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MECHANICAL ENGINEERING

Sound Generation of Pavements

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January 30, 2003

Noise control at the source (focused on pavement) – reduce need for barriers

- Noise generation mechanisms (*using Sandberg's seminal paper, Acoustical Soc. of Japan, 1999*)
- Current implementations of quiet highway technology
- Research for better solutions

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Tread Compression

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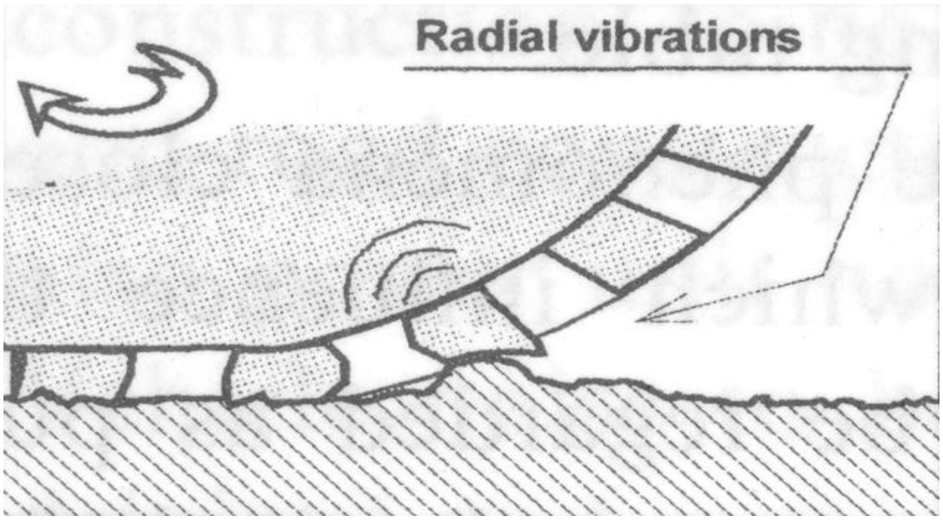
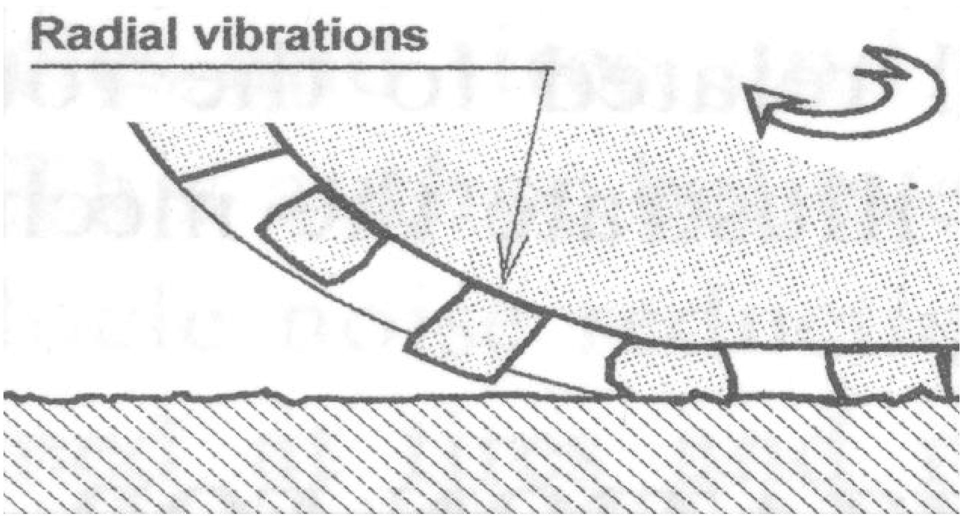


- Highway texture and tread block induce vibration of the tire carcass
- Affected by texture and tire construction
- Important at low frequency

Tread Vibration



- Occurs at contact patch, tread blocks act as little loud speakers
- Affected by pavement texture and tread block materials
- Important at high frequency.

