Tire-Noise Ramifications of Pavement Characteristics

Hugh Saurenman

Joel Garrelick

ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Goals of Study

- Identify pavement characteristics that may be significant contributors to tire noise.
- Focus on gross features: porosity, texture and stiffness.
- Develop insights through first principle structural-acoustic predictive models

Noise Generating Mechanisms

- Tire casing excitation at roadway roughness frequency
- Tread block Impact
- Air Pumping
- Stick-slip (friction)
- Stick-snap (adhesion)
- Horn effects (amplification)
- Absorption (source strength and propagation)
- Closed cavity effects

Pavement Parameters

- Porosity
- Stiffness and Binder Additives
- Texture
- Tining
- Friction
- Adhesion

Conclusions, Porosity

- Propagation over an elastic/porous surface
  - **Thickness**: Increasing thickness reduces the peak absorption frequency and broadens the range of effectiveness.
  - **Resistivity**: Increasing tends to broaden the range of effectiveness.
  - **Porosity** (% Voids): Increasing tends to increase the absorption.
  - **Tortuosity**: Mainly affects the peak frequency of the absorption coefficient.
  - **Multiple Layers**: Possible optimizations.

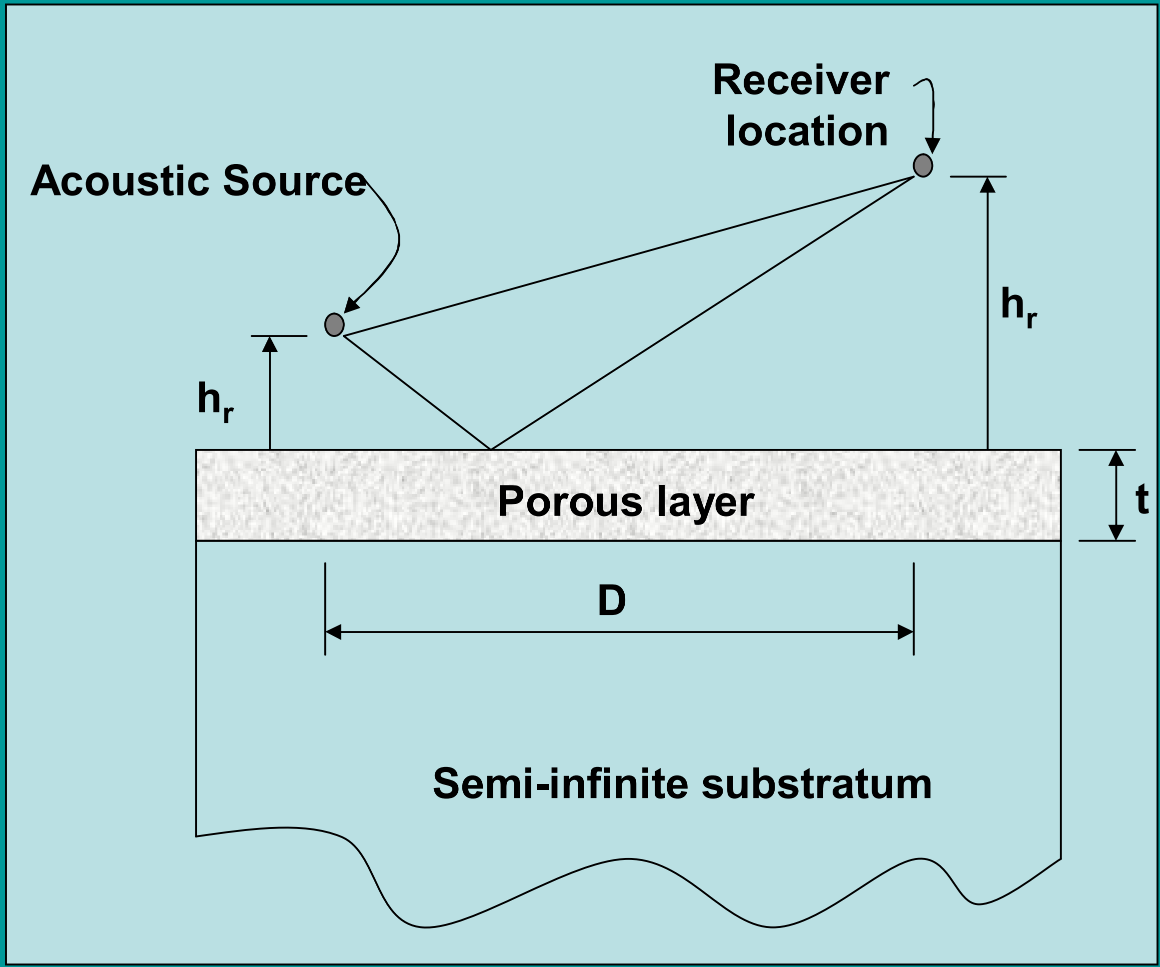
Conclusions, Other Parameters

- **Radiation from pavement**: Small compared to resonant tire casing.
- **Pavement stiffness**: No apparent effect. (Does rubber in binder have other effects???)
- **Texture**: Macro (>1/2”) will increase sound levels.

