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Finite Element Models for Sound Transmission through Foam Wedges and Foam Layers Having Spatially Graded Properties

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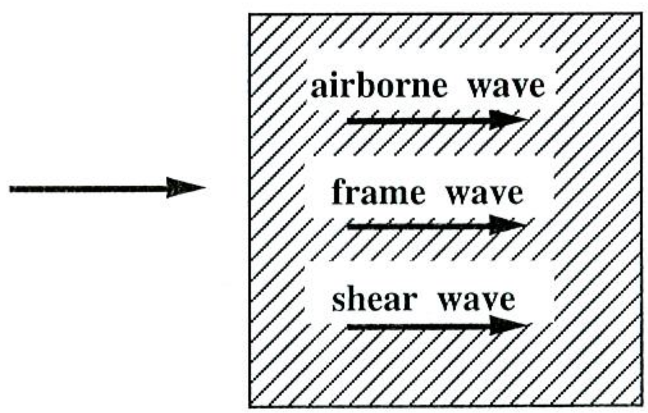
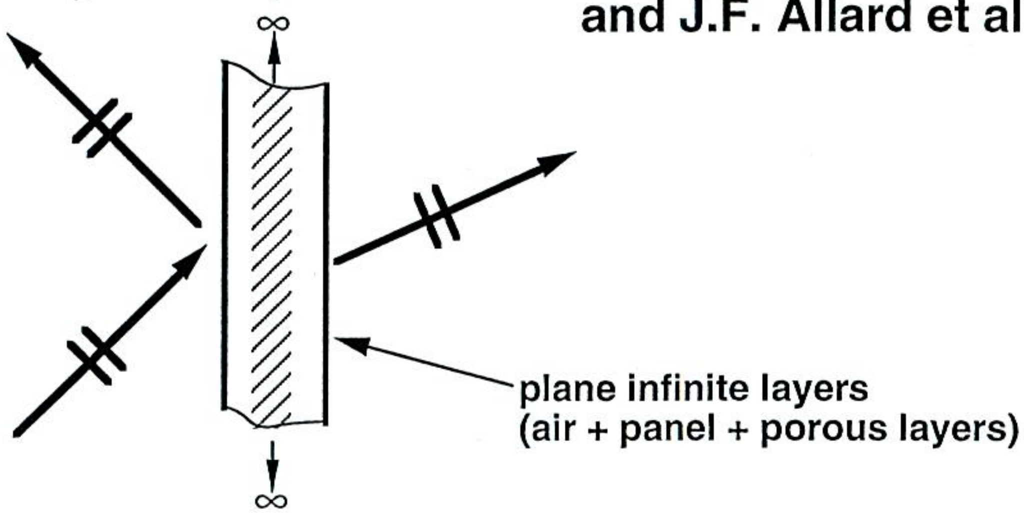
ELASTIC POROUS MATERIALS

- *Foam Material Properties*
  - Flow resistivity
  - Tortuosity (Structure Factor)
  - Porosity
  - Bulk Modulus of Elasticity
  - Poisson's Ratio
  - Loss Factor
- Biot Theory allows wave propagation to be expressed in terms of these macroscopically measurable properties.
- Multiple Wave Types → sensitive to boundary conditions

