School of Civil Engineering
Purdue University, West Lafayette, Indiana

Recent Developments in Porous Concrete Paving Materials

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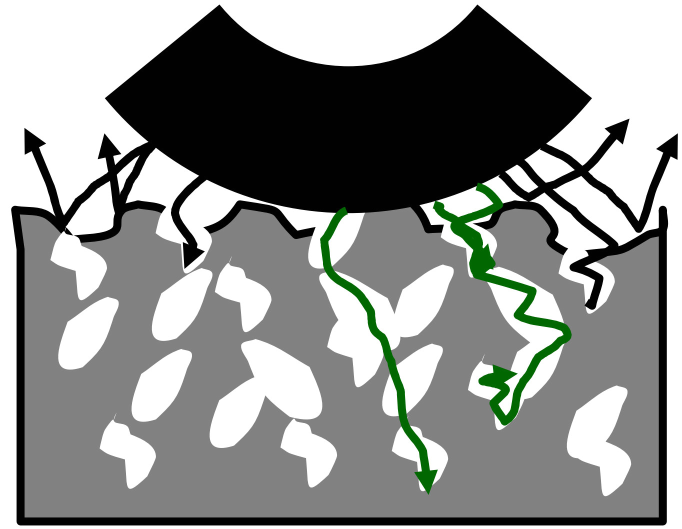
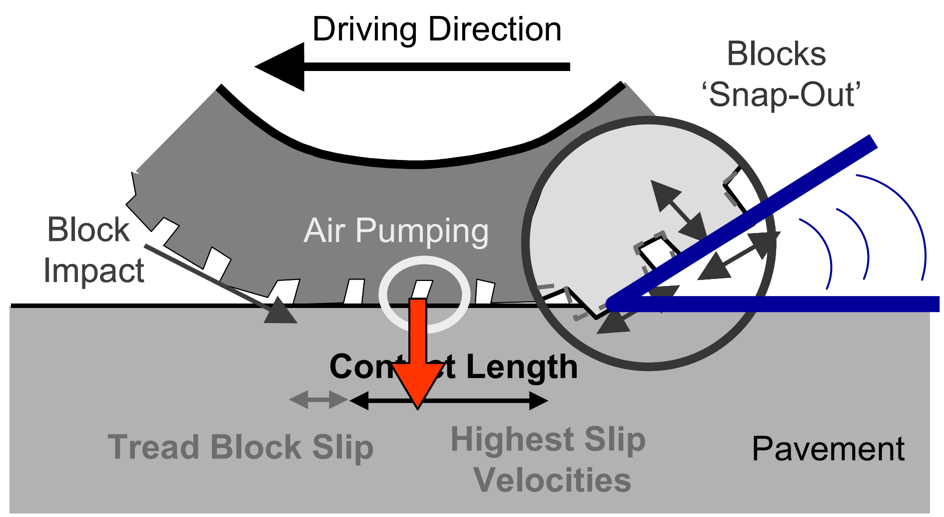
The Need for Pavements

The Time When Cursing Was Louder than Pavement-Tire Interaction

Reducing Noise Through Enhanced Porosity Concrete

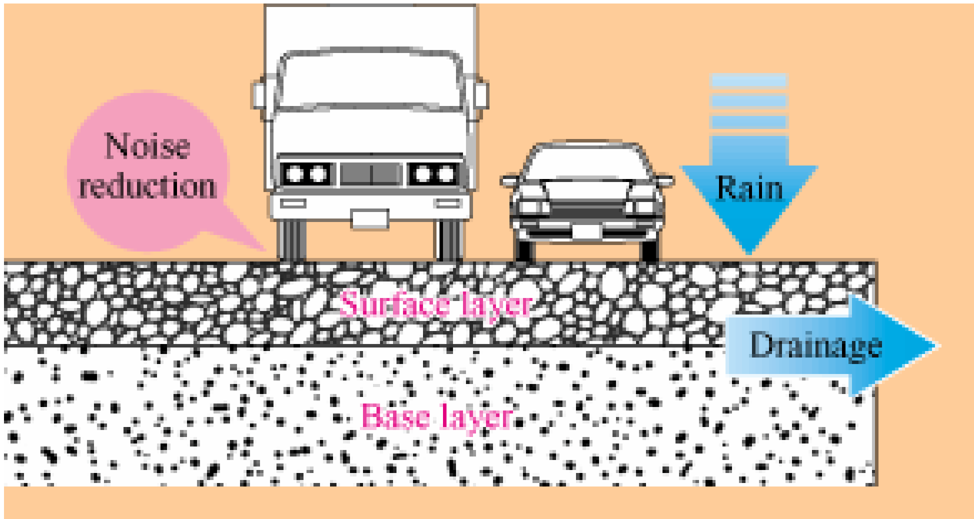
- Increasing the porosity of the non-aggregate component of the material
- Why do we think that this will work
  1. Dissipate Energy Through Friction
  2. Reduces Surface Area and Resulting "Slapping Sound"
  3. Reduces "Horn Effect"



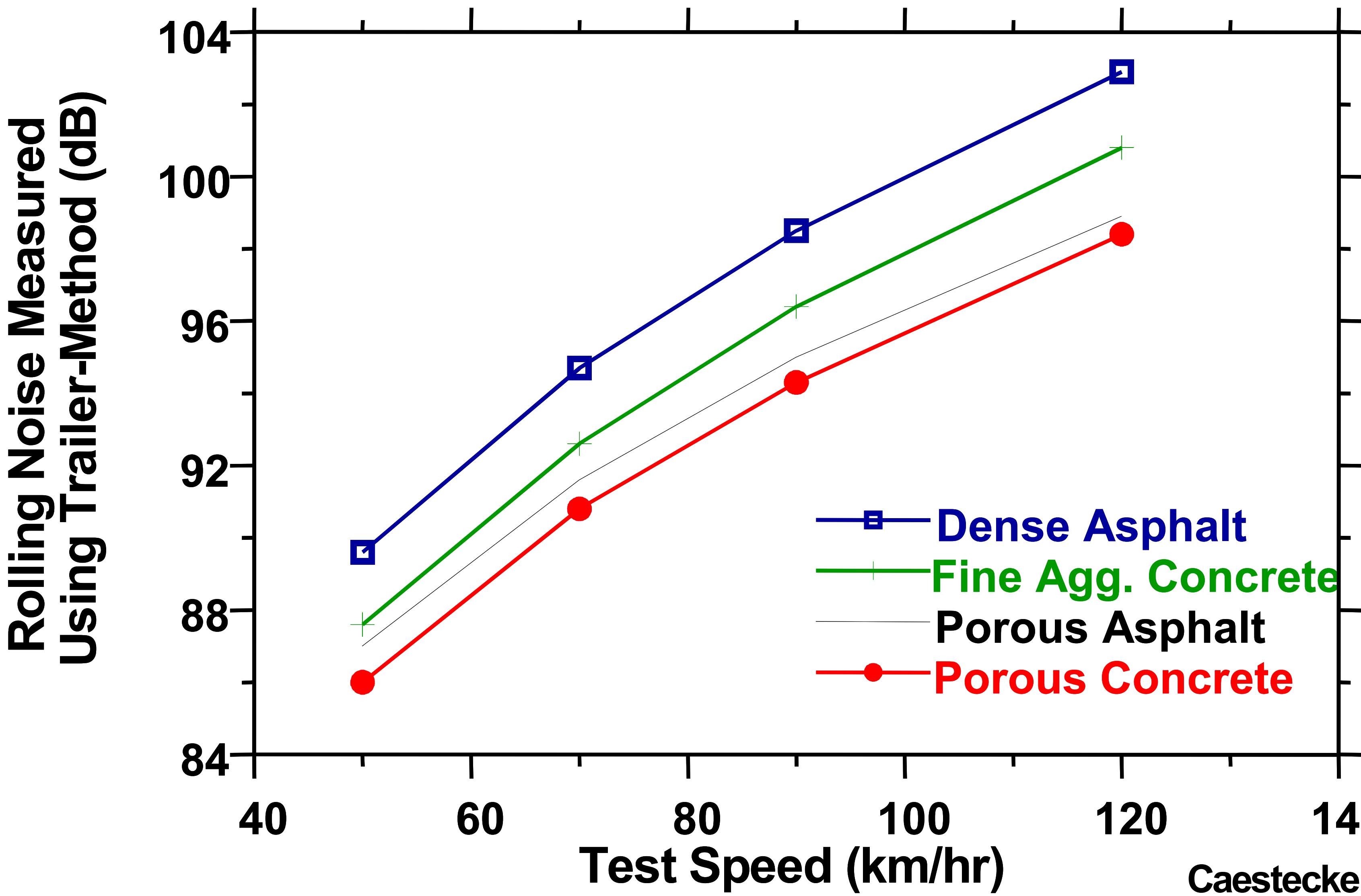


Other Benefits of Enhanced Porosity Concrete

- Work for tire and drive train noise as well
- Rapid drainage of water through interconnected voids
  - Minimizes spray
  - Minimizes glare
- In the south this is being used for “permeable” parking lots