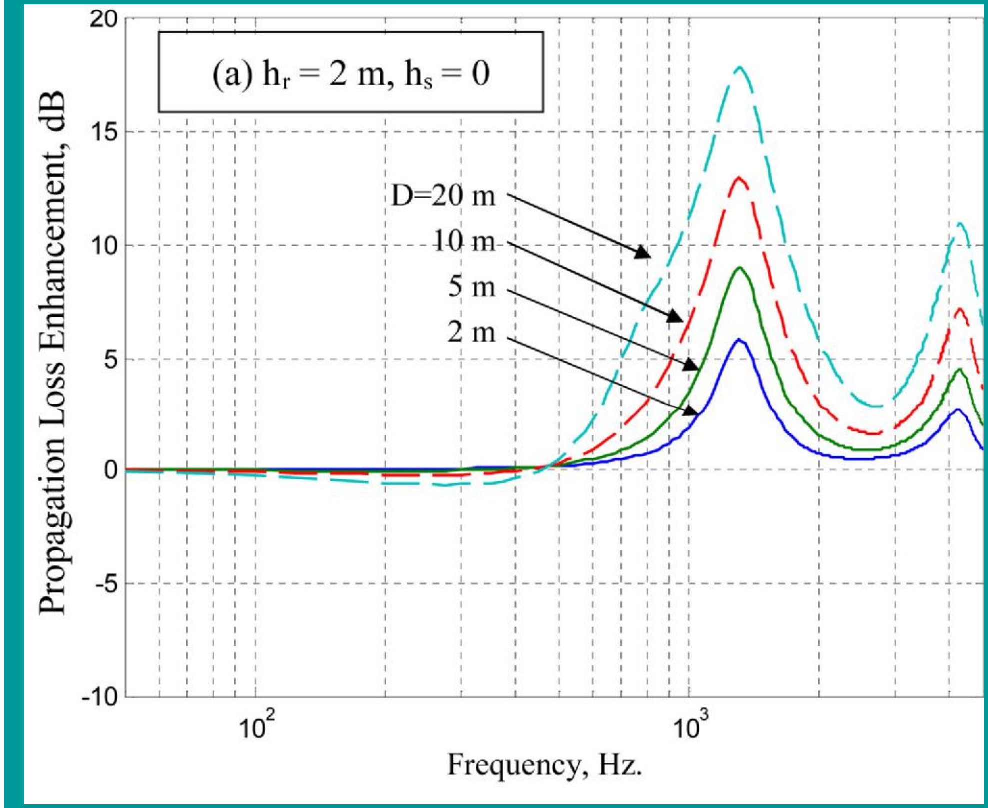
Porous Layer Acoustic Parameters

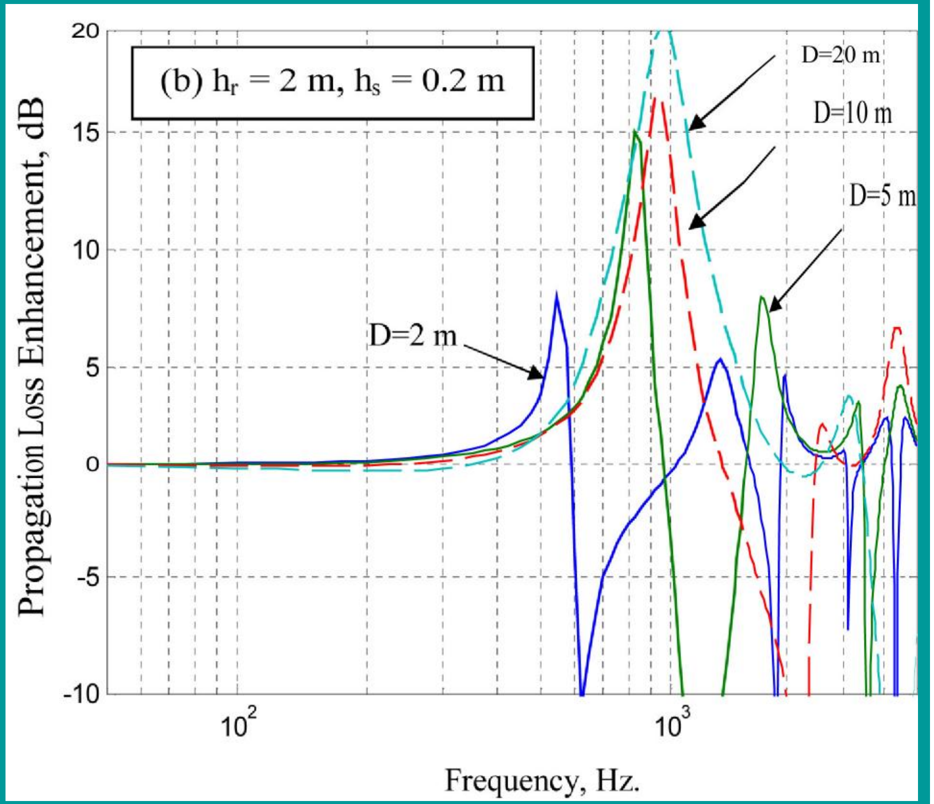
- Thickness (t, cm)
- % Porosity (W)
- Tortuosity (q)
- Flow resistivity (Rs, Ns/m4)

(Wenzel, 1974 and Embleton, et al., 1976)