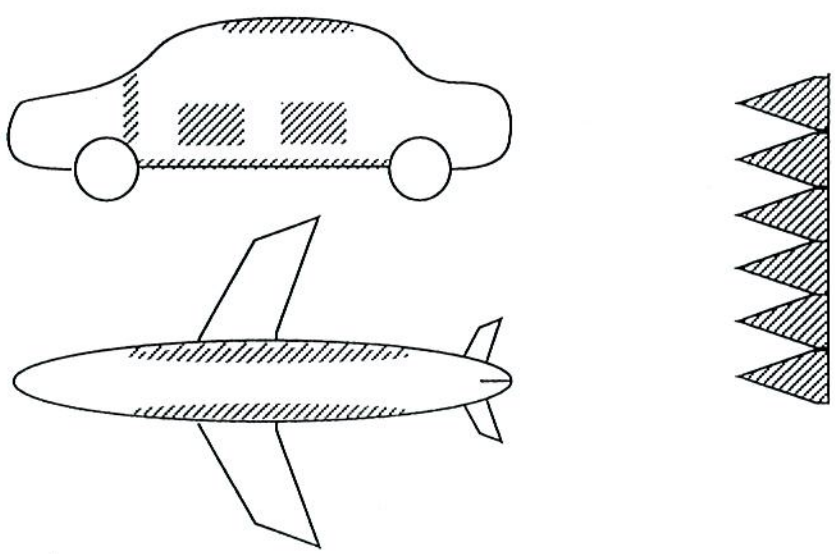


INTRODUCTION

- **Analytical Capabilities — available by J.S. Bolton and J.F. Allard et al.**

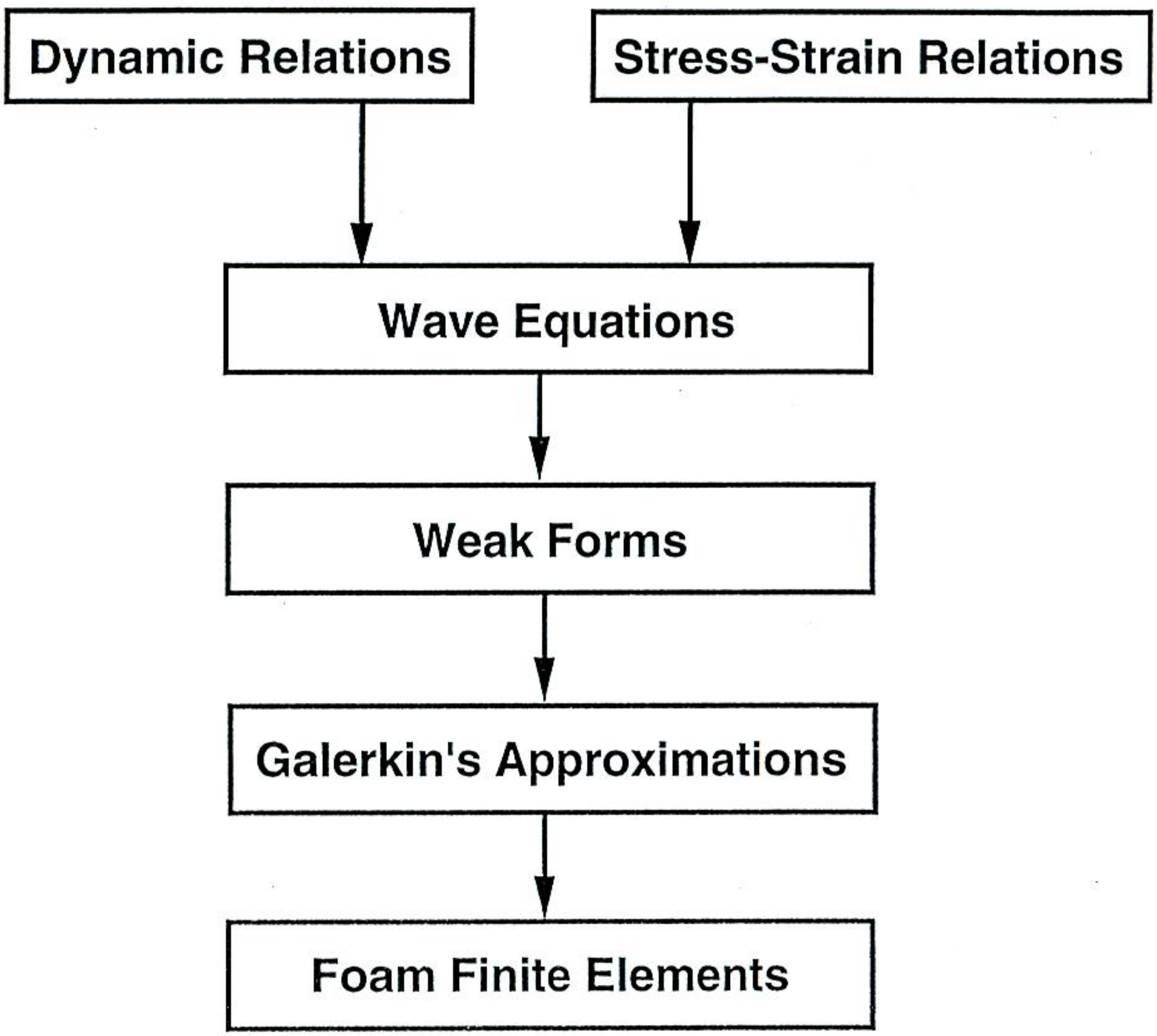


- **Practical Treatments**



FOAM FINITE ELEMENTS

Elastic Porous Material Theory based on Biot



Finite Element Models/Foam Properties

- **FEM Models**

  (i) Foam

  3-noded linear triangular elements

  (ii) Structure

  2-noded hermite cubic elements

  (iii) Airspace

  3-noded linear triangular elements

- **Foam Properties**

  bulk density of solid phase: 30 kg/m^3

  bulk Young's modulus: $8 \times 10^5 (1 + j\,0.265)$ Pa

  bulk Poisson's ratio: 0.4

  flow resistivity: 25,000 MKS Rayls/m

  tortuosity: 7.8

  porosity: 0.9

BOUNDARY CONDITIONS

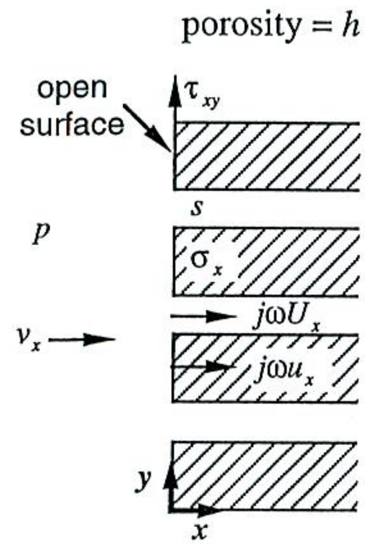
- **OPEN SURFACE**

$$-hp = s$$

$$-(1-h)p = \sigma_x$$

$$\tau_{xy} = 0$$

$$v_x = j\omega(1-h)u_x + j\omega h U_x$$



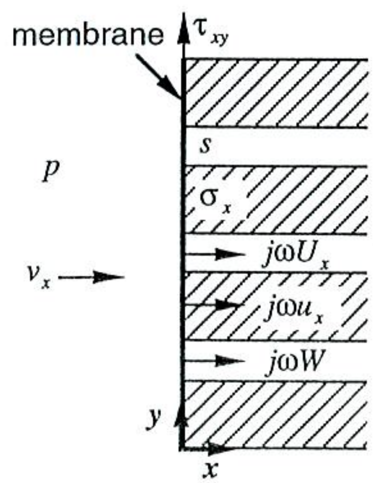
- **MEMBRANE-SEALED SURFACE**

$$v_x = j\omega W$$

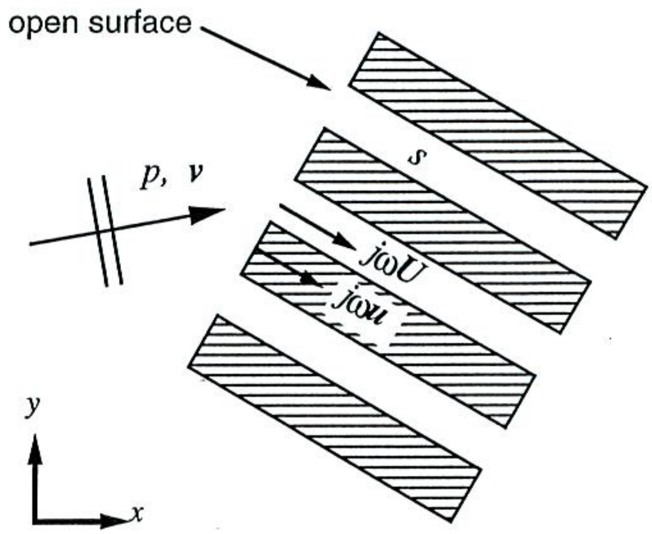
$$u_x = W$$

$$U_x = W$$

$$\pm p \pm (\sigma_x + s) = -\omega^2 m_s W$$



BOUNDARY CONDITIONS — OPEN SURFACE



$$hp\mathbf{n_a} = s\mathbf{n_f}$$

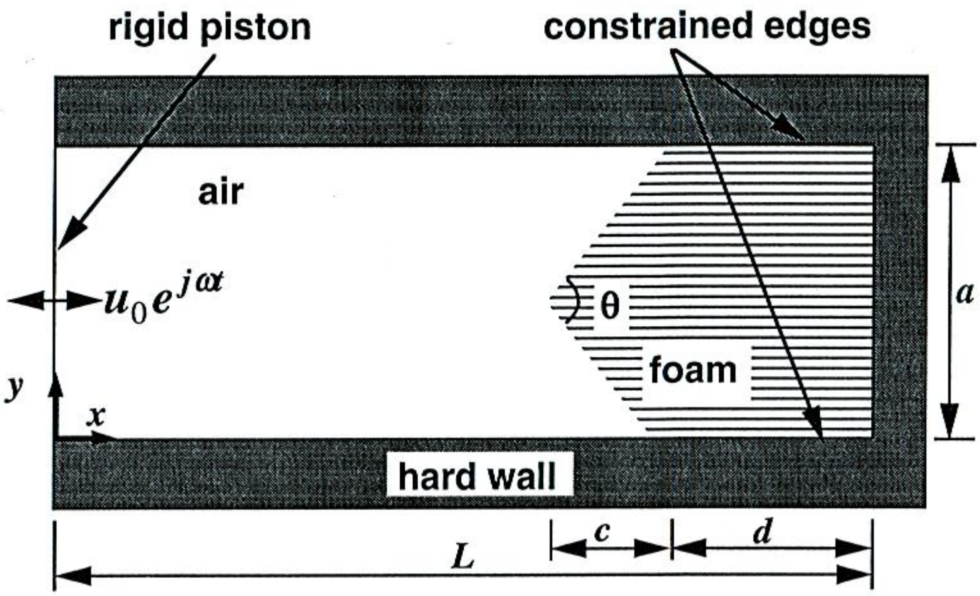
$$(1-h)\,pn_{ax} = \sigma_x n_{fx} + \tau_{xy} n_{fy}$$