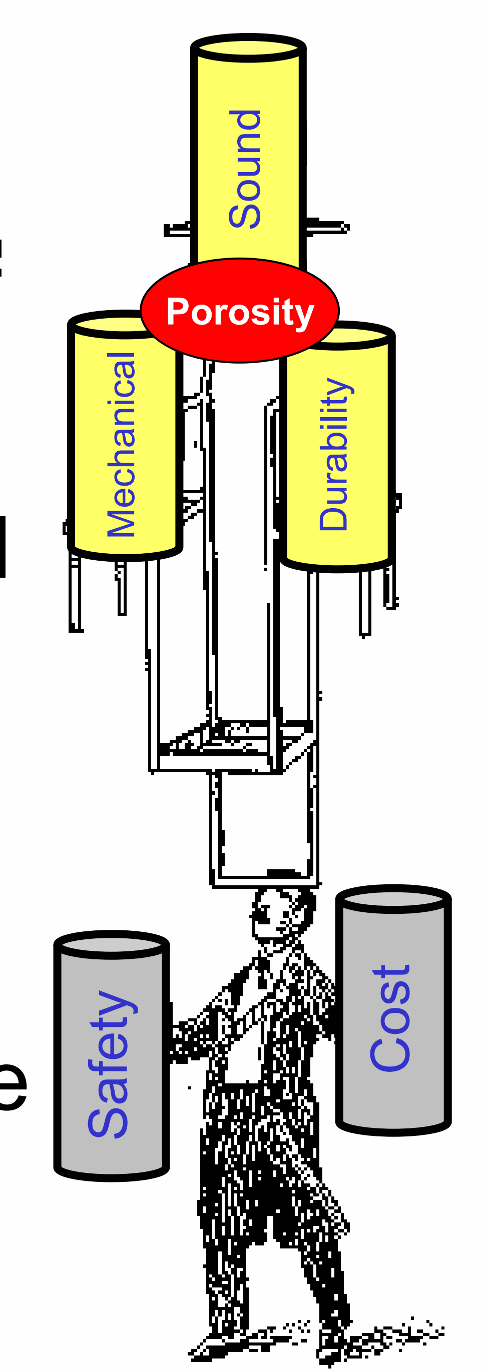
Influence of Porous Pavements



Caestecker 1997

Research Objective

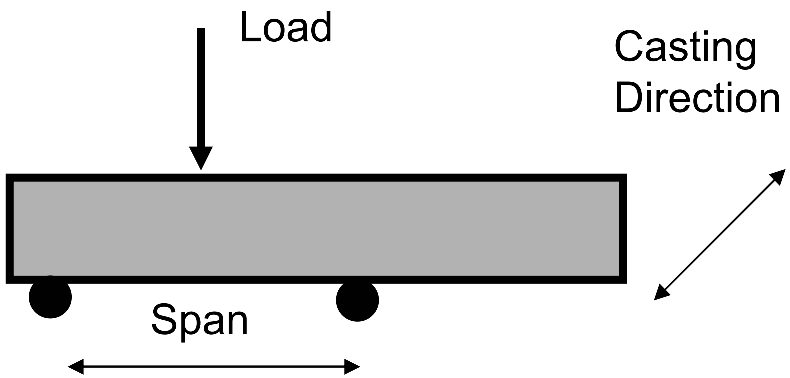
- Determine whether porous pavements can reduce the total noise level while avoiding potential problem associated with high-porosity pavements such as reduced durability
- Balance Safety, Mechanical, Durability, and Sound Performance
  - – Determine Optimal Porosity
  - – Determine Proportioning Procedures



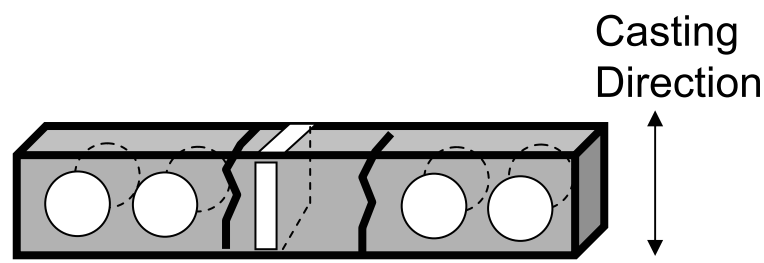
Hans Arrino (mid 19th Century)

Specimen Geometries and Test Procedures

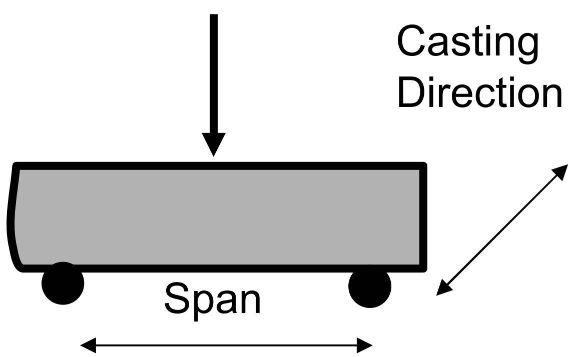
For Each Mixture – Cast 6 in x 6 in x 28 in Beam



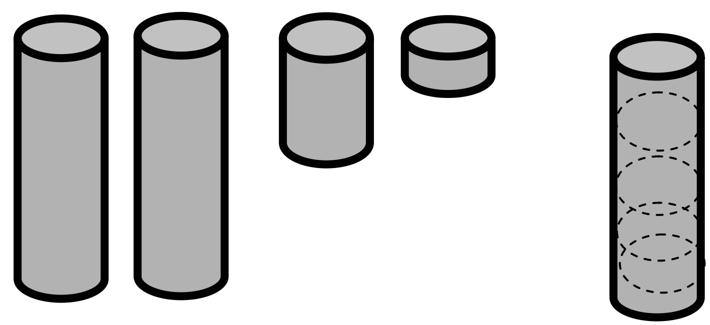
Flexural Strength #1



Sectioning For Sound and Porosity Measurement



Flexural Strength #2



Sound Measurement

Porosity Measurement

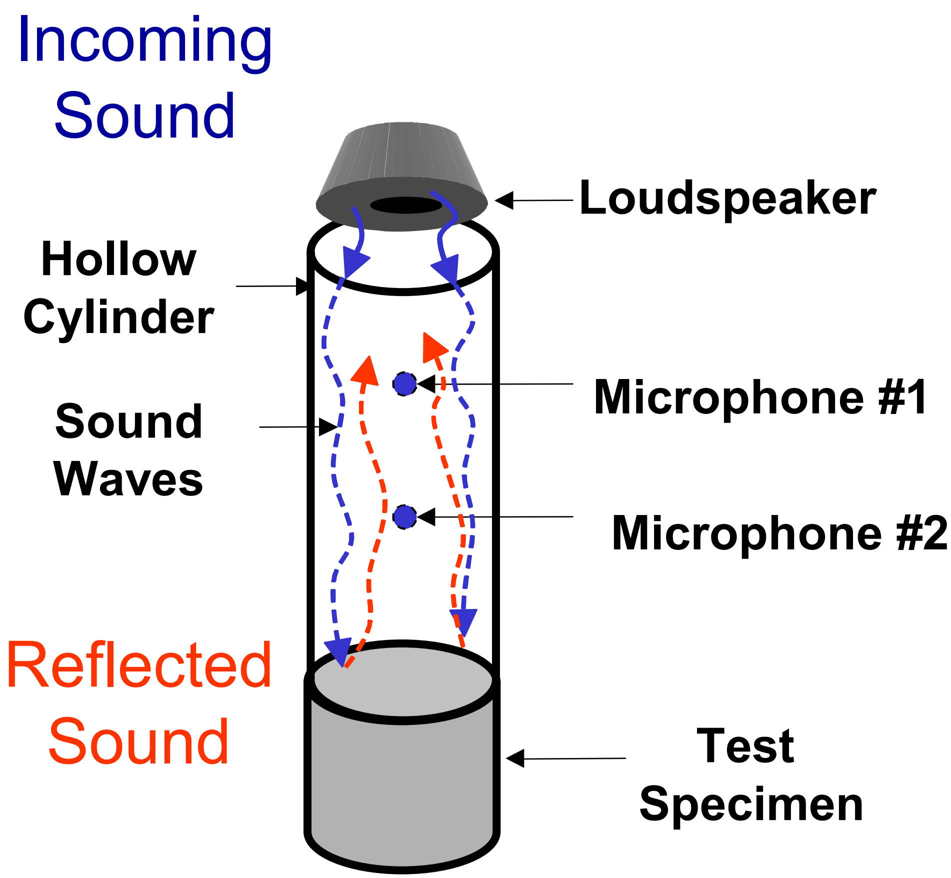
Mixtures Investigated

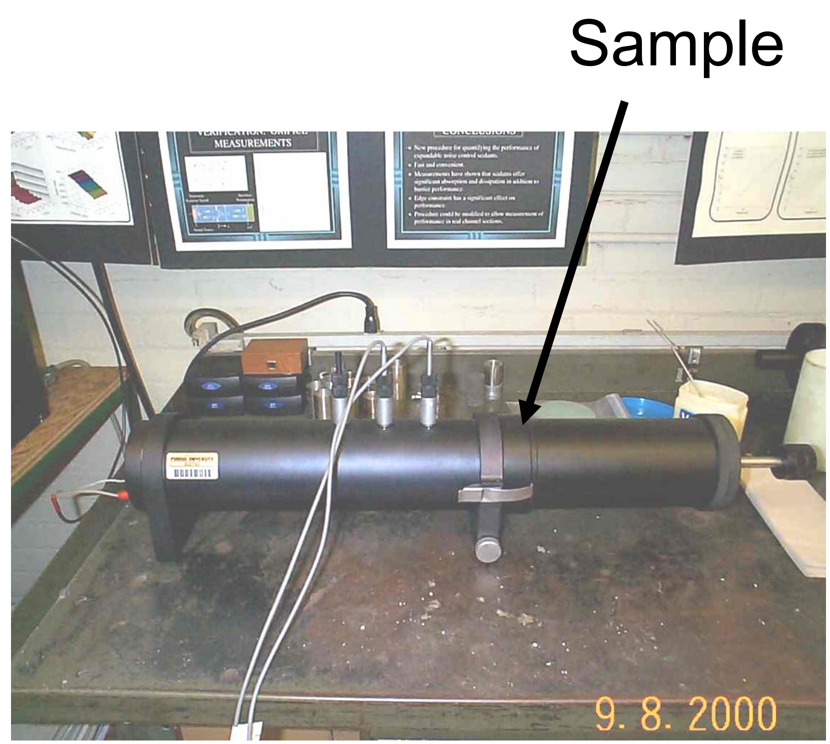
- Influence of Gap Grading and Aggregate Size (#8, #4, 3/8")
- Influence of Blending Aggregates (#8/#4, #8/3/8", #4/3/8")
- Influence of Silica Fume
- Influence of Sand Content