Tread Oscillation

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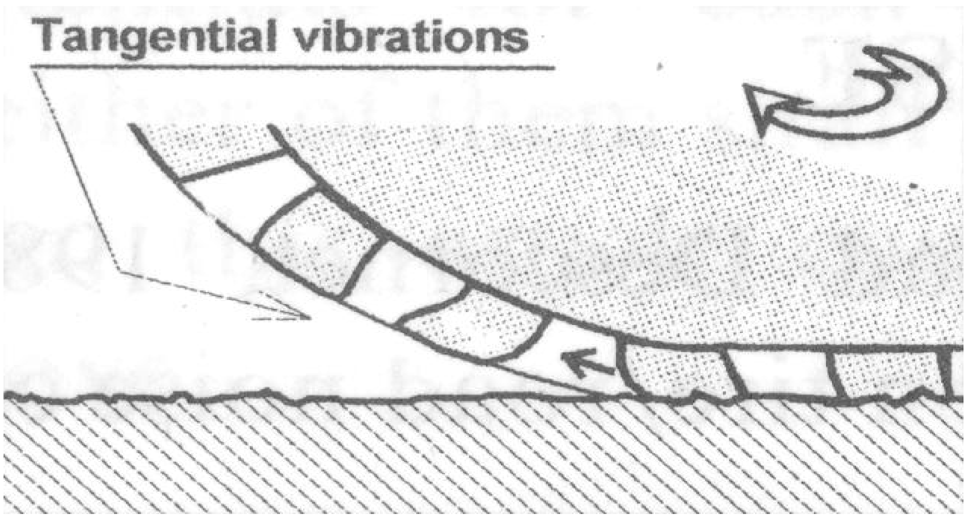

- Due to tangential strain on tread blocks and impact of pavement
- Affected by load, pavement texture and tread compounds
- Important at high frequency

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Tread Adhesion

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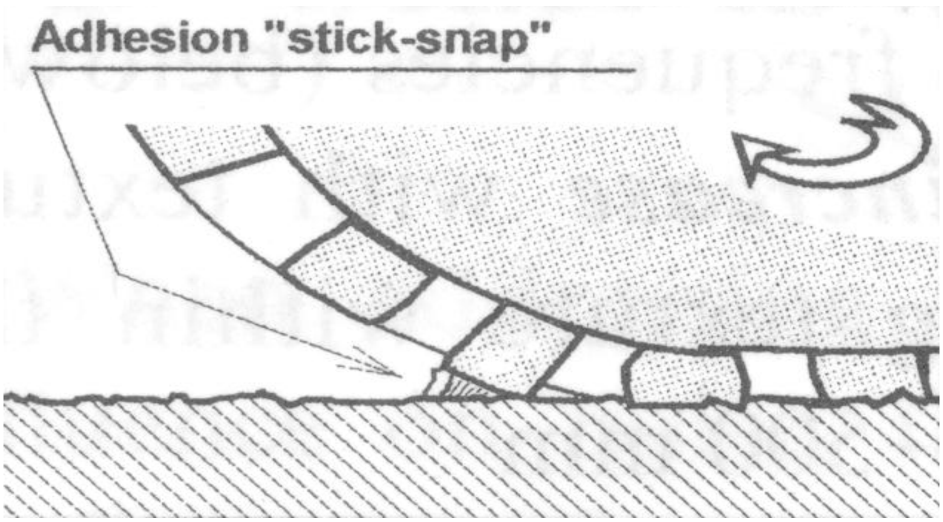
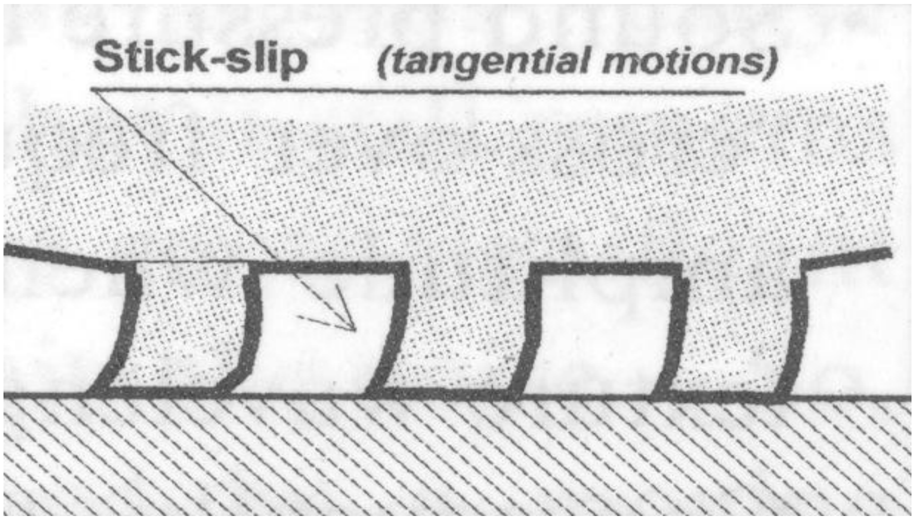