$$(1-h)\,pn_{ay} = \tau_{xy} n_{fx} + \sigma_y n_{fy}$$

$$\mathbf{v} = j\omega(1-h)\mathbf{u} + j\omega h\mathbf{U}$$

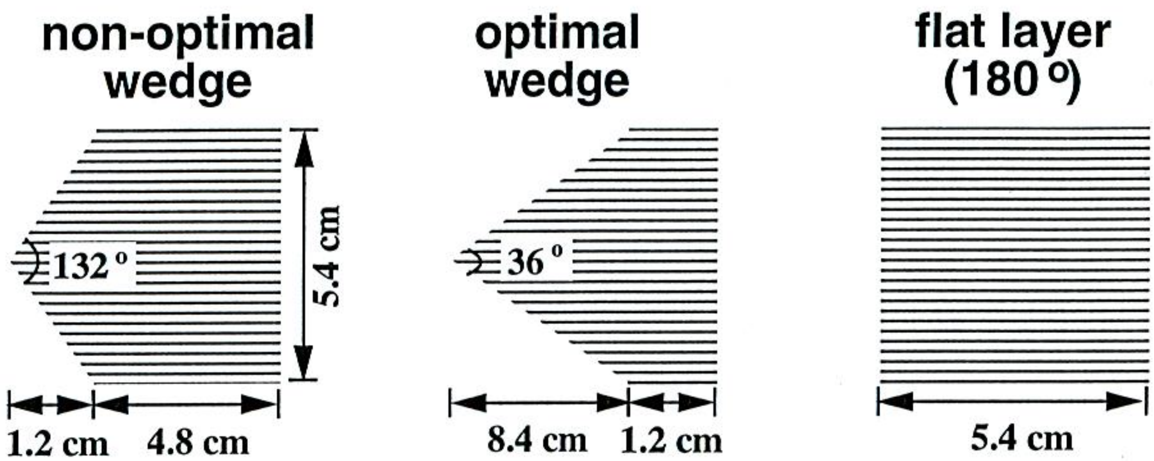
SHAPE OPTIMIZATION OF FOAM WEDGE

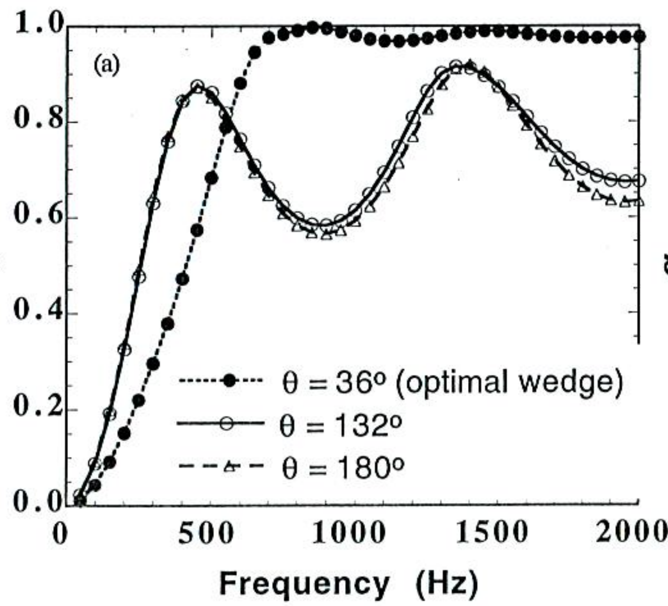
- *Objective* –maximize absorption offered by a wedge over a specified frequency range

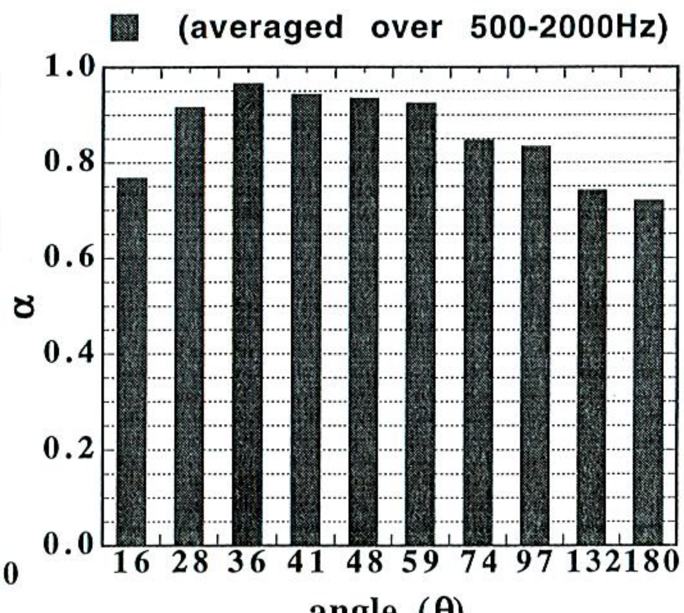


- wedge defined by θ
  when volume and *a* is held constant
- given volume find optimum angle, θ

SHAPE OPTIMIZATION OF FOAM WEDGE





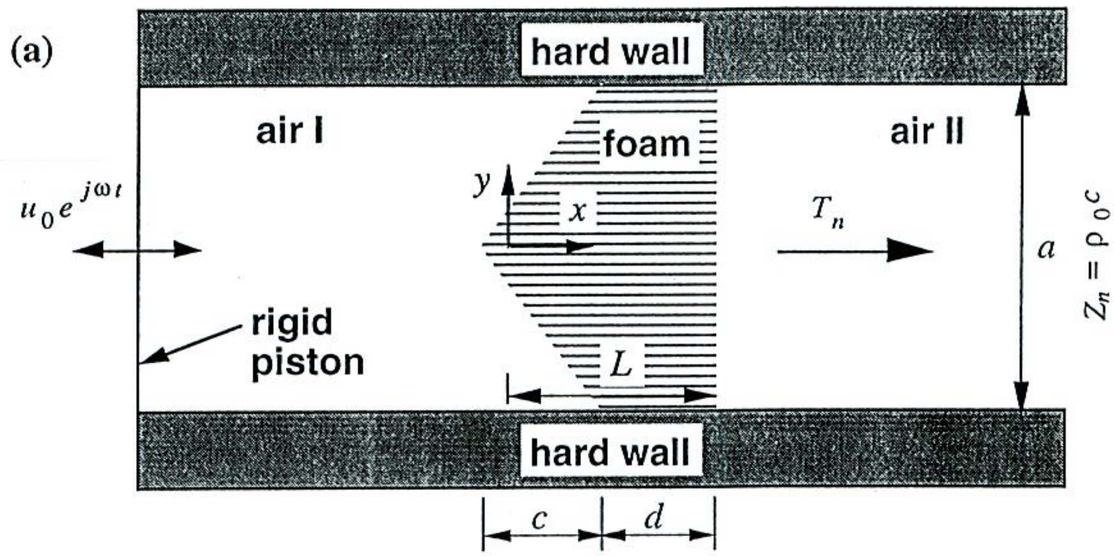


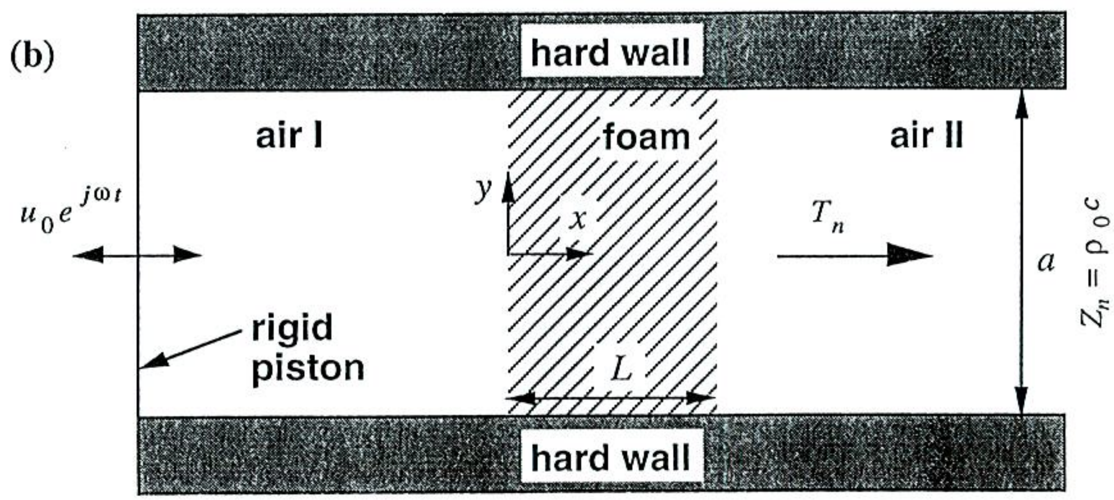
MOTIVATIONS AND OBJECTIVE

- **Motivations**
  - could optimize shape of a foam wedge by maximizing absorption offered by a wedge over a specified frequency range
  - found interesting and useful sound transmission characteristics of foam wedge in some high frequency bands
  - required larger treatment spaces if foam wedges are used

- **Objective**
  - to find a way of increasing sound transmission loss of a plane foam layer based on facts that were found from wedge studies