Porous Pavement:
Influence of source-receiver geometry

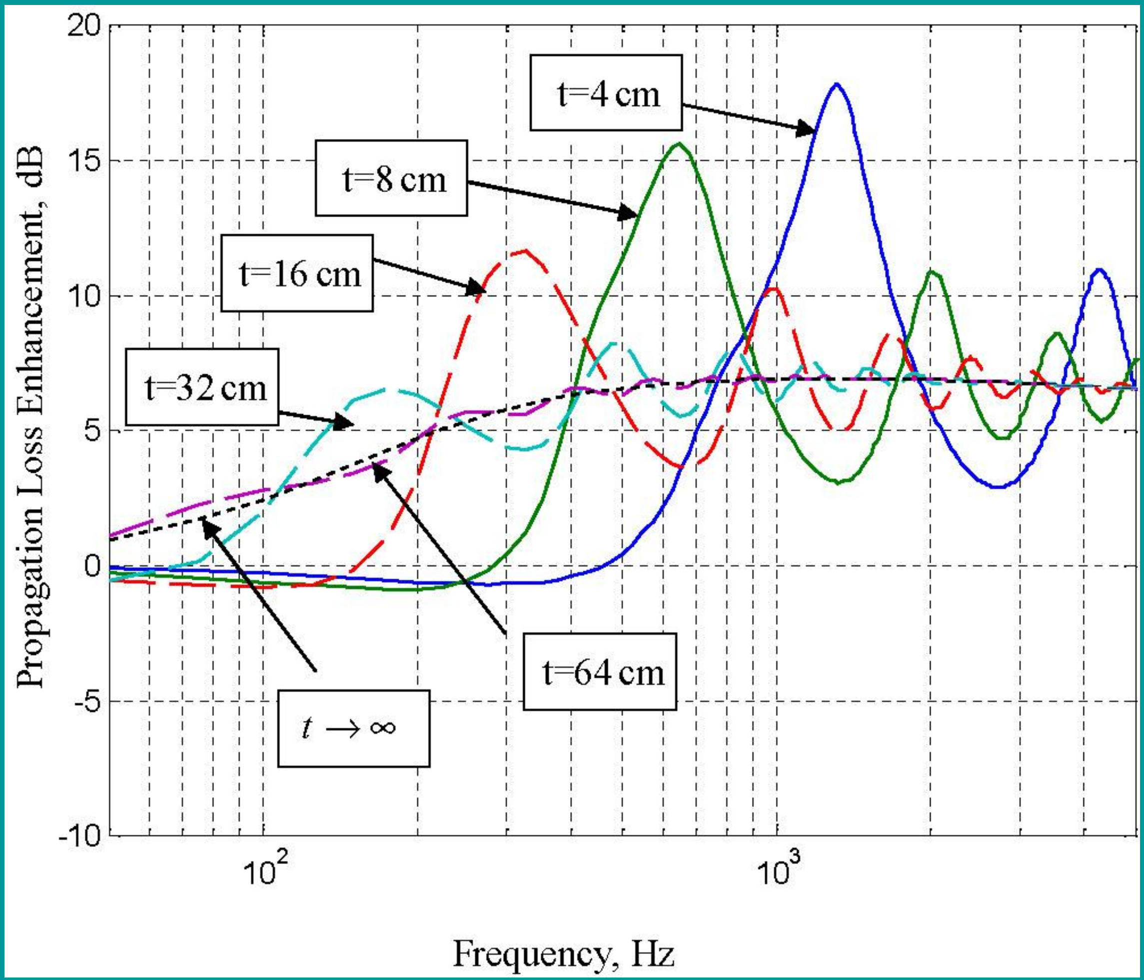


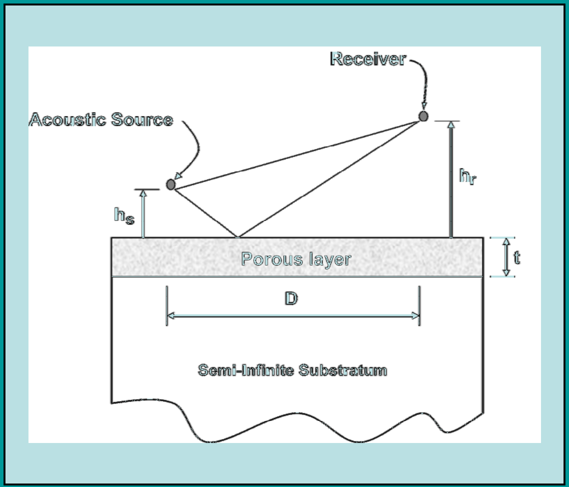


ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Porous Pavement:
Influence of layer thickness