- Causes tread and carcass vibration
- Depends on the adhesive forces between the tread and the pavement
- Important at low and high frequency

Stick-Slip



- Causes squeaks and squeals – high frequency
- Local radiation
- Depends on load and tread/pavement adhesion

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Air Pumping

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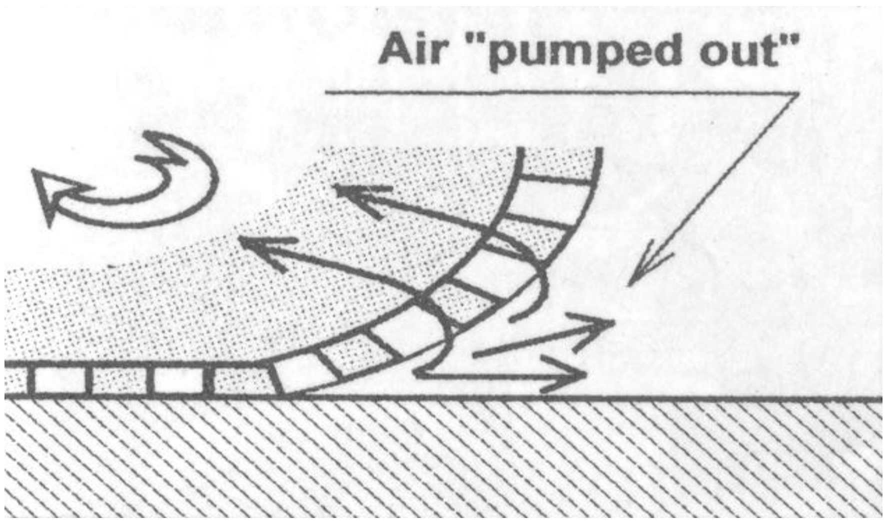

- At entrance to contact patch
- Dependent on tread passages and pavement porosity
- Important at high frequency

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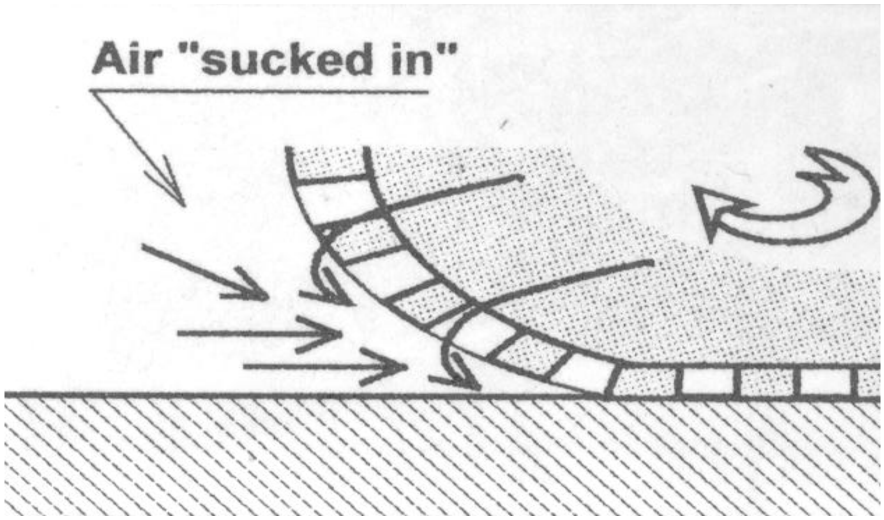
Air Pumping



- Important at contact patch exit
- Dependent on tread pattern and pavement flow resistivity
- High frequency