- Influence of W/C (To Come)
- Influence of Fibers (To Come)
- Micro-particulate (To Come)

Mixture I.D.	3/8" Aggregate	#4 Aggregate	#8 Aggregate	Fine Aggregate (Sand)	Water-to-Cement Ratio	Silica Fume Addition by Cement Weight
	%	%	%	%	~	%
Influence of Gap Grading and Aggregate Size						
PC-100-3/8-0	100	0	0	0	0.30	0.00
PC-100-#4-0	0	100	0	0	0.30	0.00
PC-100-#8-0	0	0	100	0	0.30	0.00
Influence of Blending #8 and #4 Aggregates						
PC-100-#8-0	0	0	100	0	0.30	0.00
PC-75#8-25#4-0	0	25	75	0	0.30	0.00
PC-50#8-50#4-0	0	50	50	0	0.30	0.00
PC-25#8-75#4-0	0	75	25	0	0.30	0.00
PC-100-#4-0	0	100	0	0	0.30	0.00
Influence of Blending #8 and 3/8" Aggregates						
PC-100-#8-0	0	0	100	0	0.30	0.00
PC-75#8-25-3/8-0	25	0	75	0	0.30	0.00
PC-50#8-50-3/8-0	50	0	50	0	0.30	0.00
PC-25#8-75-3/8-0	75	0	25	0	0.30	0.00
PC-100-3/8-0	100	0	0	0	0.30	0.00
Influence of Blending #4 and 3/8" Aggregates						
PC-100-#4-0	0	100	0	0	0.30	0.00
PC-75#4-25-3/8-0	75	25	0	0	0.30	0.00
PC-50#4-503/8-0	50	50	0	0	0.30	0.00
PC-25#4-753/8-0	25	75	0	0	0.30	0.00
PC-100-3/8-0	100	0	0	0	0.30	0.00
Influence of Sand Content						
PC-100-#4-0	0	100	0	0	0.30	0.00
PC-95#4-5Sand-0	0	97	0	3	0.30	0.00
PC-97.5#4-2.5Sand-0	0	95	0	5	0.30	0.00
PC-92.5#4-7.5Sand-0	0	92	0	8	0.30	0.00
Influence of Silica Fume						
PC-100-#4-0	0	100	0	0	0.30	0.00
PC-100-#4-06SF	0	100	0	0	0.30	0.06
PC-100-#4-12SF	0	100	0	0	0.30	0.12

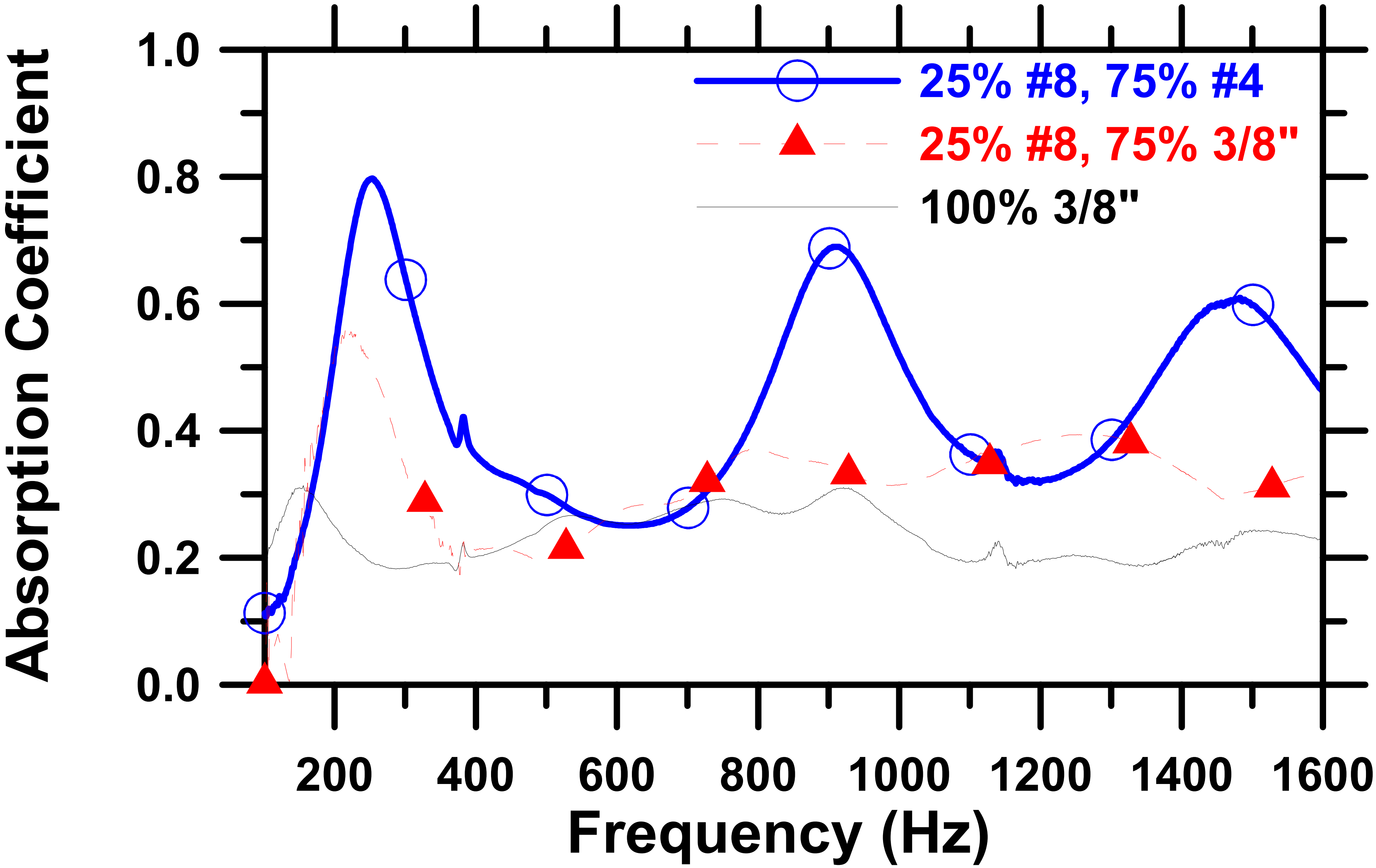
Using A Simple Method for Screening Mixtures