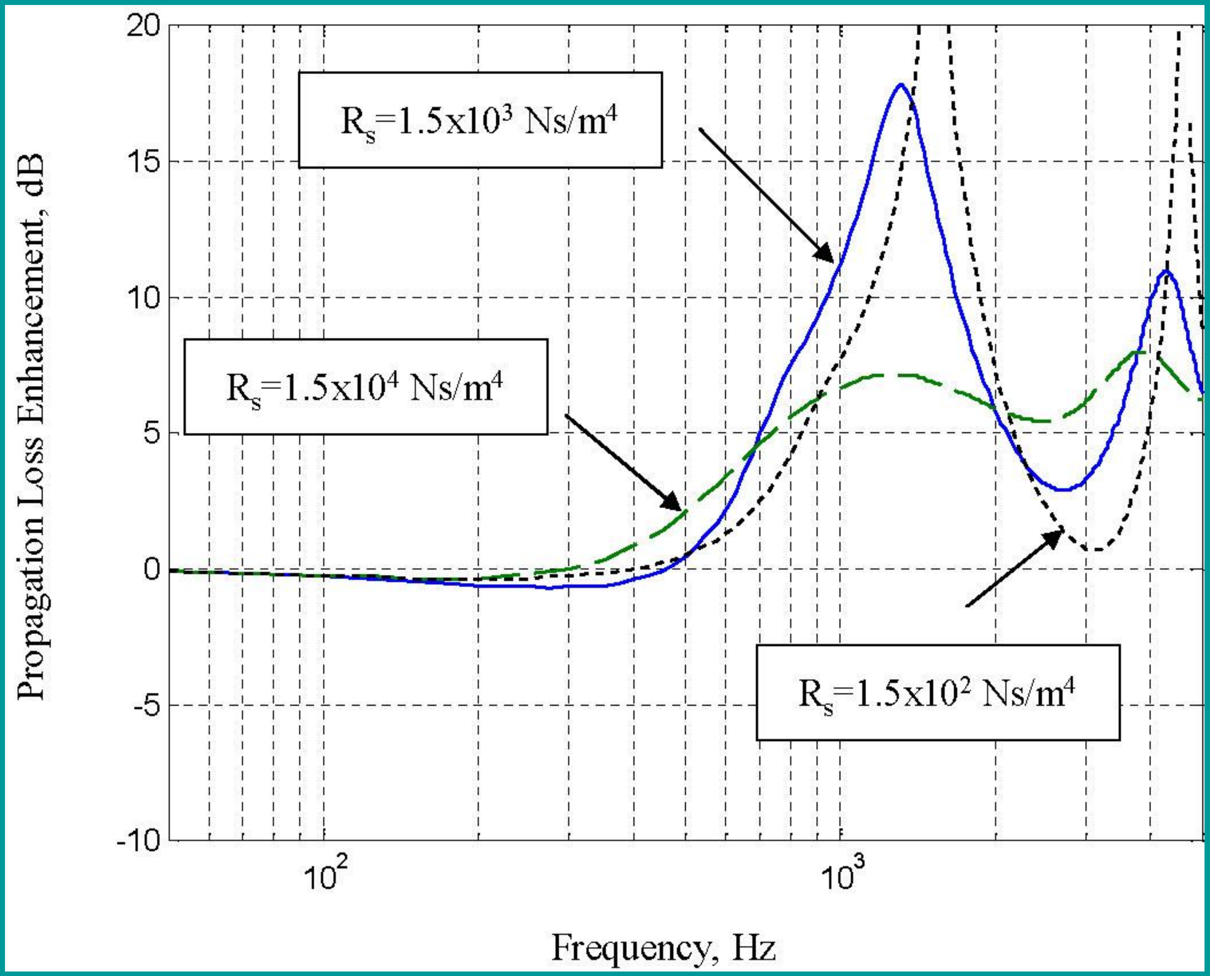


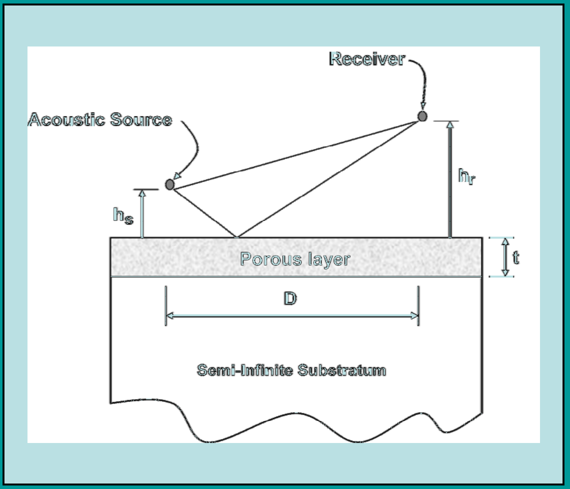


ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Porous Pavement:
Influence of flow resistance