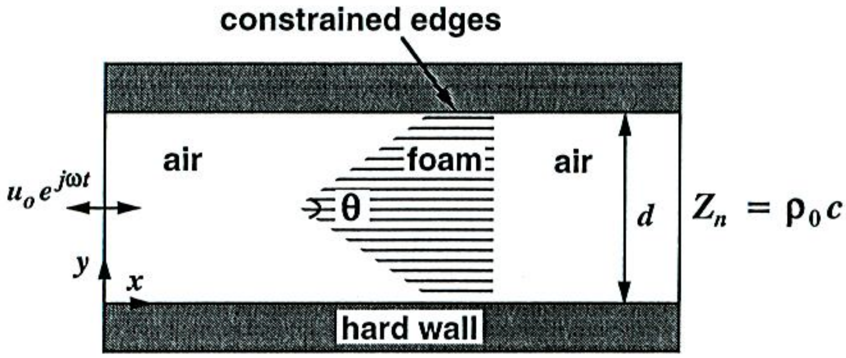
SYSTEM CONFIGURATIONS



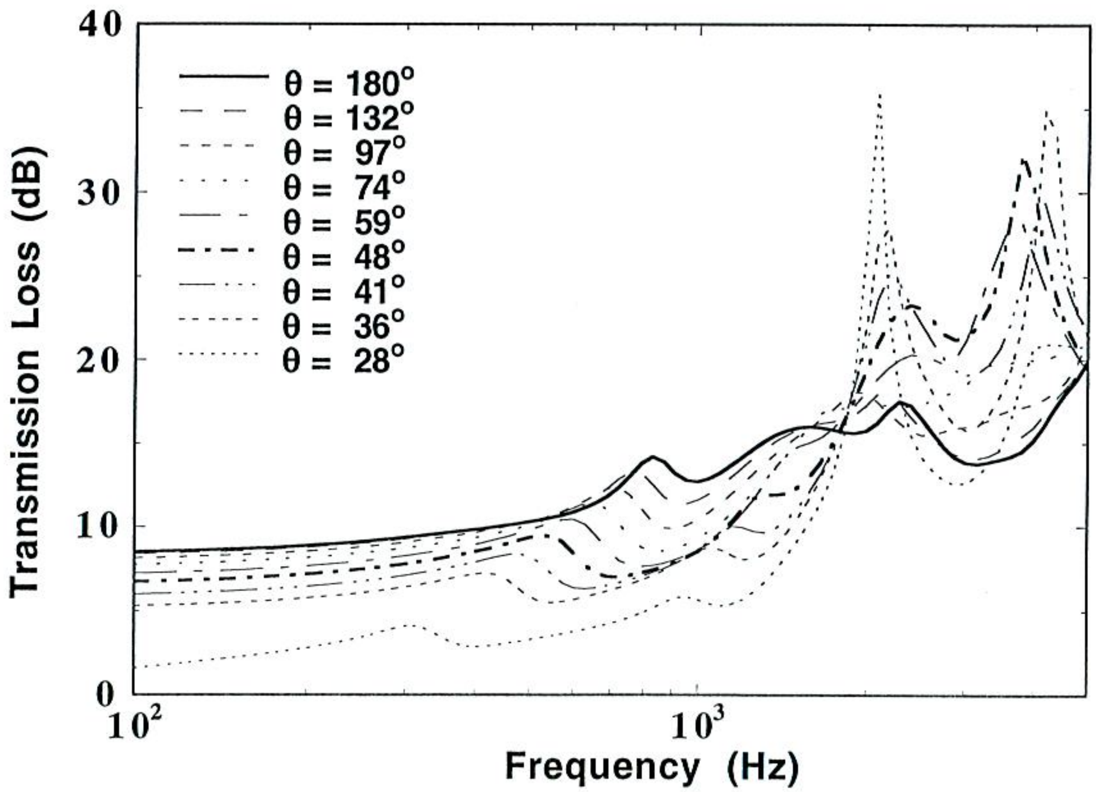


In system (b), tortuosity of a foam layer is varied spatially across the duct (in y-direction).