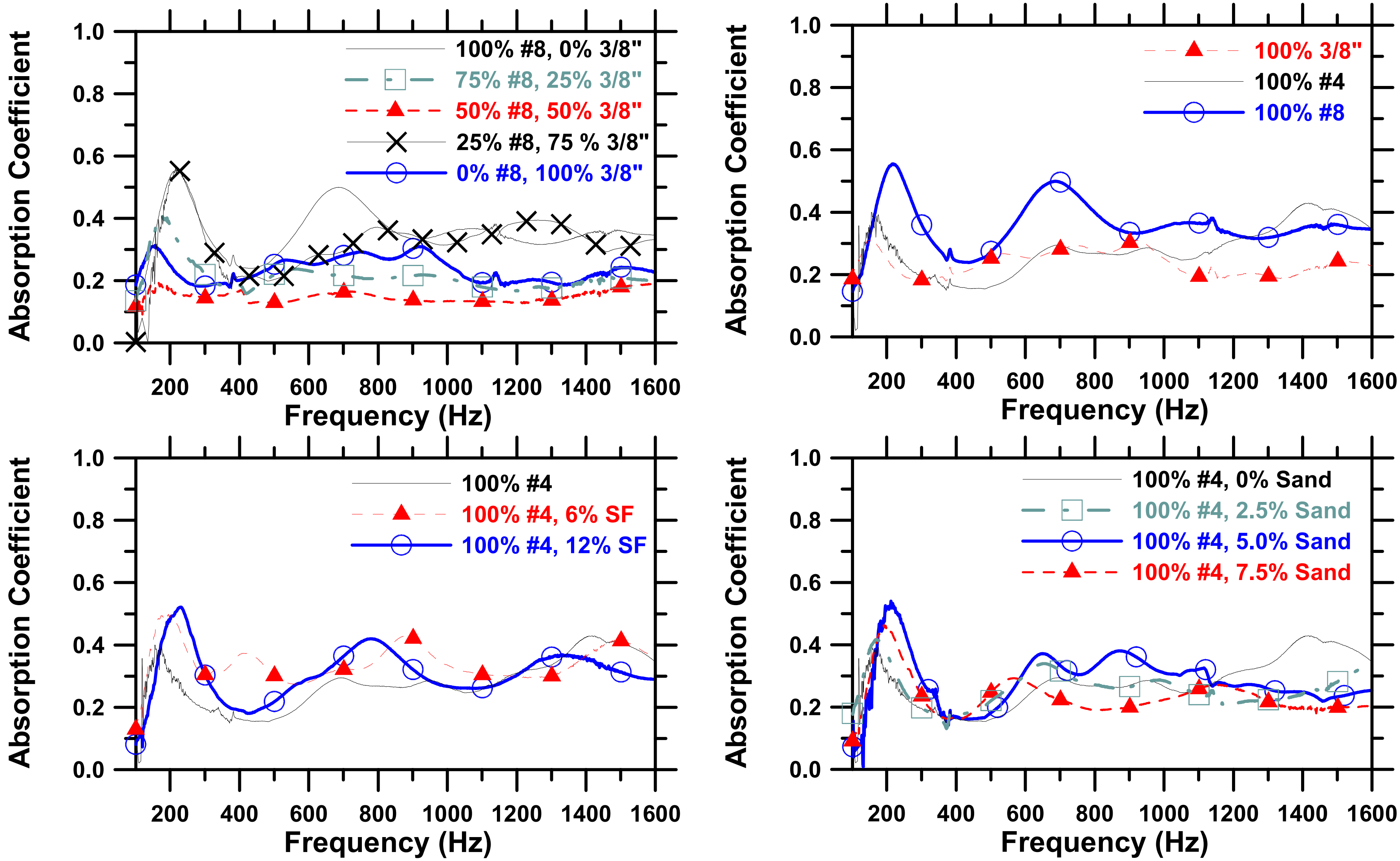


Impedance Tube

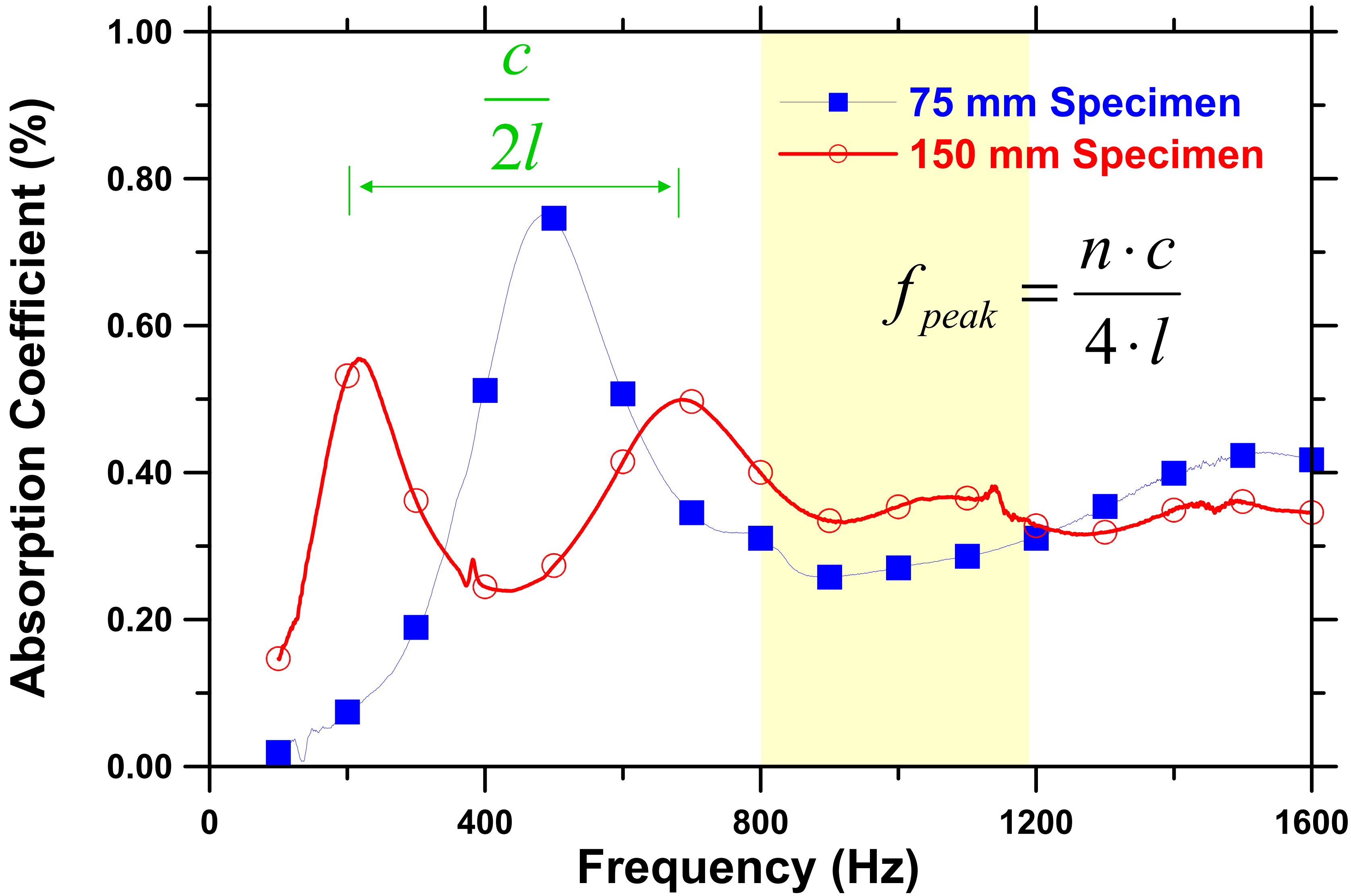
Absorption in 150 mm Thick Specimens (Typ. Conc. 0.05)



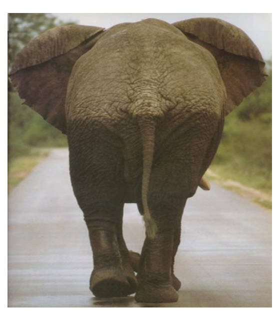
Typical Impedance Tube Results



Influence of Specimen Length



How Do We Gain an Idea of What the Internal Porosity Looks Like



Goal: Separate Porosity Into Total and Accessible Porosity

Steps: Cut At Various Depths and Image

Seal Sides and Add Low Viscosity Epoxy

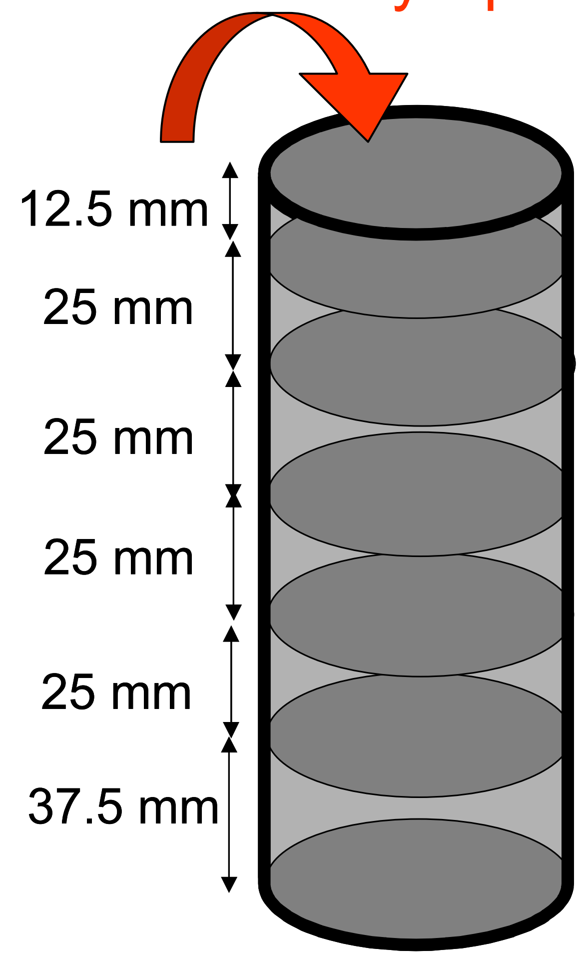
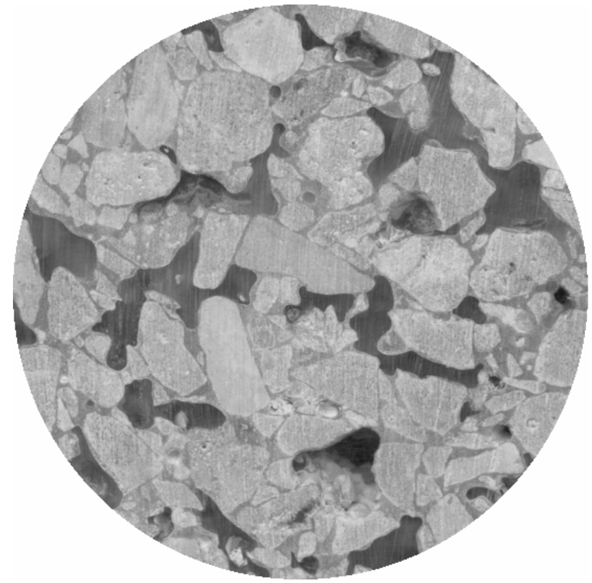