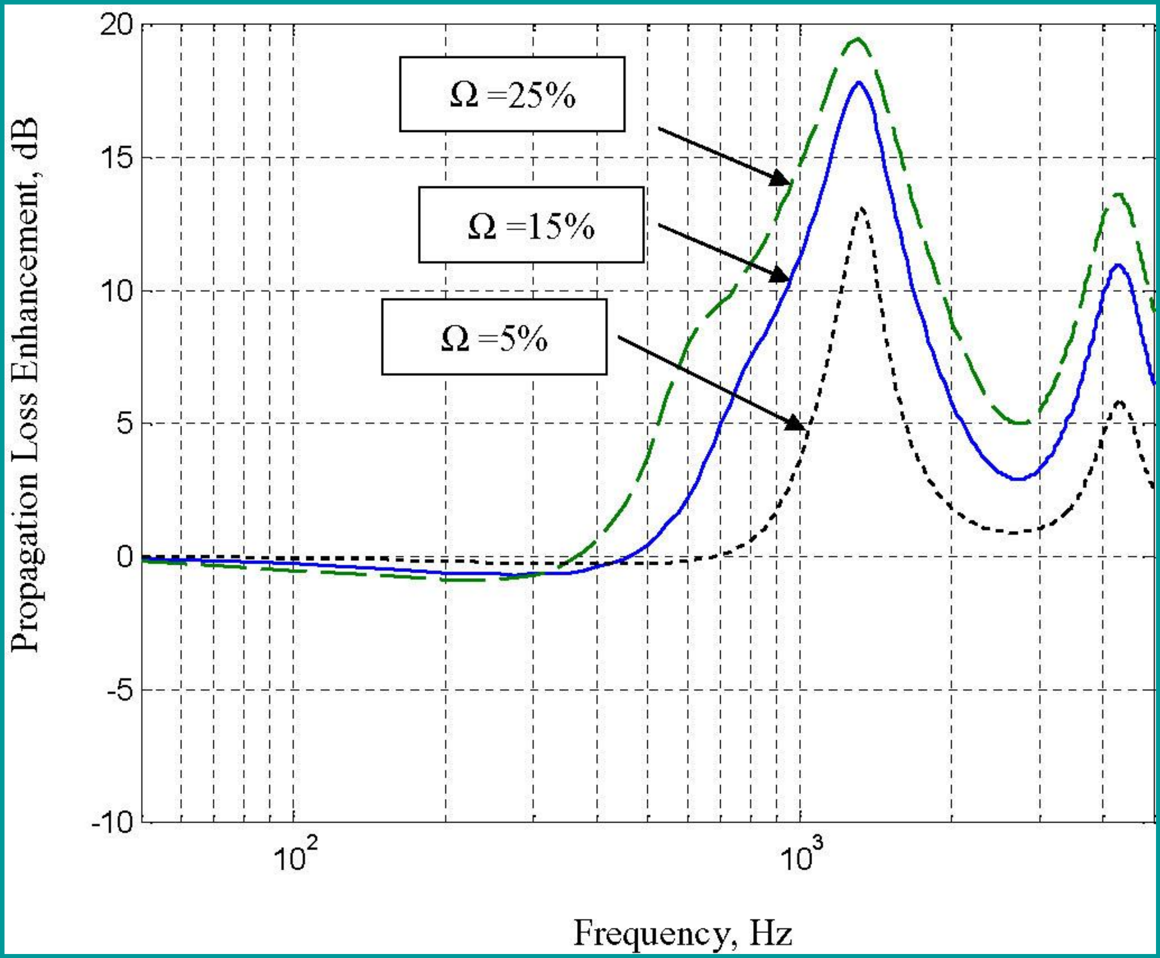


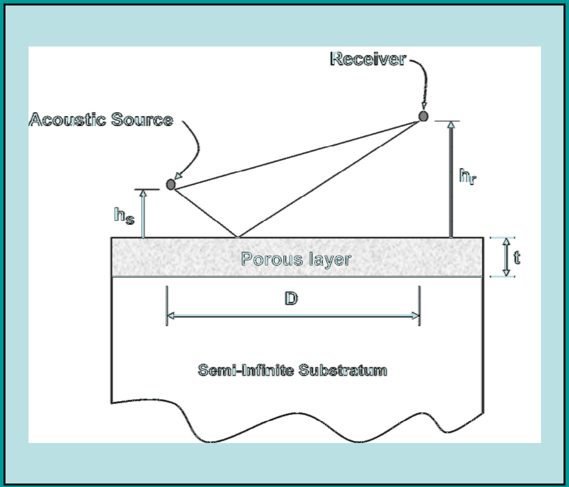


ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Porous Pavement:
Influence of porosity