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Acoustical Hologram

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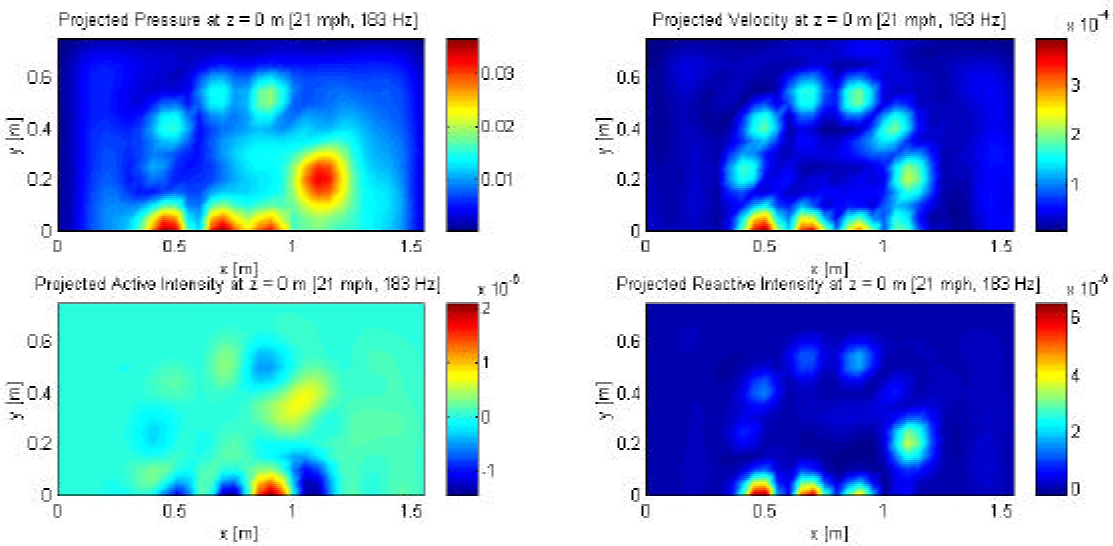

- From *Kim and Bolton*
- 21 mph
- 183 Hz
- Radiation from contact patch

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Carcass Radiation

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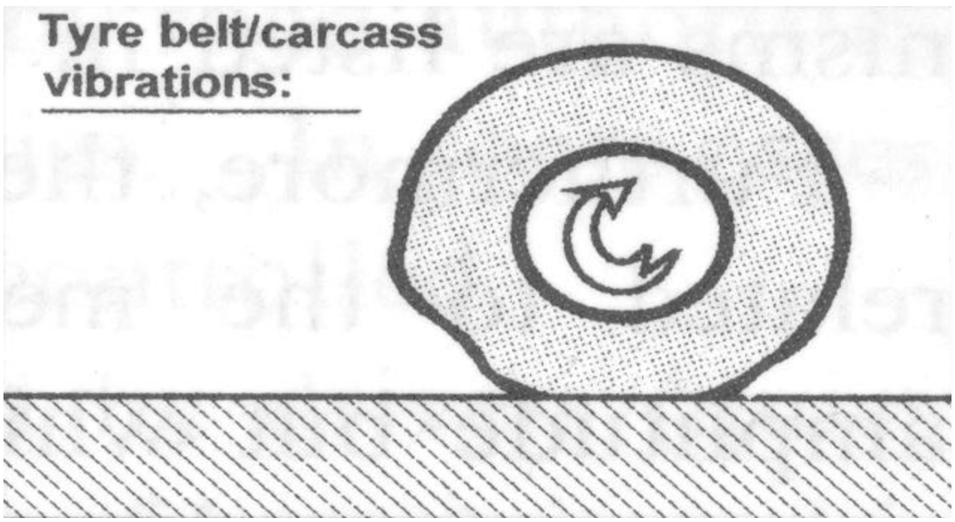

- Source amplification, low frequency
- Depends on carcass construction
- Important to sideline radiation