Image Processing
Sample Preparation

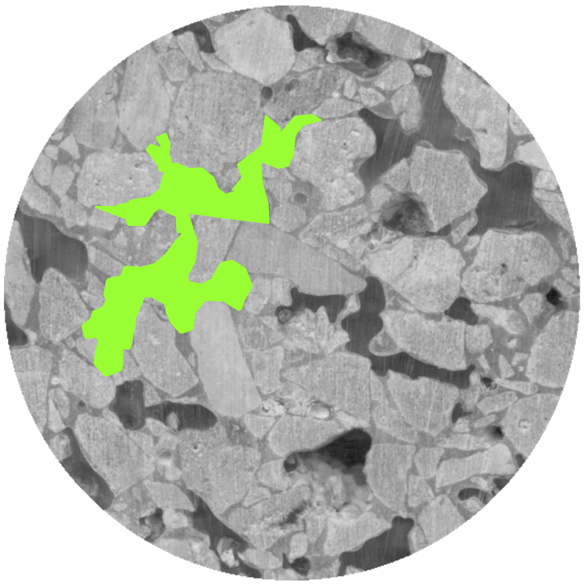
Epoxy Added and Specimen Sectioned Using Diamond Bladed Saw

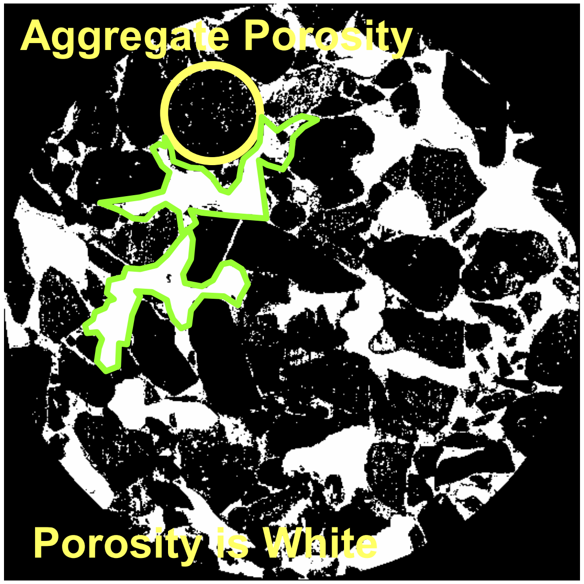
Scanning Using a Flatbed Scanner

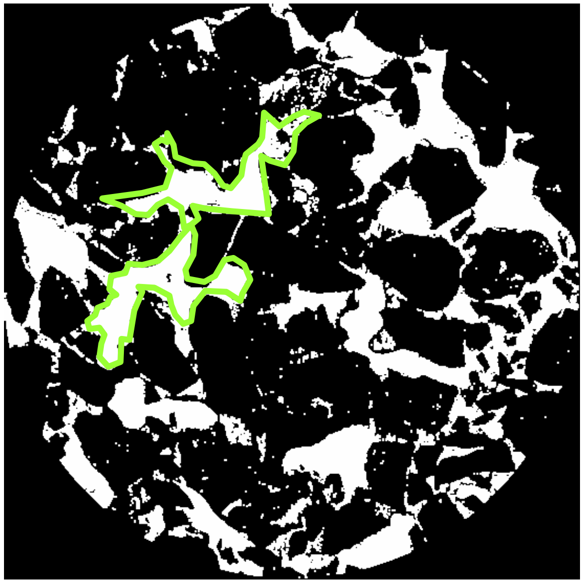


Scanned Image Cropped to a Diameter of 2.75 in (550 Pixels)

Image Processing
Determine Total Porosity





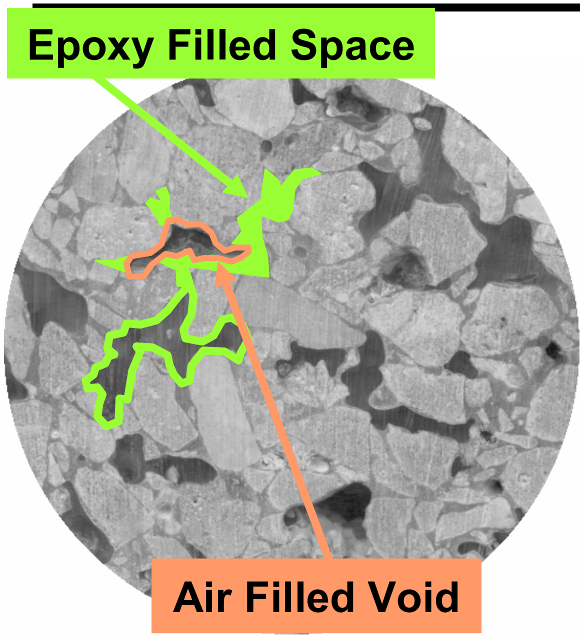


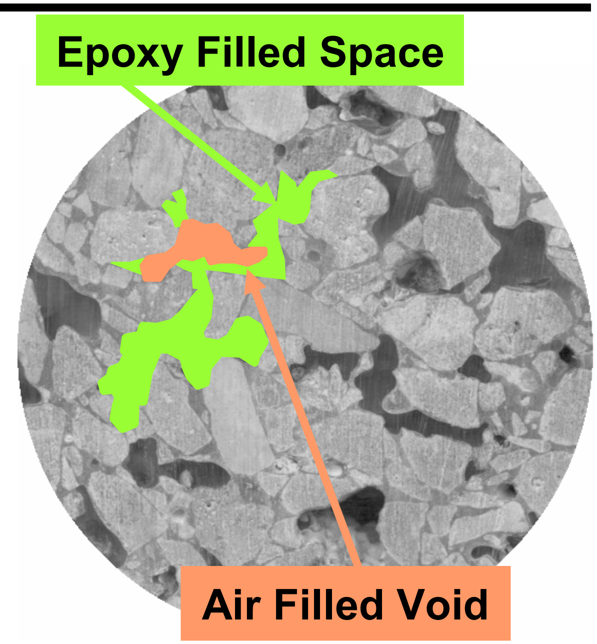
Scanned Image Cropped to a Diameter of 2.75 in (550 Pixels)

Color Intensity Threshold Established (~ 150) To Separate Total Porosity (i.e., air and Epoxy Filled Space)

Image Cleaned White Pixels (Porosity) Counted = 72,641 Divide By Total Pixels 72,641/237463 = 30.6%

Image Processing
Determine Inaccessible Porosity





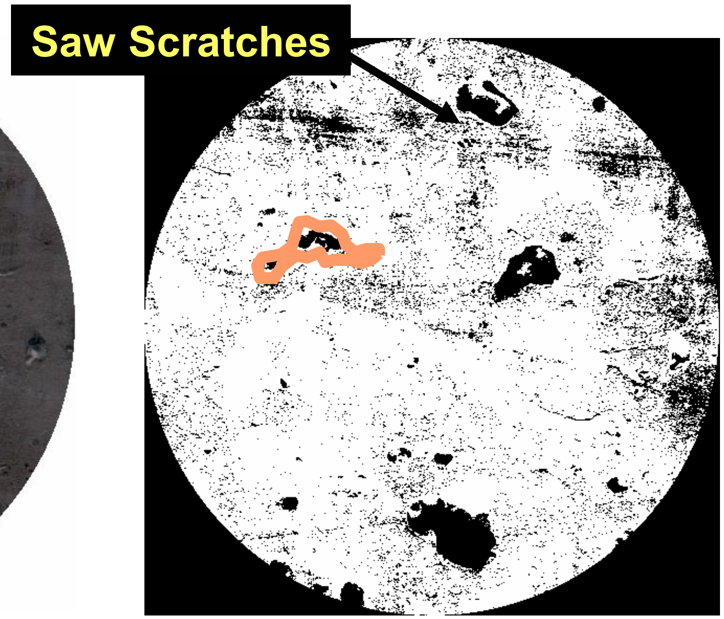
Scanned Image Cropped to a Diameter of 2.75 in (550 Pixels)

Color the Surface of the Scanned Image Cropped to a Diameter of 2.75 in (550 Pixels)

Separate Total Porosity into Accessible Porosity and Inaccessible Porosity

Image Processing
Determine Inaccessible Porosity

Color the Surface of the Scanned Image Cropped to a Diameter of 2.75 in (550 Pixels)



Color Intensity Threshold Established (~ 70) To Separate Inaccessible Porosity (i.e., Air Filled Space)

