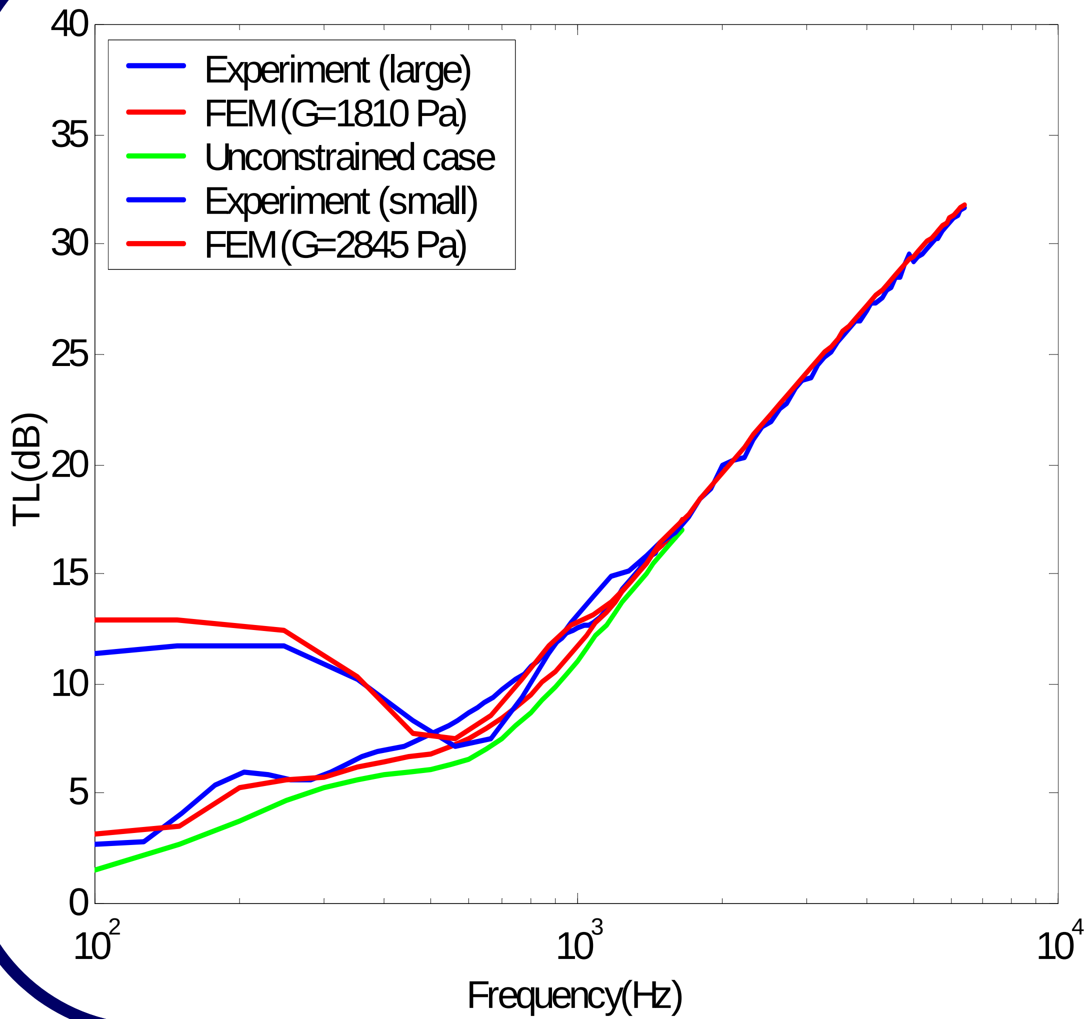


- **10 cm diameter samples, 7.5 cm deep**
- **Aviation grade glass fiber, 9.61 Kg/m^3**

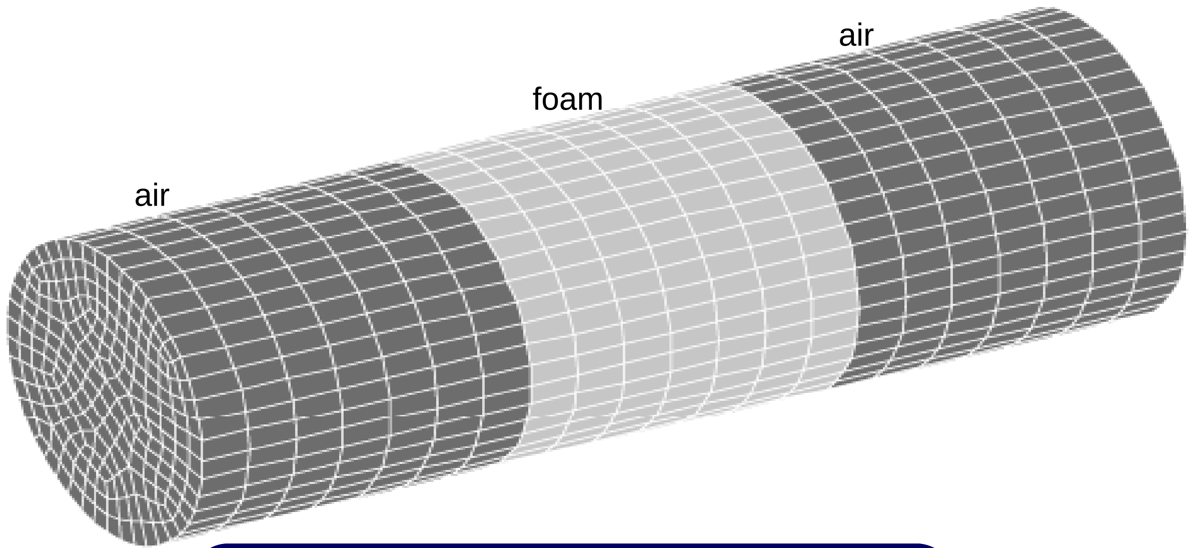
Transmission Loss (50 Hz - 1600 Hz)



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).**
- **Light and stiff fibrous materials combined with edge constraint mechanisms may enable us to design, light, high performance low frequency noise control barriers.**