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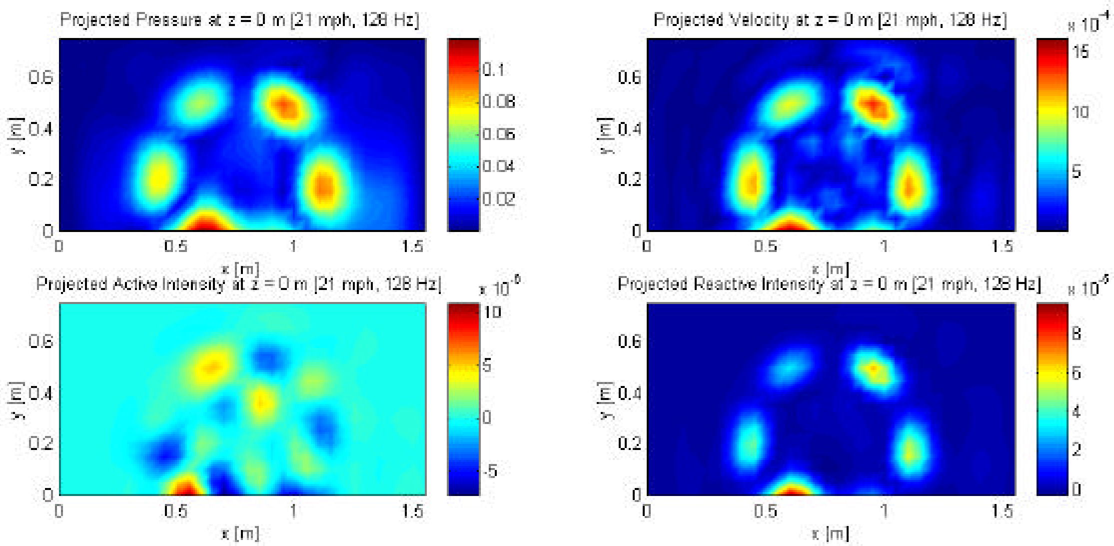
Acoustical Holography

MECHANICAL ENGINEERING



- Acoustical hologram of a rolling tire (from *Kim and Bolton)*
- Speed 21 mph
- Frequency 128 Hz (low frequency)

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Sidewall Radiation

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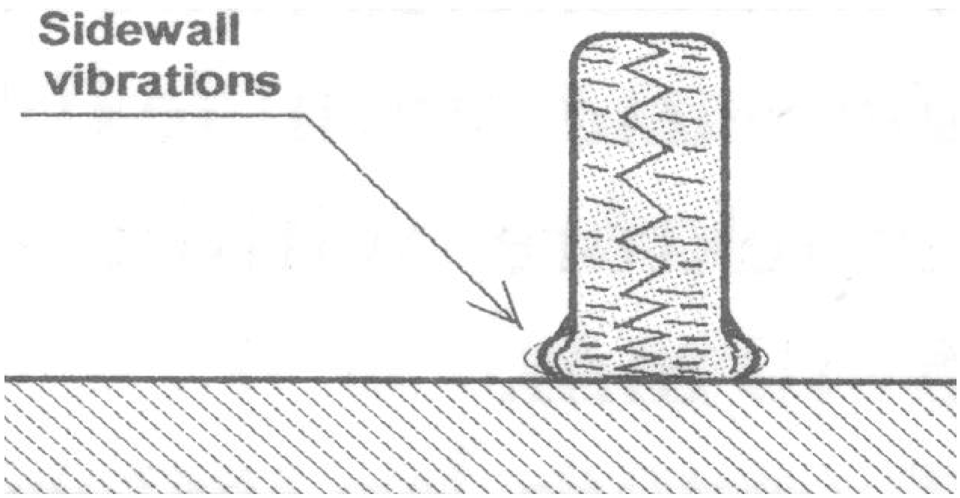
MECHANICAL ENGINEERING



- Source amplification
- Important to sideline radiation
- Depends on tire construction

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Horn Effect

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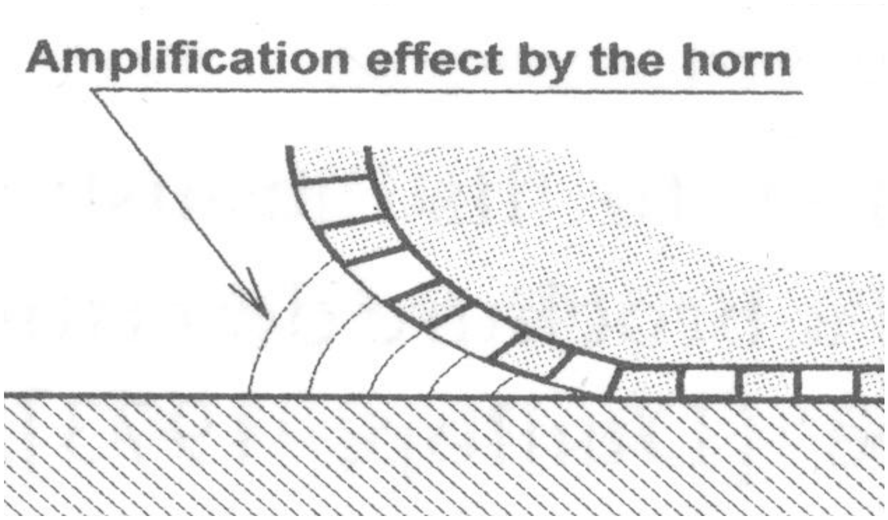