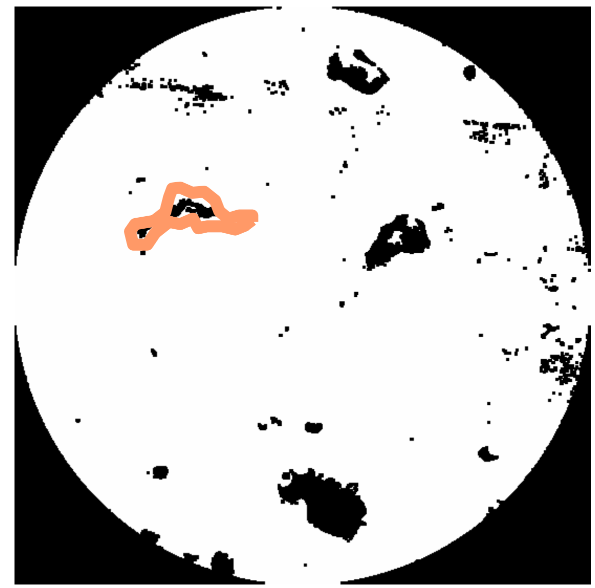
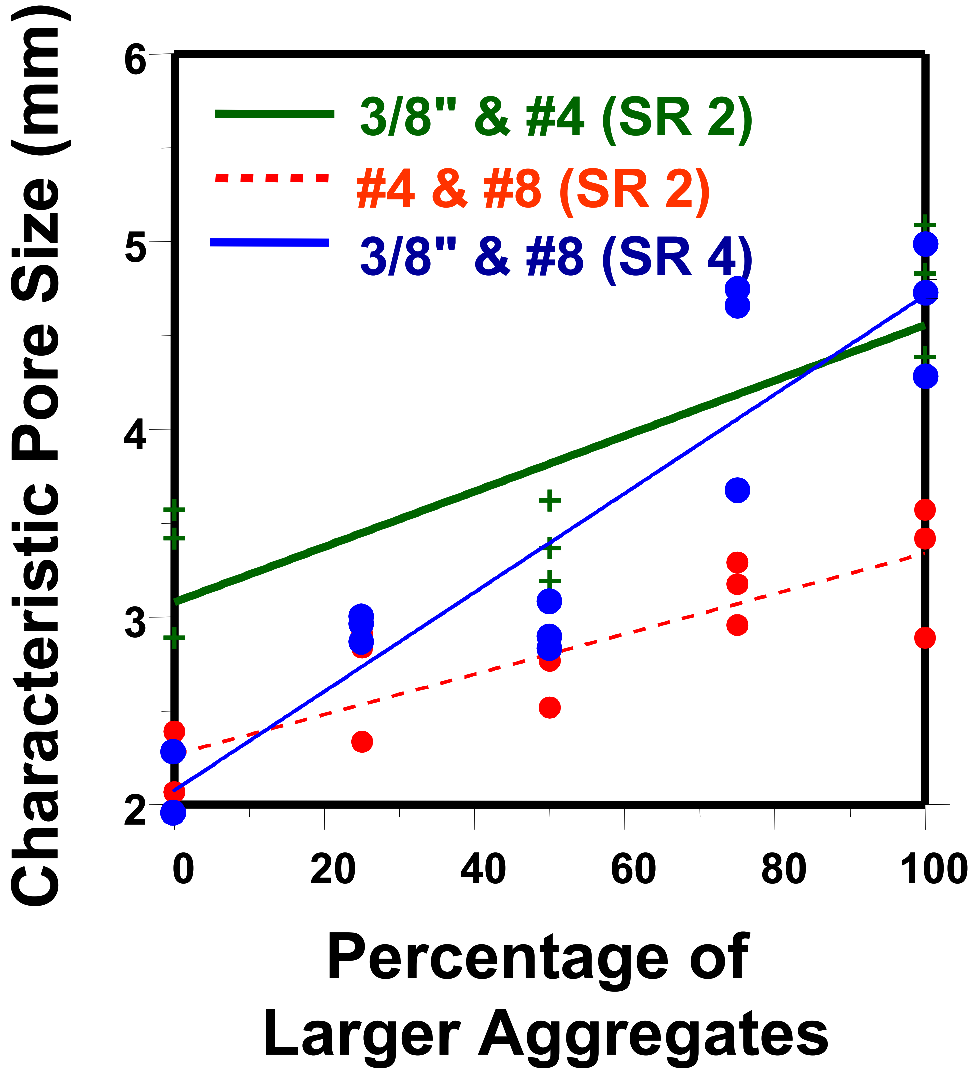
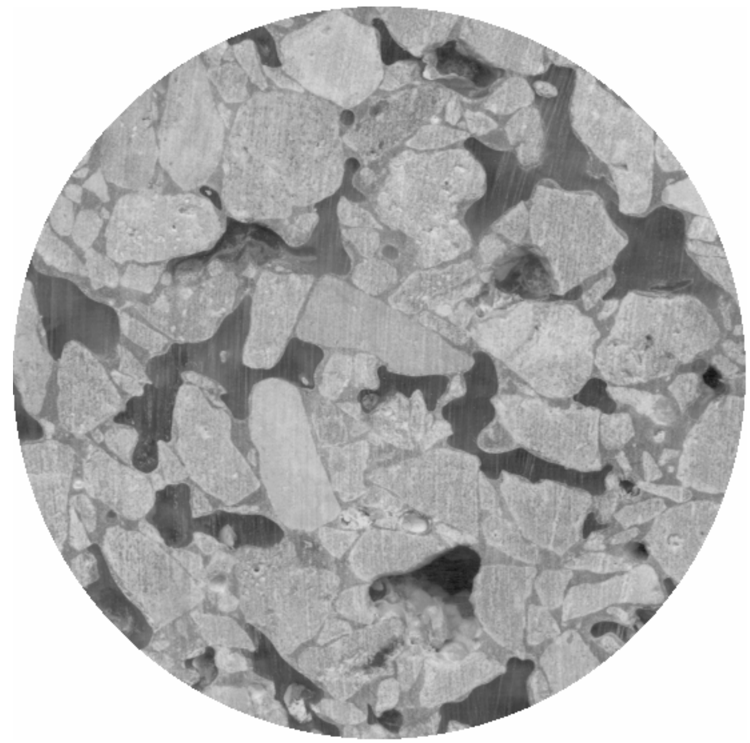


Image Cleaned
Black Pixels (Porosity +Background) and Subtract Background
Counted = 225,087
12,376/237463 = 5.2%