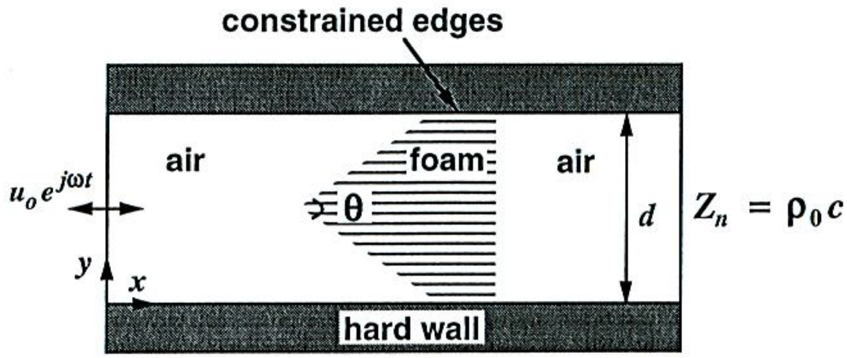
SOUND TRANSMISSION THROUGH A WEDGE



$d = 5.4$ cm



SOUND TRANSMISSION THROUGH A WEDGE



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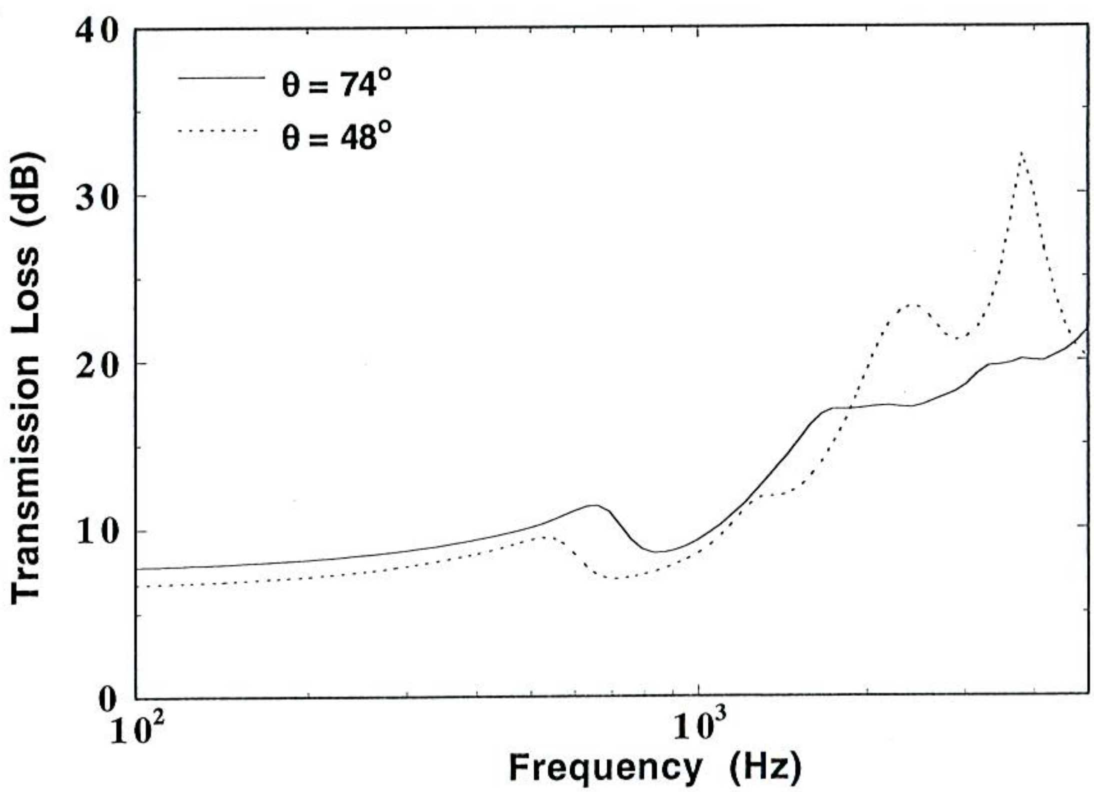
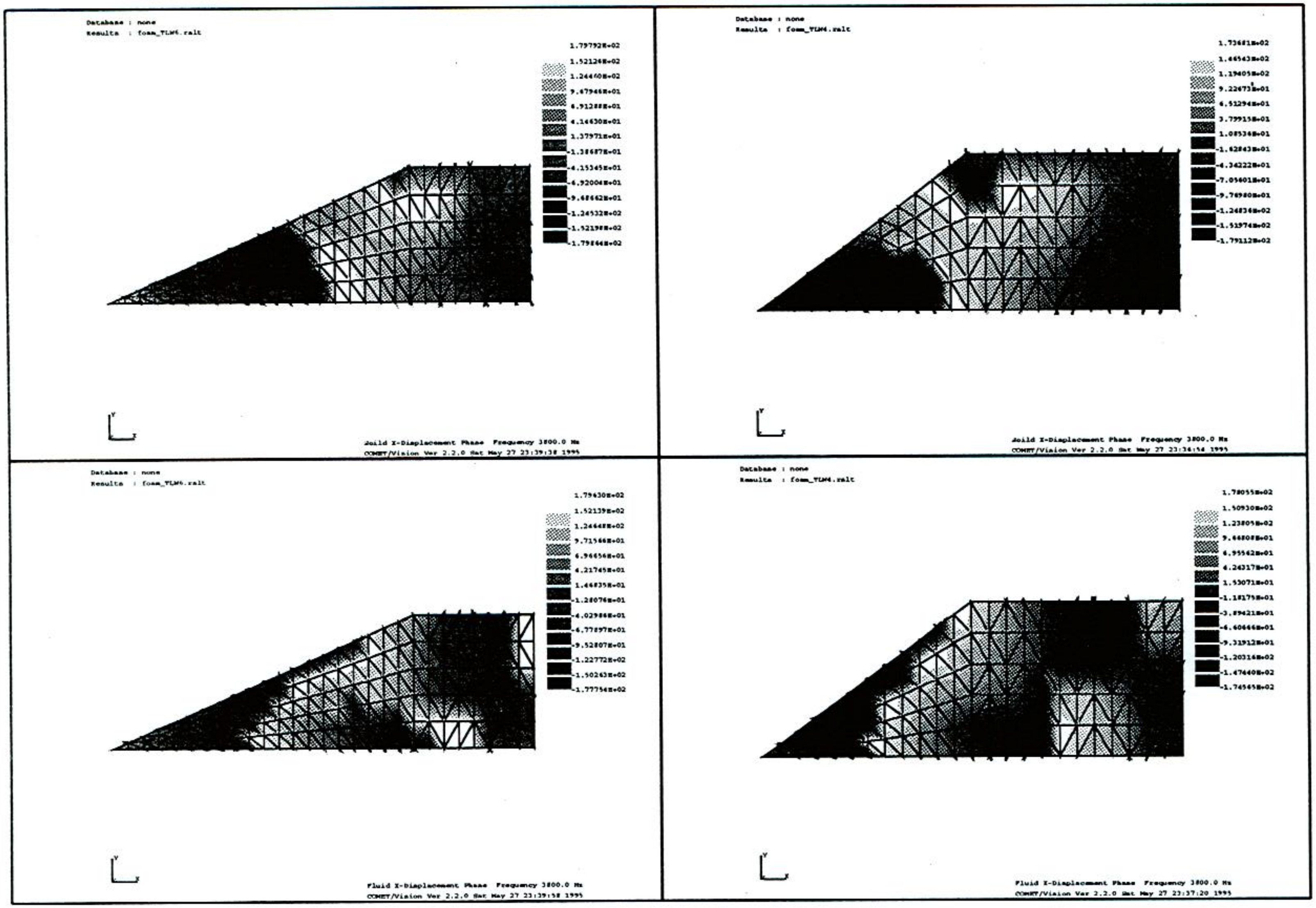


PHASES OF THE X-DISPLACEMENTS OF THE SOLID AND FLUID PHASES (f = 3800 Hz)