- Source amplification of air pumping and tread vibration
- Dependent on width of tire and pavement acoustical characteristics
- High frequency, directive effect

Helmholtz Resonance

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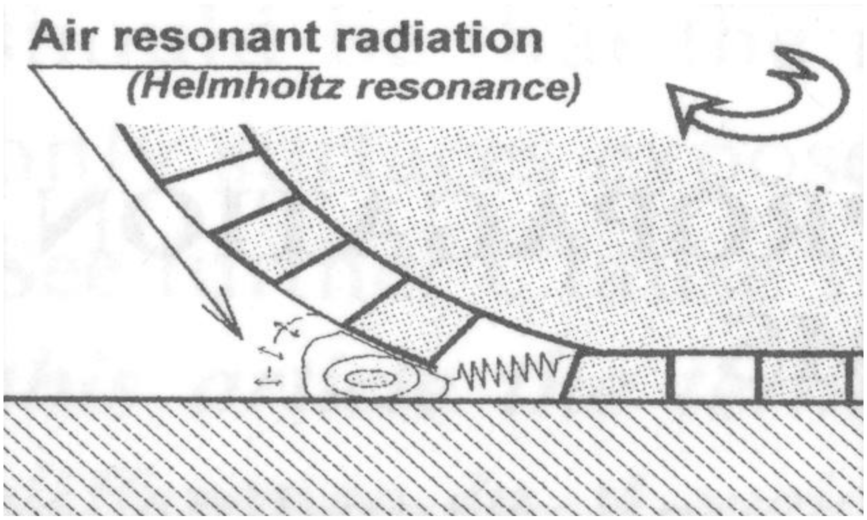

- Source amplification near entrance and exit of contact patch
- High frequency effect

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Channel Resonance

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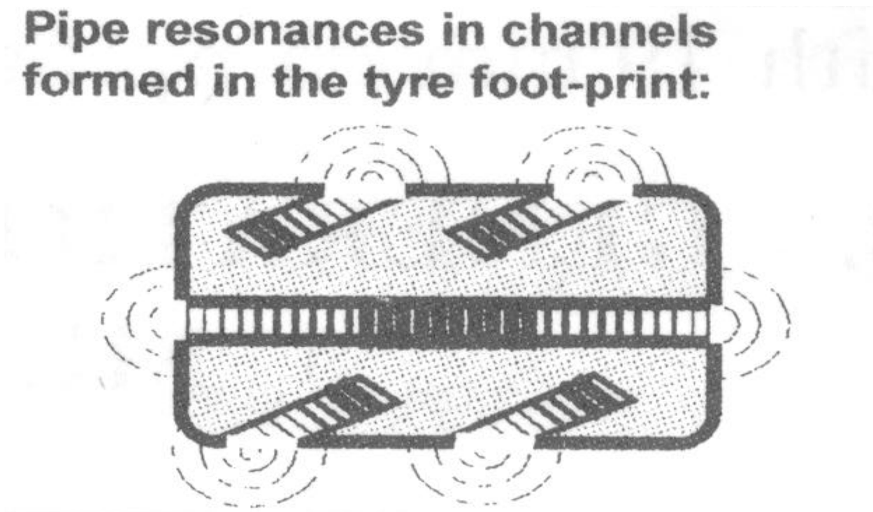

- Source amplification mechanism
- The organ pipe resonance effect
- Mid frequency