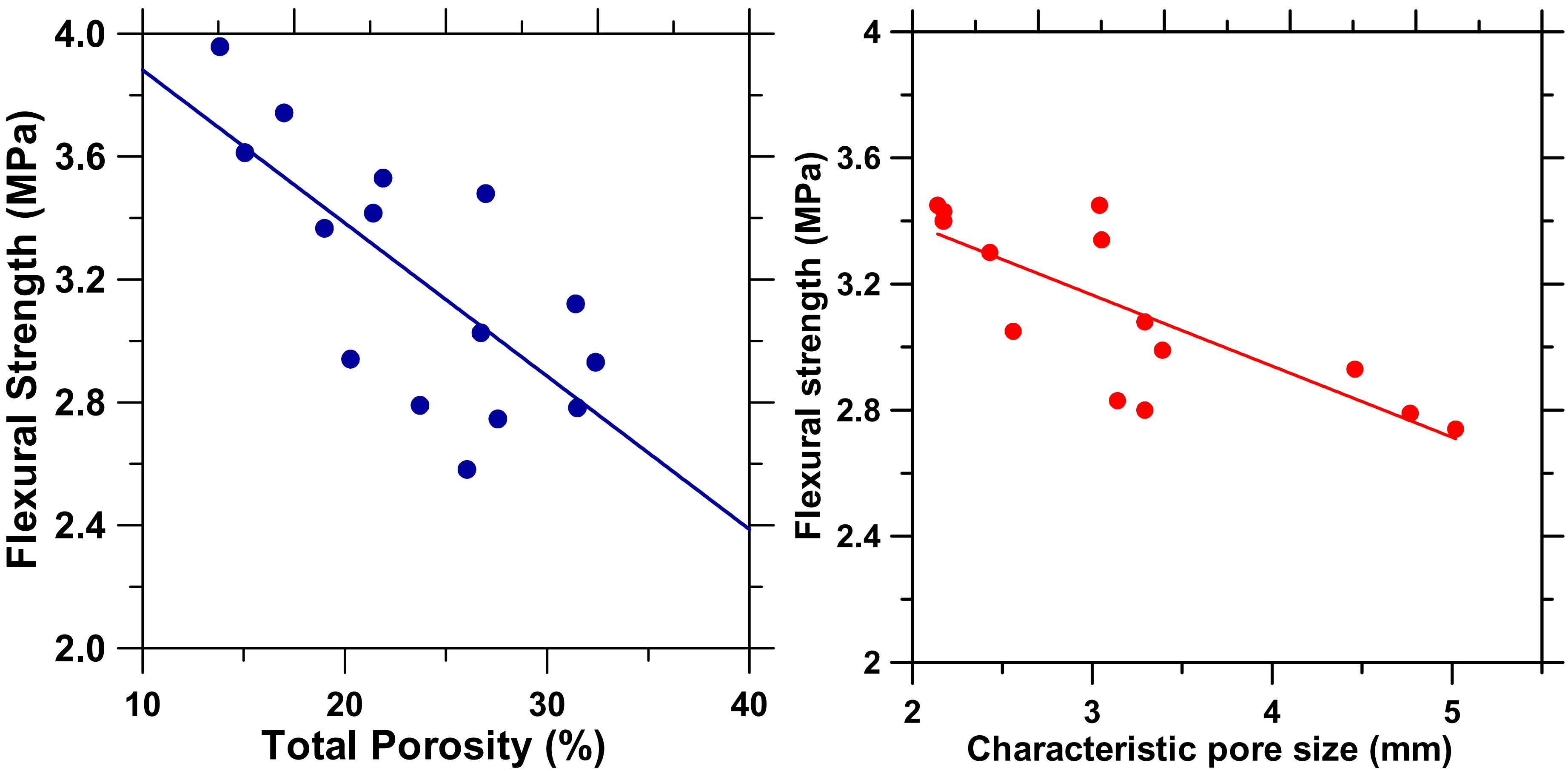
30.6%-5.2% = 25.4% AP

Aggregate Size and Pore Size

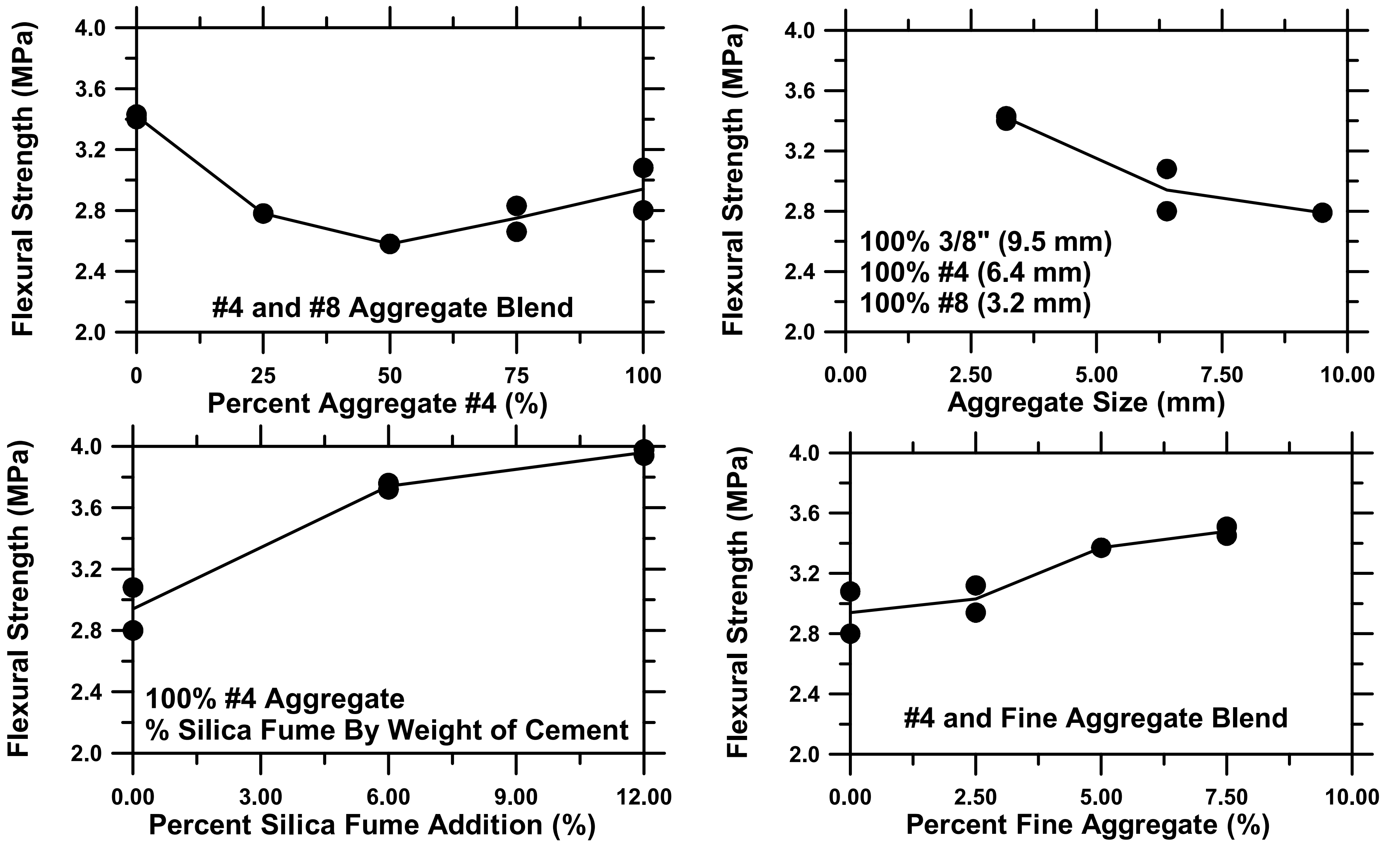




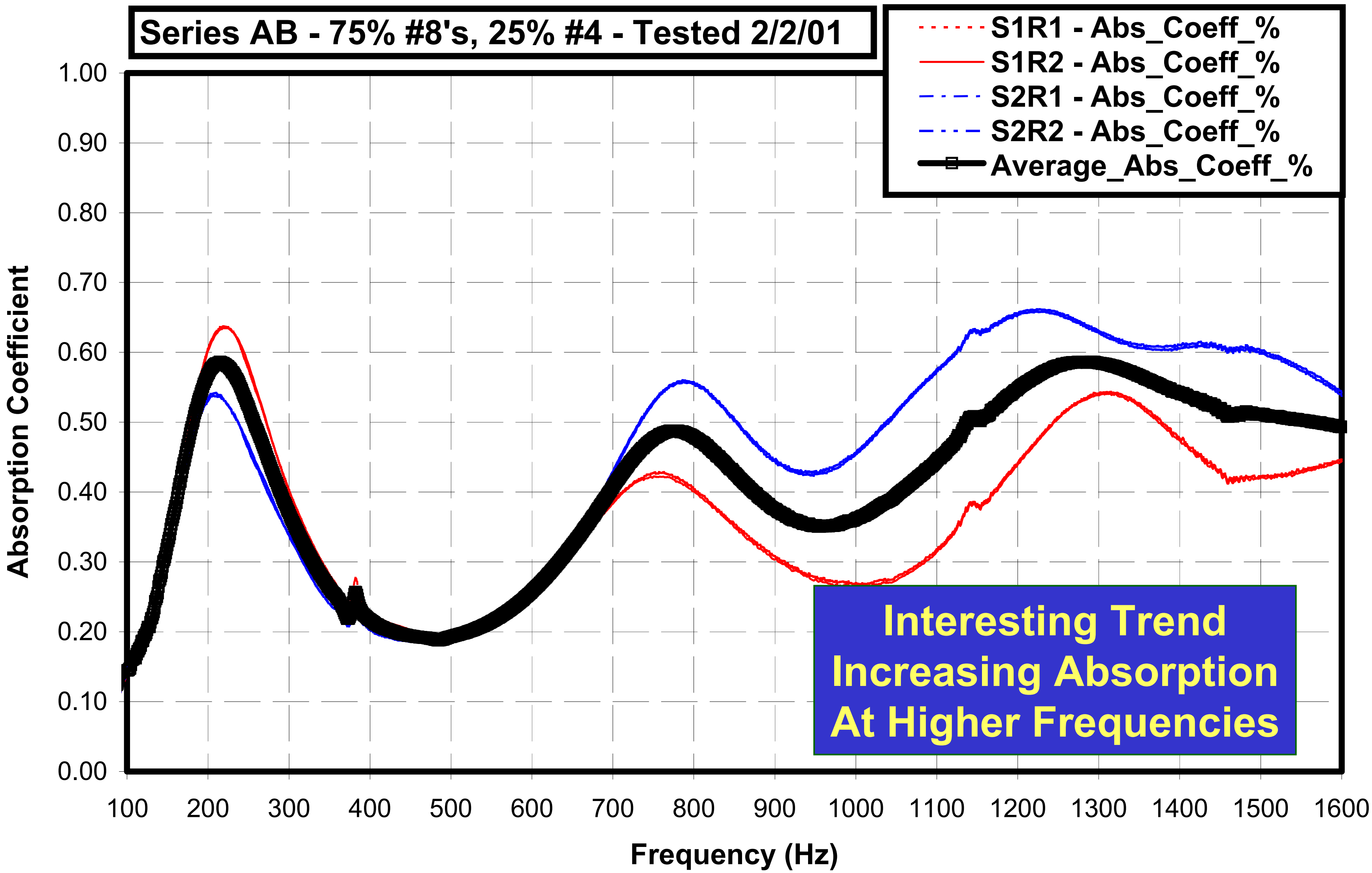
Flexural Strength



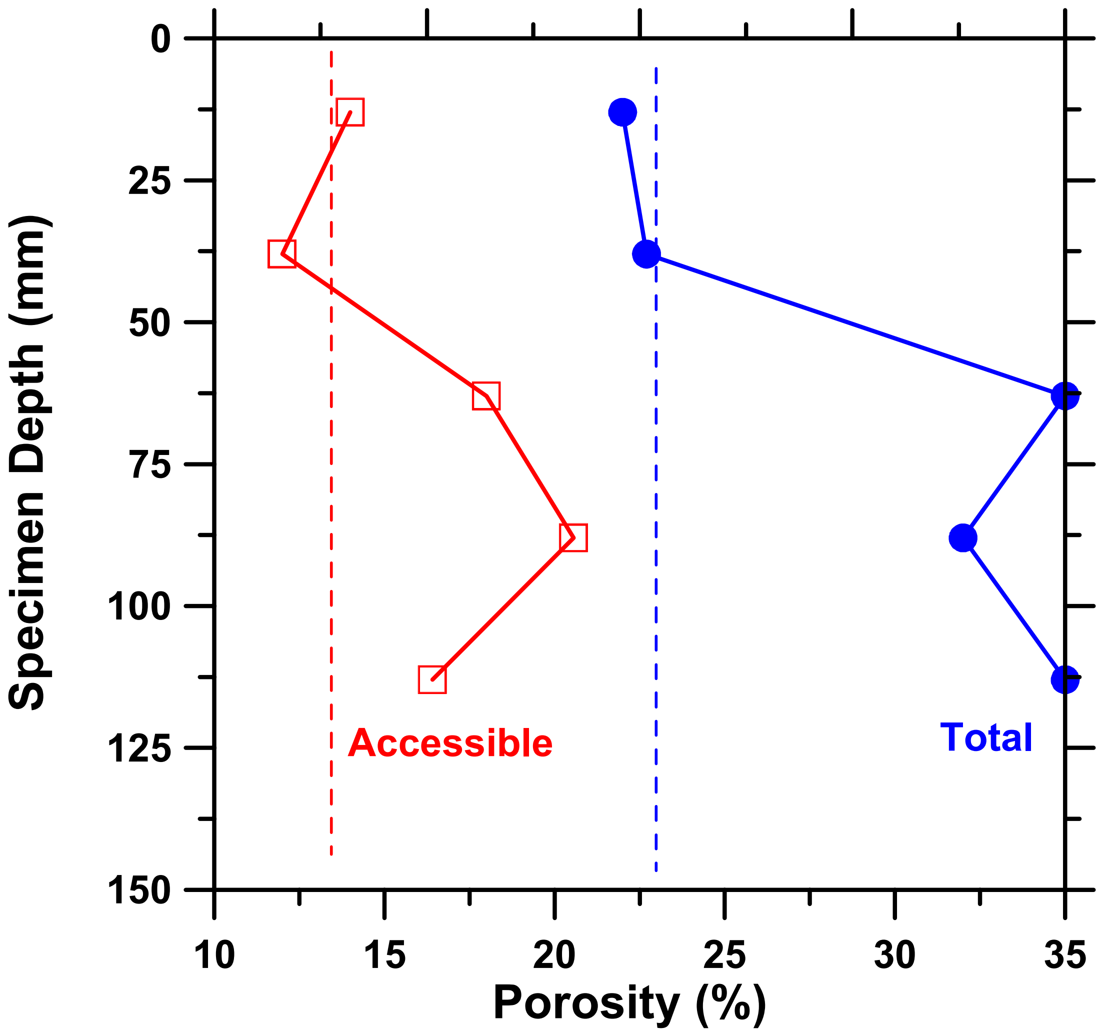
Examples of Basic Trends