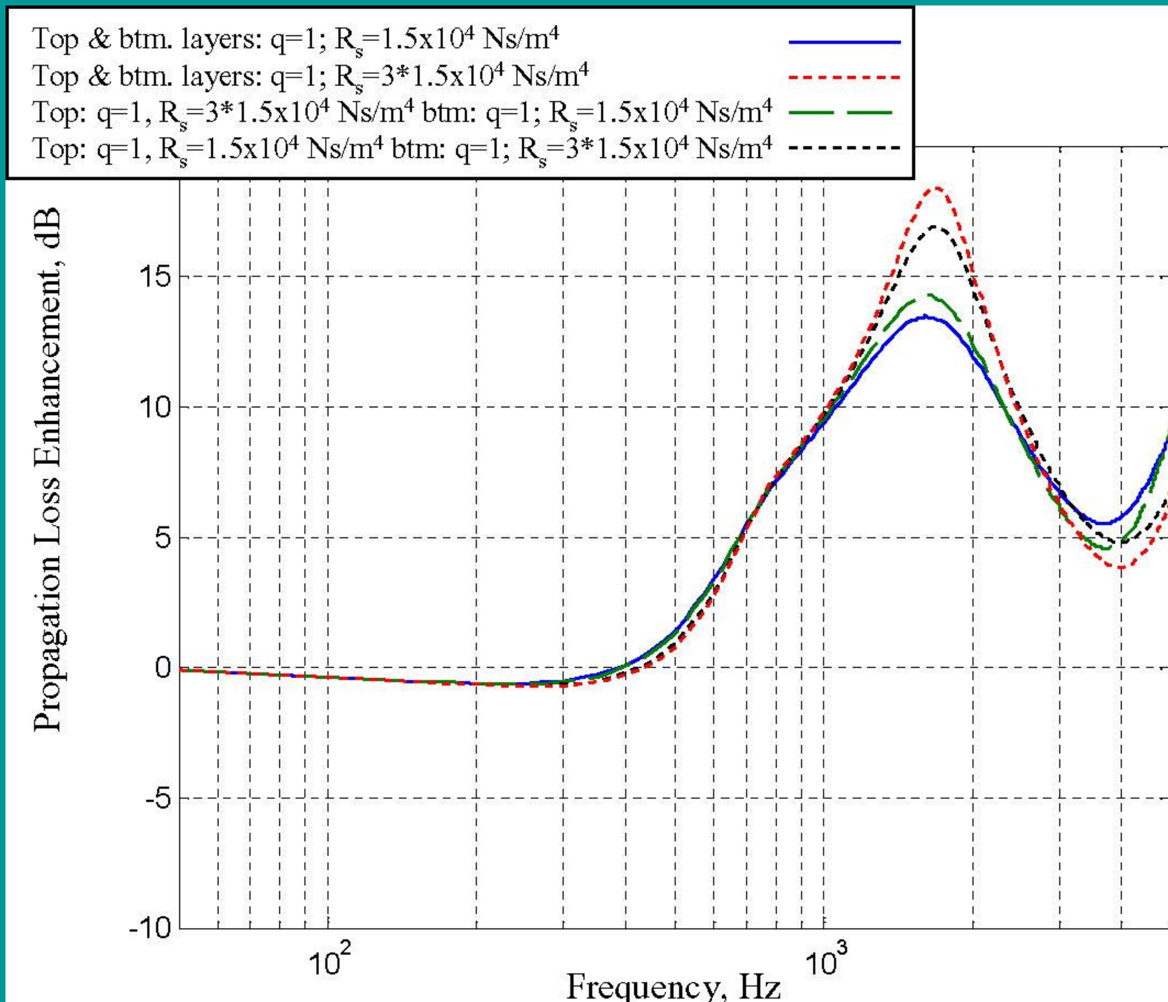


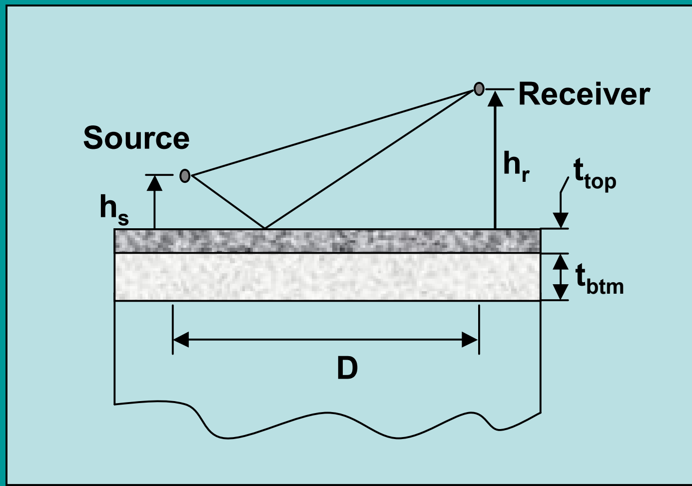
ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Porous Pavement:

Influence two tiered layer

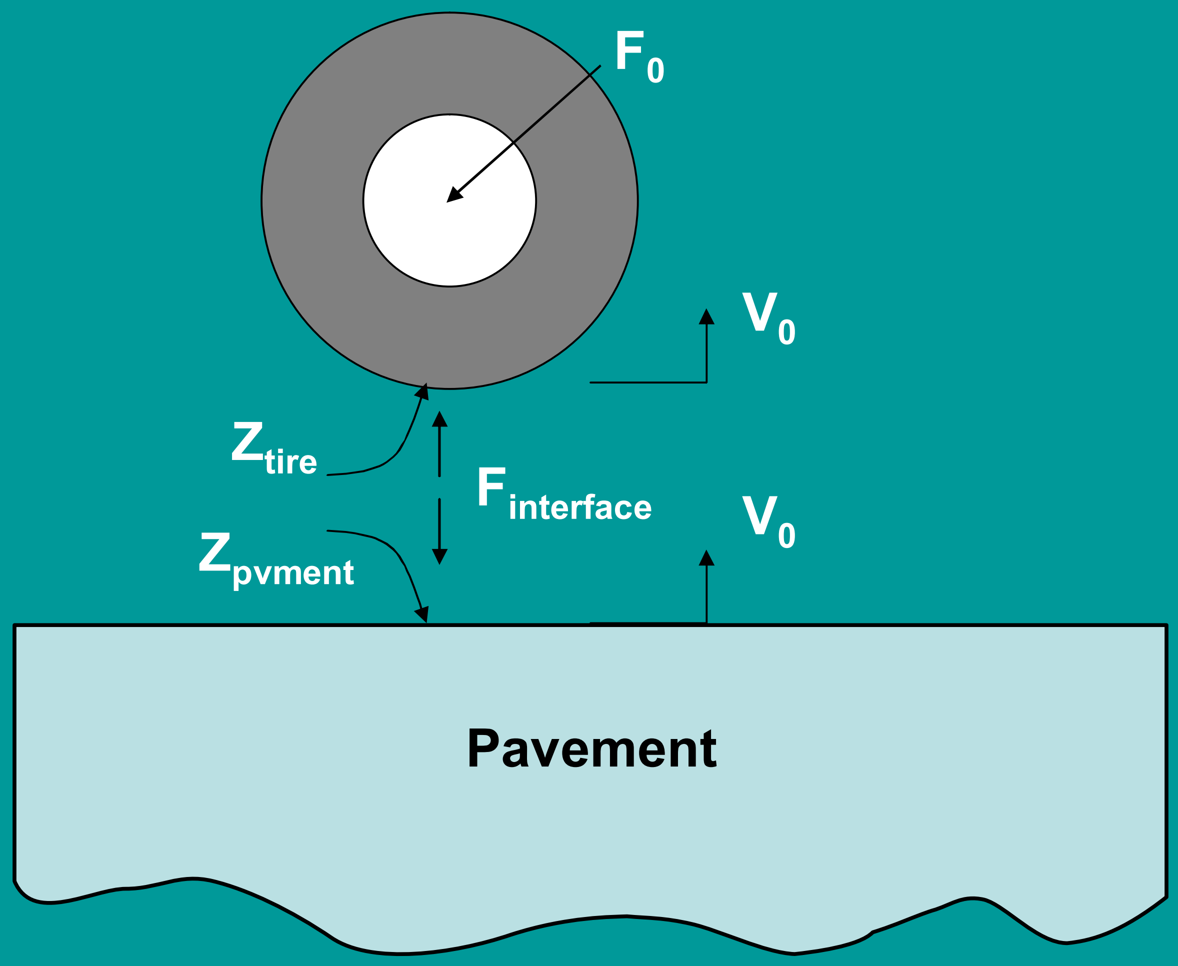




ATSConsulting, LLC
acoustics, transportation + strategy

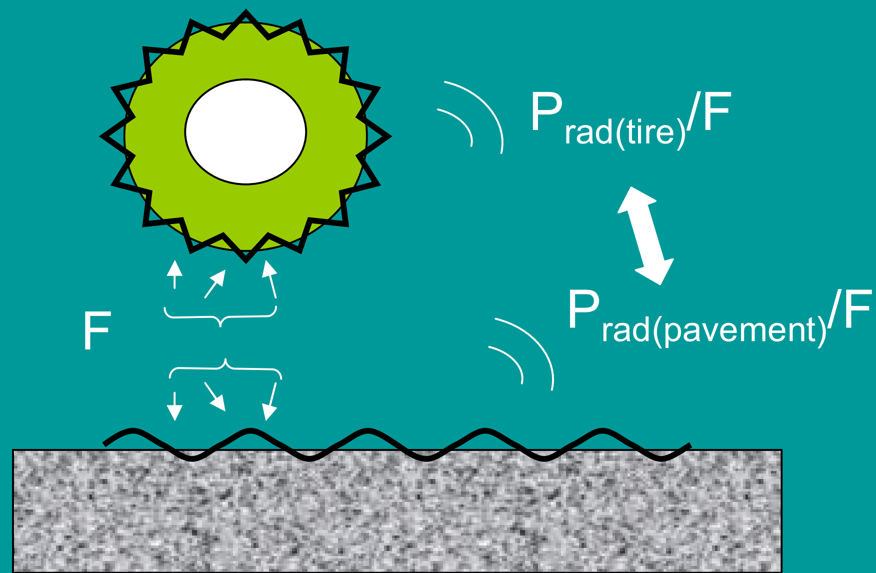
Applied Physical Sciences Corp.

Pavement Impedance (Stiffness)



$$
\begin{aligned}
\vec{F}_{interface} &= V_0 \vec{Z}_{tire} \vec{Z}_{pvment} / (\vec{Z}_{tire} + \vec{Z}_{pvment}) \\
&= V_0 \vec{Z}_{tire} / (1 + \vec{Z}_{tire} / \vec{Z}_{pvment}) \\
&\approx V_0 \vec{Z}_{tire} \\
&\neq f(\vec{Z}_{pvment})
\end{aligned}
$$

Parameters for Tire and Pavement Radiation



Tire Related Parameters

ρ_{air} = air density
m_{tire}= effective tire mass per unit surface area
S_{tire}= effective surface area of tire casing
η = effective dissipation (loss) factor of resonant tire mode
v_{tire}= avg velocity of tire response at resonance
ω_{res} = frequency of tire resonance

Pavement Related Parameters

θ, R = elevation angle, range
p_{rad}/F = radiated pressure normalized to interaction force
ω = circular frequency(=$2\pi f$)
c_{air} = sound speed in air
c_{dil} = dilatational speed in pavement
c_{shr} = shear speed in pavement

ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.