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Cavity Resonance

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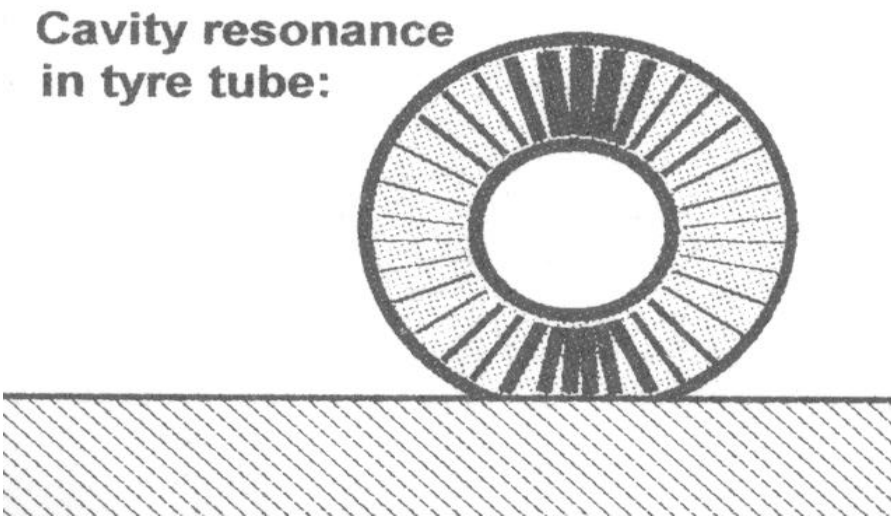

- Lightly damped resonance near 250 Hz
- Very evident both internal to the vehicle and externally

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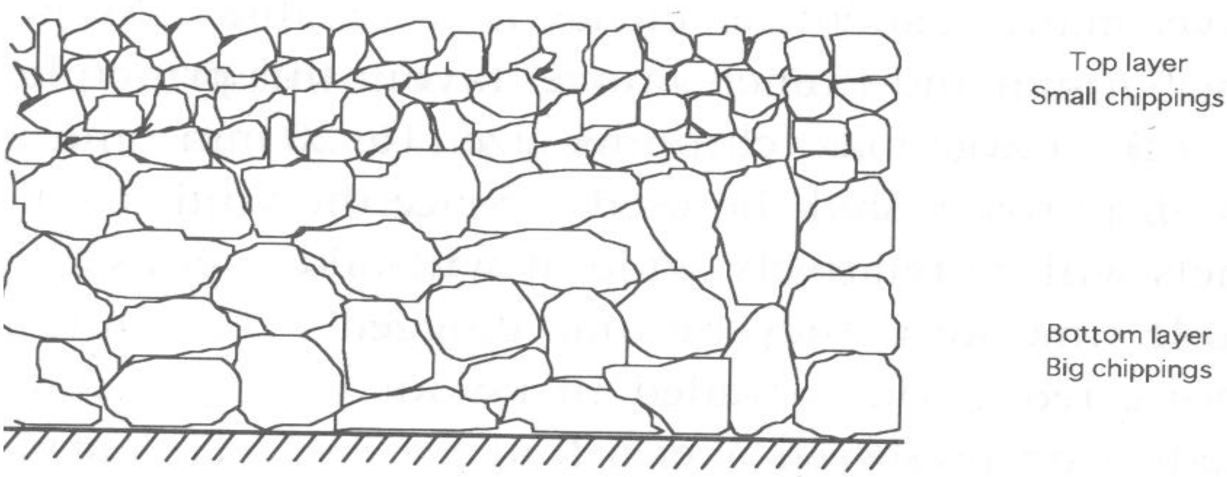
Quiet Pavement Literature

- NCHRP Synthesis 268 "*Relationship Between Pavement Surface Texture and Highway Traffic Noise*", *R. Wayson et al.*
- PCC – porous concrete, exposed aggregate concrete, tining concepts
- Asphaltic concrete – porous asphalt, open-graded asphalt, rubberized asphalt, twin-lay

Quiet Asphalt Europe

- Porous Asphalt
  - 20%+ porosity, various aggregate sizes
  - Durability OK
  - Lost noise reduction effect due to plugging
- Twin-lay
  - 2 layers
  - Durability OK
  - Self cleaning from tire pumping

Twin-Lay



- Top layer 6-10 mm aggregate
- Second layer 15-20 mm aggregate
- 20-25% porosity

Cost/Benefit

- Study done in the Netherlands (*Larsen and Bendtsen, Inter-Noise 2001*)
- NPV in euros for 3 roads, 3 noise mitigation solutions (twin-lay, barriers, home insulation)