$\theta = 48^{\circ}$ | $\theta = 74^{\circ}$

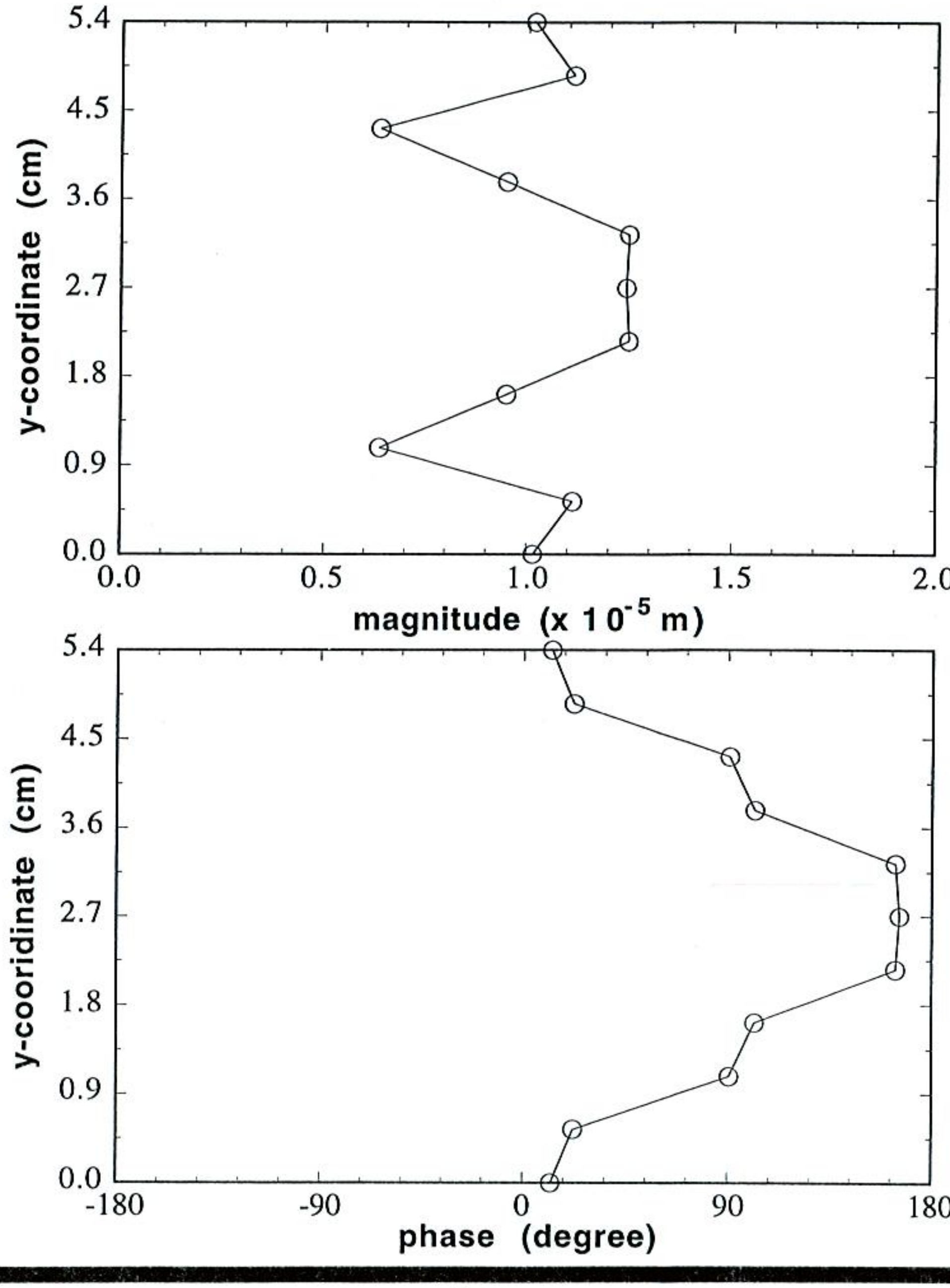
Solid

Fluid

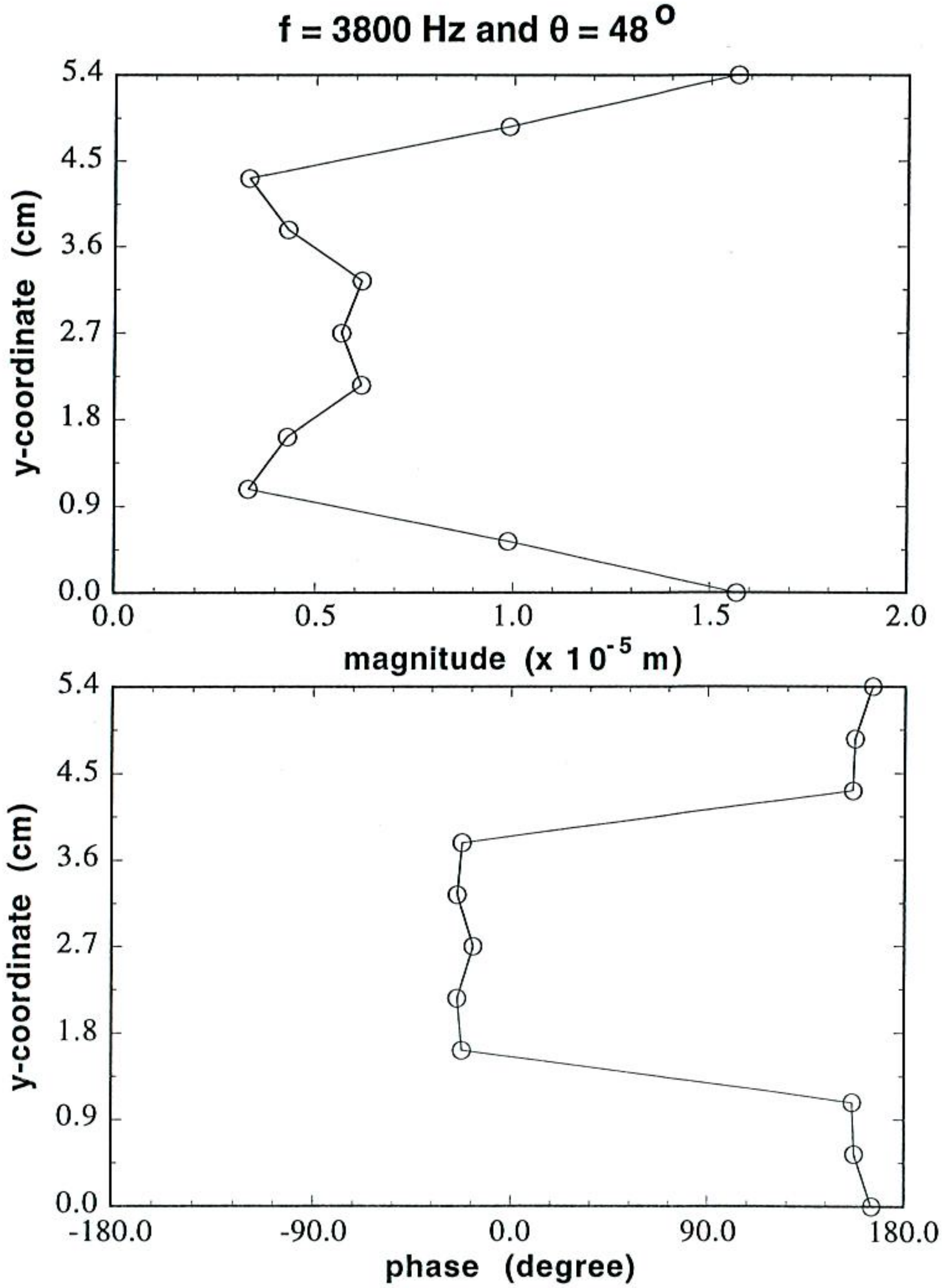


MAGNITUDE AND PHASE OF THE X-DISPLACEMENT OF THE FLUID PHASE AT THE REAR SURFACE OF THE WEDGE

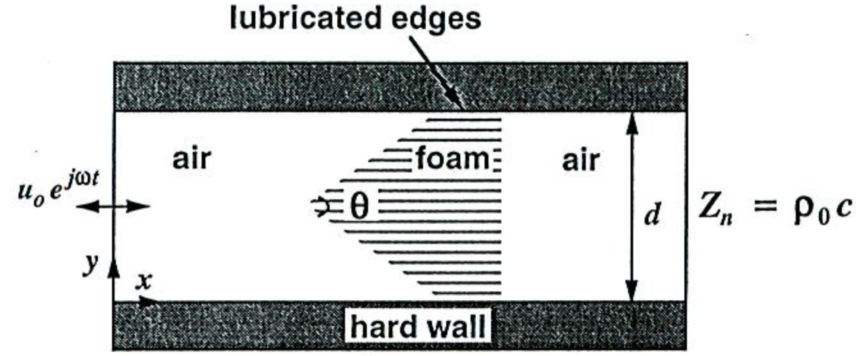
f = 2300 Hz and θ = 48°



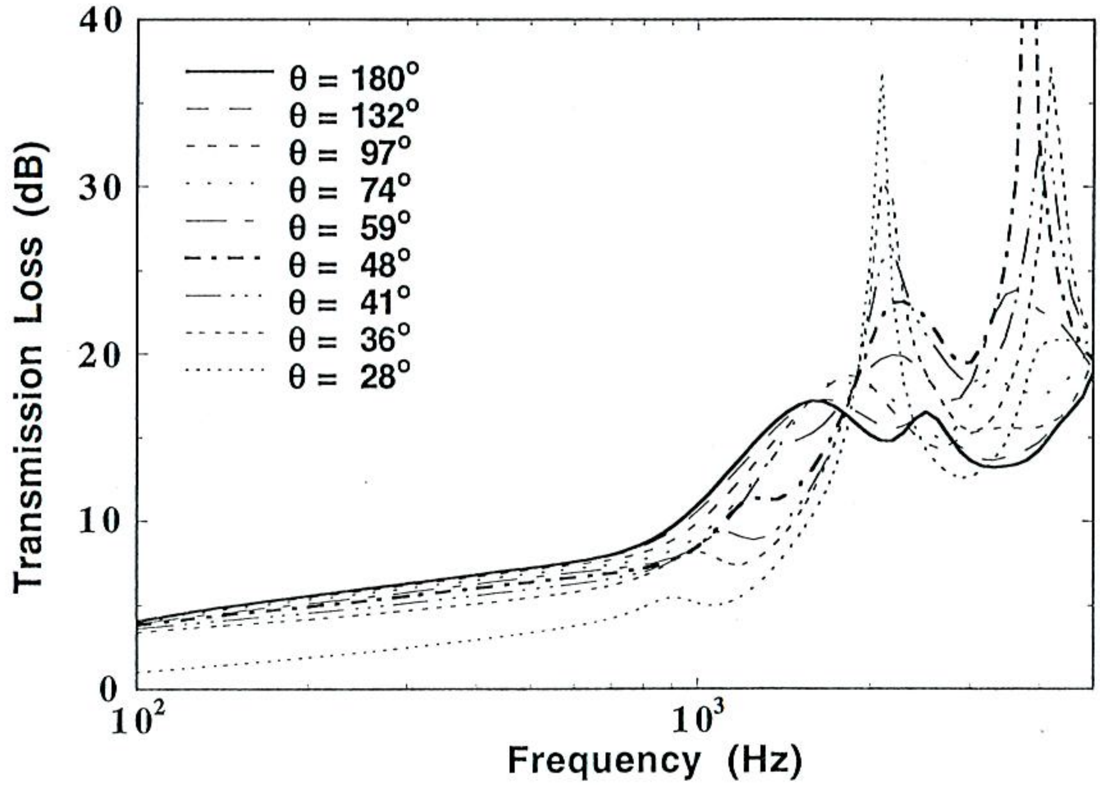
MAGNITUDE AND PHASE OF THE X-DISPLACEMENT OF THE FLUID PHASE AT THE REAR SURFACE OF THE WEDGE