Radiation from viscoelastic half-space and tire casing vibrations

$$|\, p_{rad}(R,\theta;\omega)\,|\, R/F = \frac{(2\pi)^{-2}(c_{air}/c_{shr})^{4}(\omega/c_{air})\sqrt{\sin^{2}\theta-(c_{air}/c_{dil})^{2}}}{[2\sin^{2}\theta-(c_{air}/c_{shr})^{2}]^{2}-4\sqrt{\sin^{2}\theta-(c_{air}/c_{dil})^{2}}\sqrt{\sin^{2}\theta-(c_{air}/c_{shr})^{2}}}$$

$$|\, v_{tire}/F\,|_{\omega=\omega_{res}} = \frac{1}{\omega_{res.}(mS)_{tire}\,\eta}$$

$$\begin{aligned} |\, p_{tire}(R,\theta;\omega_{res})\,|\, R/F &= (\rho_{air}\omega_{res}/2\pi)(vS)_{tire}/F) \\ &= (\rho_{air}/m_{tire})/2\pi\eta \end{aligned}$$

Relative Contribution

$$\left|\frac{p_{pvmnt}(R;\omega_{res.})}{p_{tire}(R;\omega_{res.})}\right| = (\omega_{res.}t_{tire}/c_{dil})(c/c_{shr})^2\eta(\rho_{tire}/\rho_{air})/8\pi$$

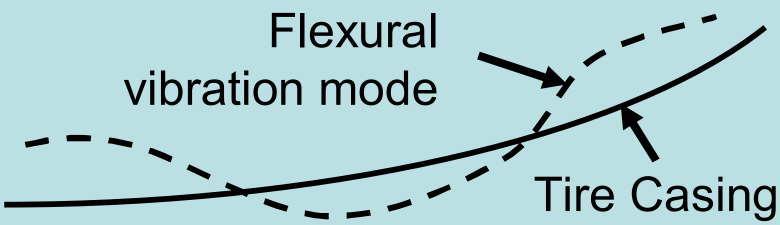
$$= O(10^{-1}) \qquad O(10^{-1})O(10^{-2})O(10^{3})O(10^{-1}) \quad << 1$$

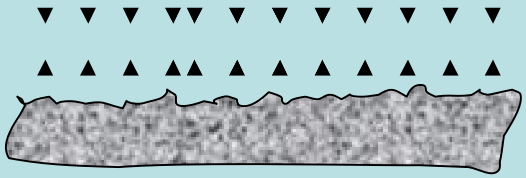
$$= \quad O(10^{-1}) \qquad O(10^{-1})O(10^{0})O(10^{3})O(10^{-1}) = O(1)(nonresonant)$$

Contribution to overall noise levels is

- Small relative to that from resonant tire casing vibrations
- The same order as that from non-resonant tire modes (broad-band)

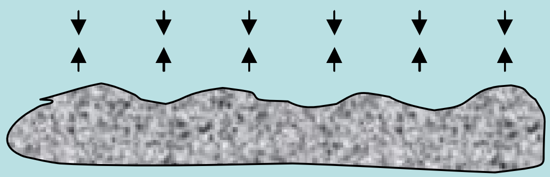
Influence of Pavement Texture on Tire Vibrations





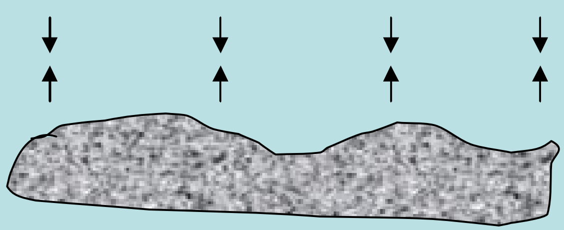
Micro-texture

$$\lambda_{texture} \le O(1mm) << \lambda_{flexure}$$



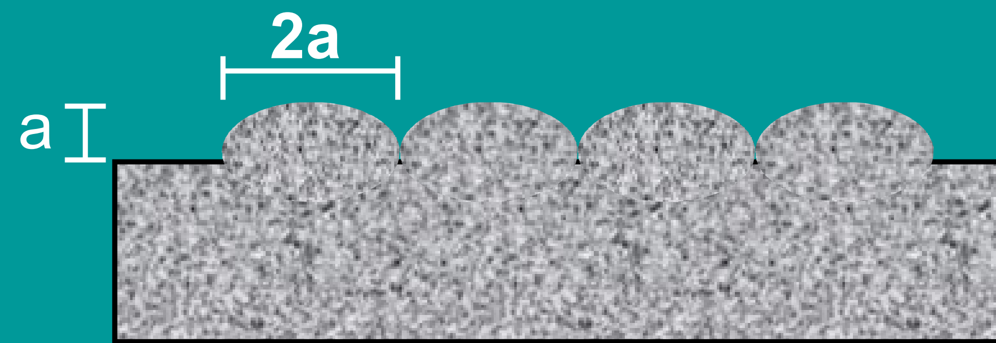
Macro-texture

$$\lambda_{texture} = O(1-10mm) < \lambda_{flexure}$$



Mega-texture

$$\lambda_{texture} = O(10-10^2 mm) \approx \lambda_{flexure}$$



$$F_{texture}^2 = (K_{tire} a)^2 (S / \pi a^2)$$

$$= K_{tire}^2 S / \pi$$

$$\ne f(a)$$

S=tire-pavement contact area

K_{tire}=Dynamic stiffness of tire casing

$a(\lambda_{texture})$=texture length scale

ATSConsulting, LLC
acoustics, transportation + strategy

Applied Physical Sciences Corp.