		City street	Ring road	Freeway
Asphalt	30 year cost	296,000	360,000	477,000
	dB reduction	5	6	7
	NEF reduction	103.2	153.2	215.8
	Cost/dB/dwelling	89	150	157
	Cost/NEF	2,870	2,350	2,210
Barrier	30 year cost	–	1,335,000	1,590,000
	dB reduction	–	0–12 (average: 3.9)	4–13 (average: 8.5)
	NEF reduction	–	75.5	218.6
	Cost/dB/dwelling	–	851	430
	Cost/NEF	–	17,680	7,270
Insulation	30 year cost	2,685,000	1,607,000	578,000
	dB reduction	9	9	9
	NEF reduction	99.0	170.0	124.3
	Cost/dB/dwelling	449	448	148
	Cost/NEF	27,120	9,450	4,650

Quiet Highways Europe

- "Rubberized" highway
  - Rubber as part of the binder
  - Seems to affect tread vibration mechanisms
  - Durability OK
- "Poro-elastic" Concepts
  - Small proof of concepts tests only in Sweden, Italy and Japan
  - Affects tread vibration and air pumping and horn effect mechanisms

Quiet Pavement USA

- Georgia, Alabama, and Florida
  - Utilize open-graded asphalt for noise and splash control
  - 1-3 dB better than dense graded asphalt
- Arizona
  - Rubberized asphalt pavement – extensive investigation ongoing
- California
  - Sacramento – rubberized highway (3-4 dB)
  - Open-graded asphalt
  - Advanced PCC
- Wisconsin
  - PCC tining – reduced annoyance

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SQDH Research

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1. ***Measurement and Evaluation of Roadside Noise Generated by Transit Buses,*** E. Mockensturm, B. Kulakowski; The Pennsylvania State University
2. ***Study of the Performance of Acoustic Barriers for Indiana Toll Roads,*** L. Mongeau, J.S. Bolton; Purdue University
3. ***Development of Porous, Modified Asphalt Mixes for Noise Control Applications,*** R. McDaniel, J. Olek; Purdue University
4. ***Fundamentals of Tire/Road Interaction Noise,*** J. S. Bolton, J. Olek, R. Bernhard; Purdue University

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SQDH Research

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5. ***Development of Quiet and Durable Porous Portland Cement Concrete Paving Materials,*** J. Olek, W. J. Weiss; Purdue University
6. ***Concrete Mixtures that Incorporate Inclusions to Reduce the Sound Generated on Portland Cement Pavements,*** J. Olek, W. J. Weiss; Purdue University / B. Magee; University of New Hampshire
7. ***Tire/Pavement Interaction Noise Generation and Radiation Mechanisms,*** C. Burroughs; The Pennsylvania State University

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8. ***Investigation of Novel Acoustic Barrier Concepts, Phase I: Concept Development and Preliminary Evaluation,*** L. Mongeau, J.S. Bolton; Purdue University
9. ***A Guide for the Construction of Reduced Noise Pavement,*** R. Bernhard; Purdue Univ. & R. Wayson; Univ. of Central Florida
10. ***Identification of Laboratory Techniques to Optimize Superpave HMA Surface Friction Characteristics,*** **R**. McDaniel, NCSC, & B. Coree, Iowa State Univ.

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TPTA - Objectives

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To understand fundamental generation mechanisms of tire/road interaction noise

- **Construct a test apparatus** to measure tire and pavement responses due to a rolling tire on a realistic pavement
- **Examine tire and pavement behavior** to determine the impact of tire and pavement design combinations on noise generation

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TPTA - Specs

MECHANICAL ENGINEERING

- Two rolling tires
- Realistic pavement on the exterior of the drum
- Motor rated for 60 hp for braking capability
- Speeds up to 30 mph
- Loading capacity up to 1000 lbs
- Drum diameter of 12 feet
- Pavement depths of either 8” or 16”

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TPTA - Status

- Tire/Pavement Test Apparatus (TPTA) was delivered in July, 2001.
- Recent studies of
  - PCC tining and texturing
  - Tire sidewall and treadband designs

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TPTA – 30 mph

MECHANICAL ENGINEERING

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TPTA Pavement

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- Typical PCC samples
- Smooth, textured, and porous samples available
- Asphalt samples this spring

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Conclusions

MECHANICAL ENGINEERING

- Existing solutions 1-4 dB better than traditional pavement of same type:
  - Longitudinal tining on PCC
  - Open-graded or porous asphalt
- 5-10 dB should be possible when we resolve the challenges of
  - Understanding noise generation
  - Controlling pavement construction
  - Maintaining safety (friction)
  - Maintaining durability

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