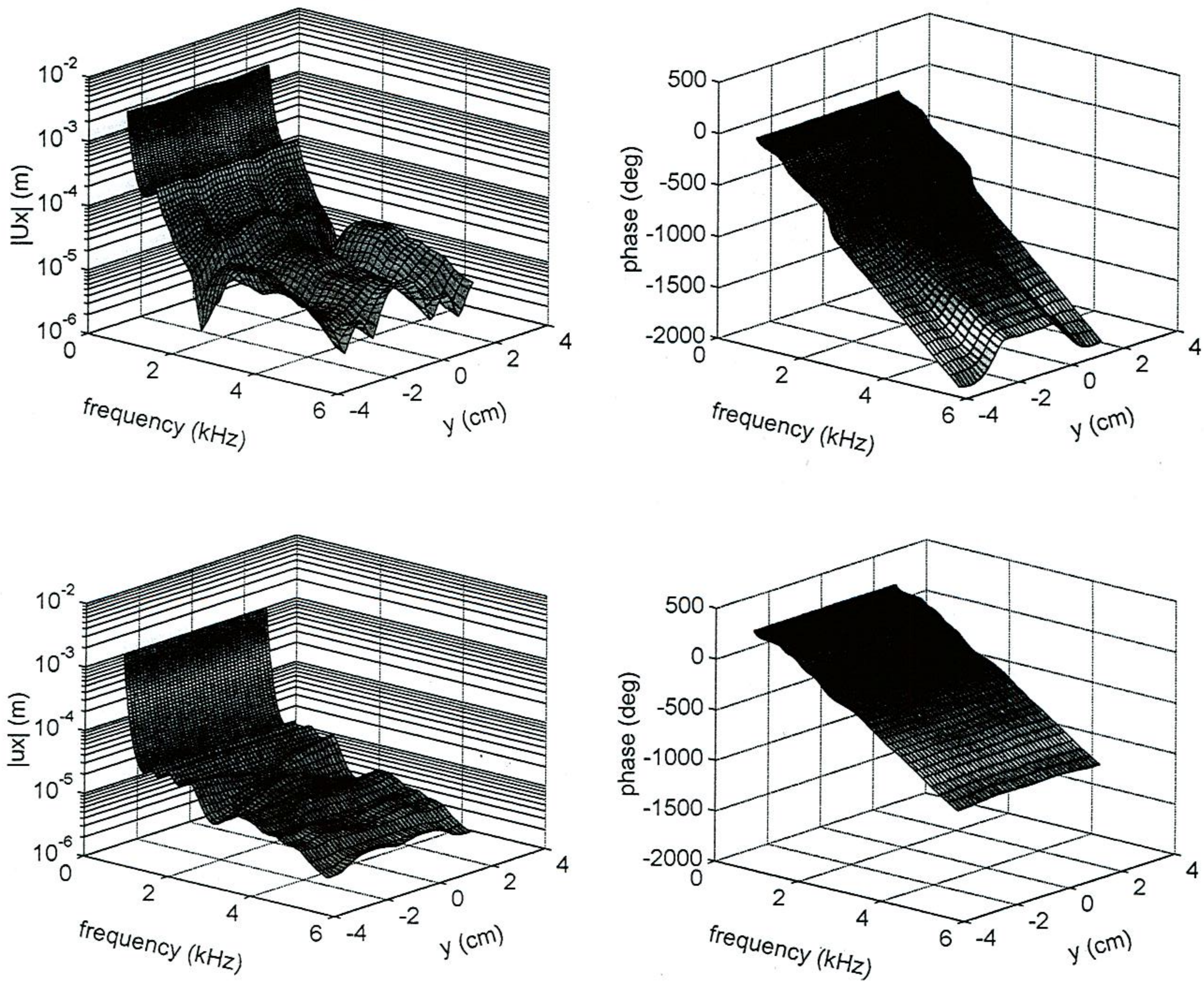
SOUND TRANSMISSION THROUGH A WEDGE



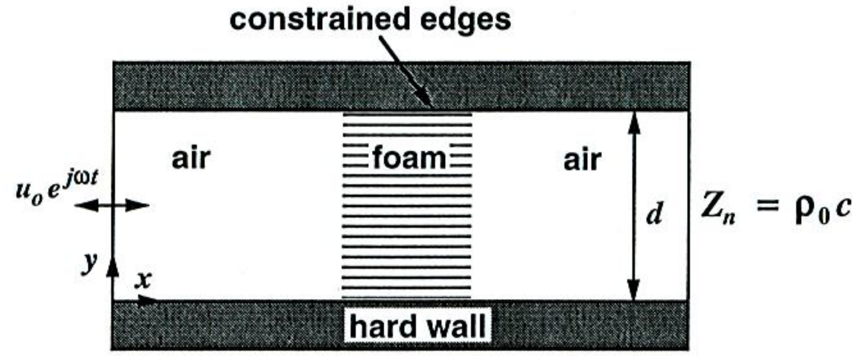
$d = 5.4$ cm



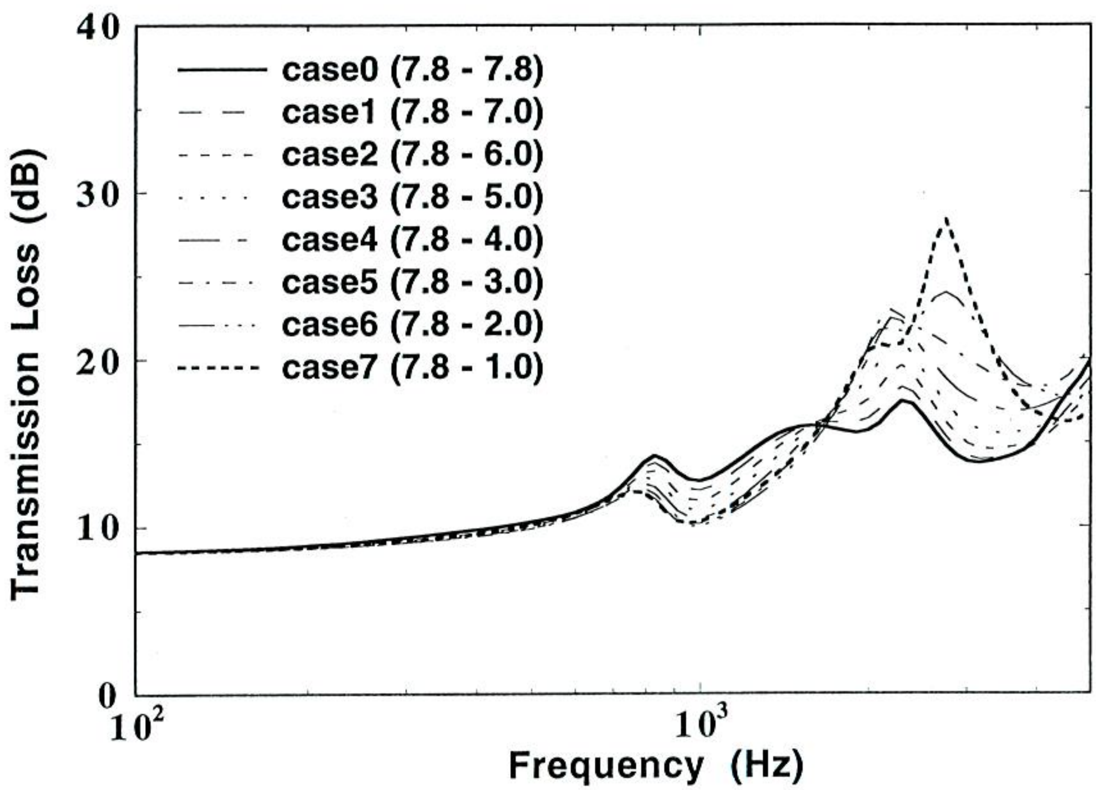
LUBRICATED FOAM WEDGE



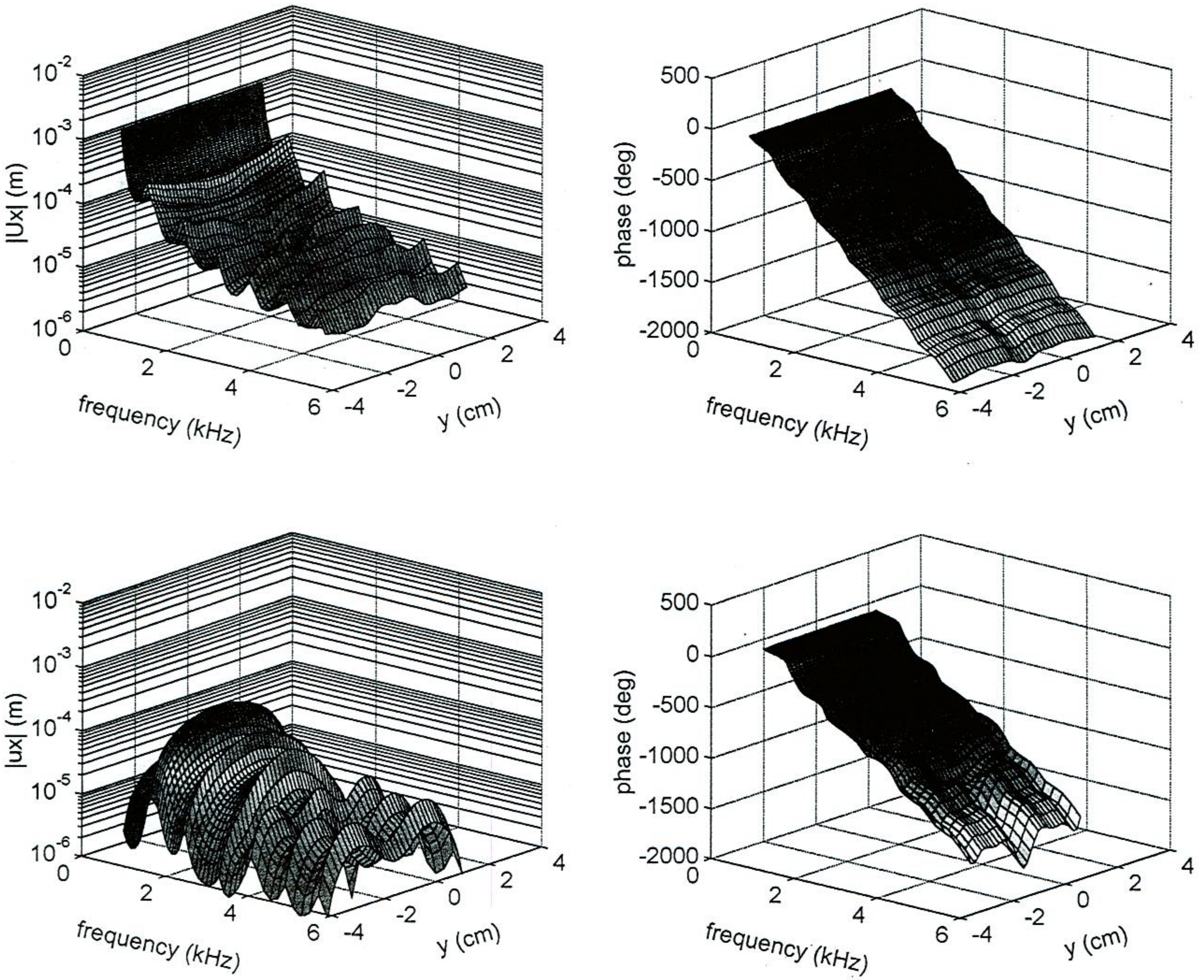
SOUND TRANSMISSION THROUGH A FOAM LAYER HAVING SPATIALLY GRADED TORTUOSITY



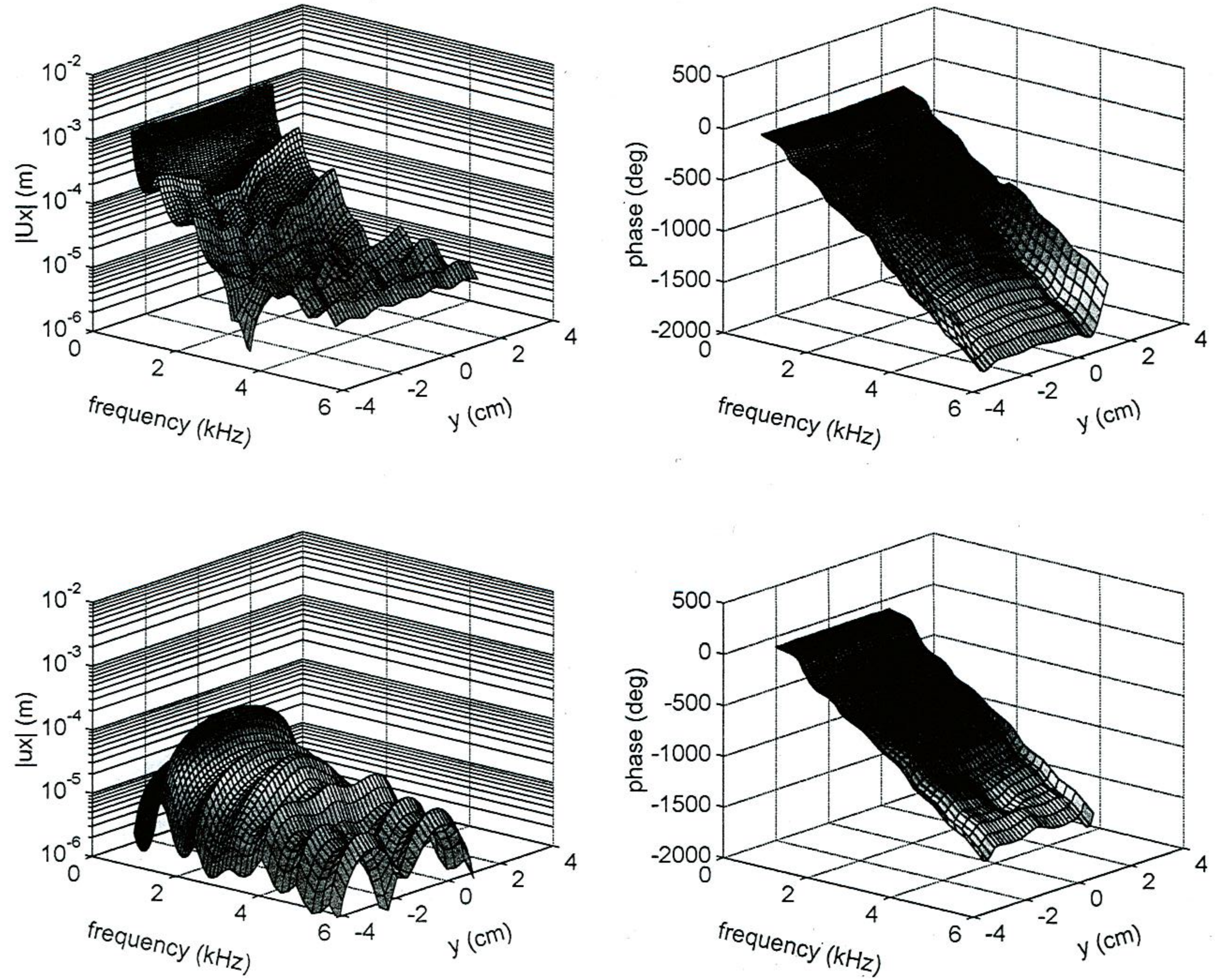
$d = 5.4$ cm



CONSTRAINED FLAT FOAM LAYER



CONSTRAINED FLAT FOAM LAYER HAVING SPATIALLY GRADED TORTUOSITY



CONCLUSIONS

- It has been found that the transmission loss of the wedge is significantly higher than that of a plane foam layer of the same volume in some high frequency bands.

- The TL appears to be enhanced by "converting" the incident plane wave into a non-radiating higher-order symmetric mode.

- The same increase in TL can be produced using a plane, constant depth foam layer if tortuosity is varied across the width of the foam layer.