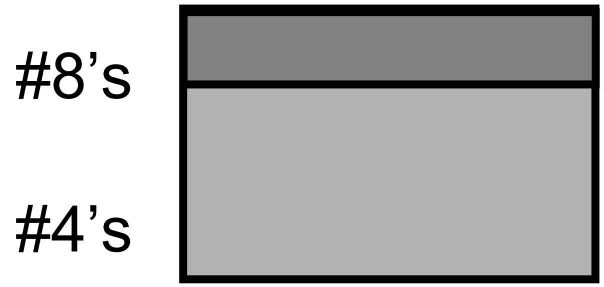


Inspiration for Trying Multi-Layer Systems



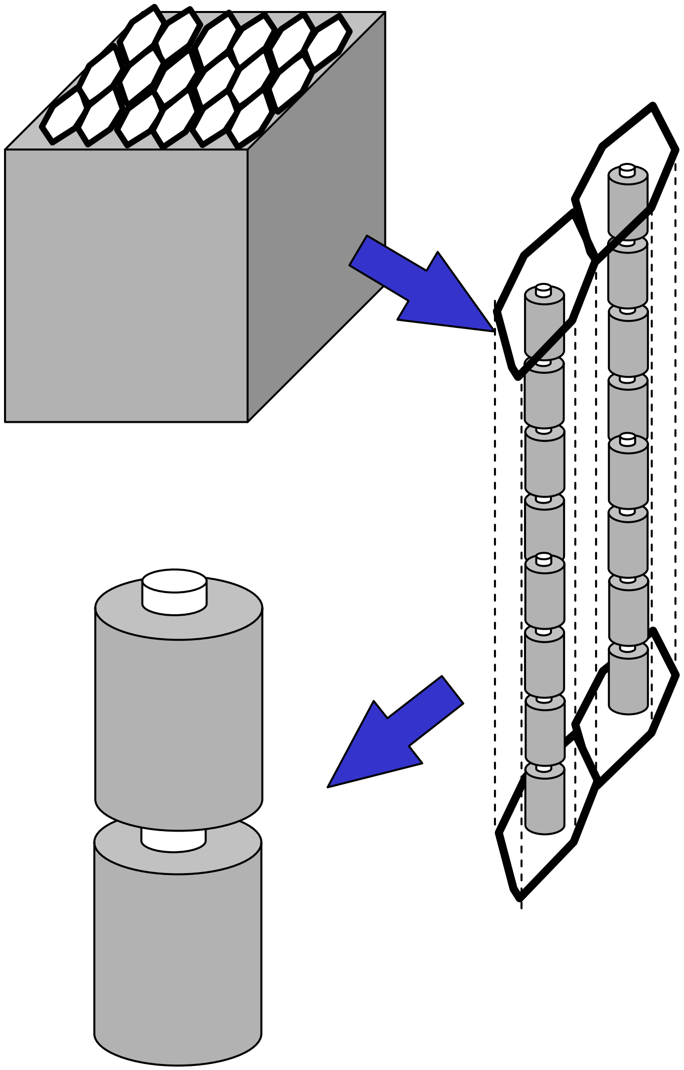
Multi-Layer Pavements

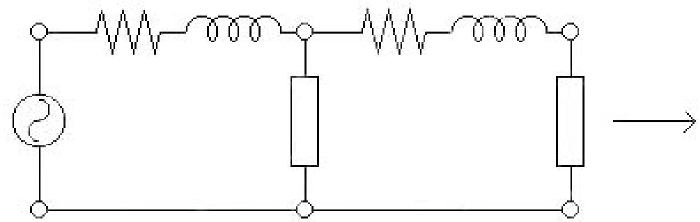




75% #8 and 25% #4

Modeling Sound Absorption and Porosity

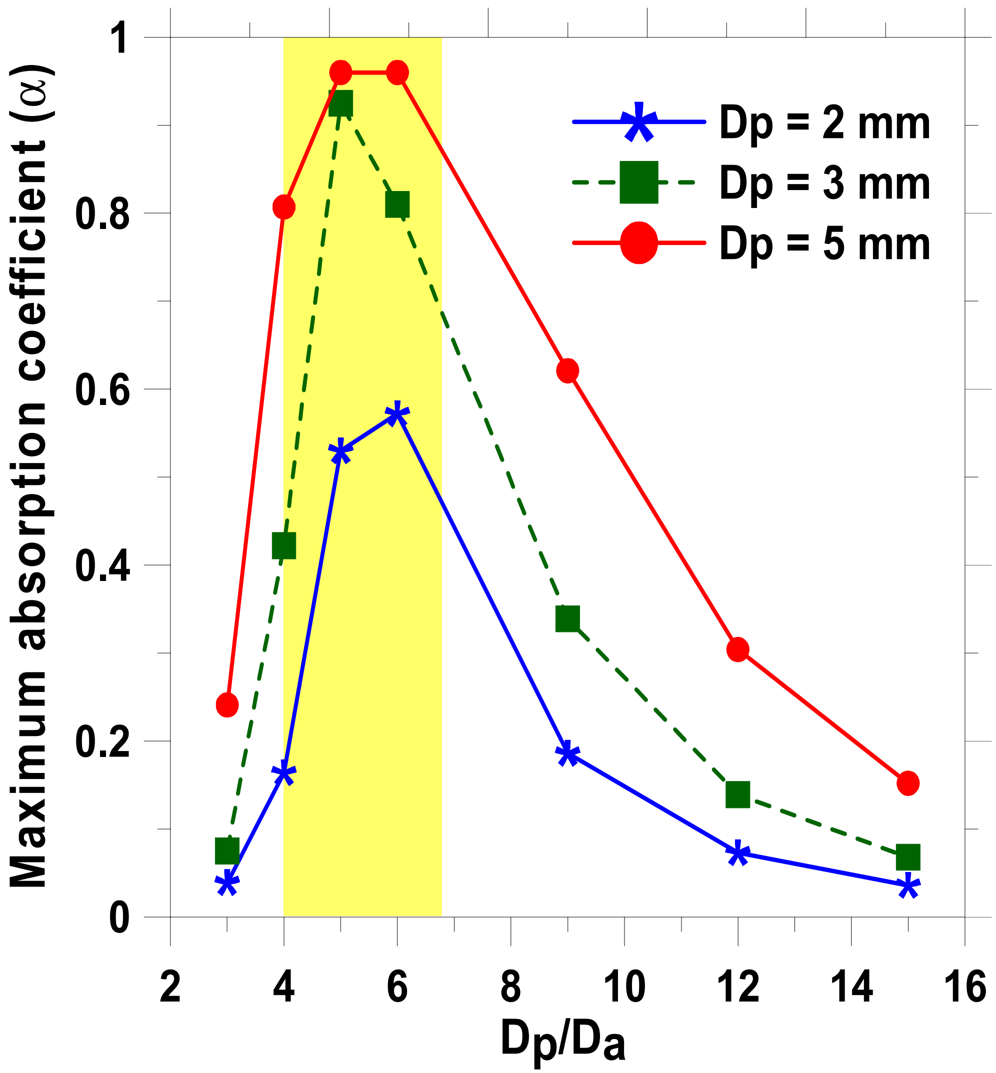




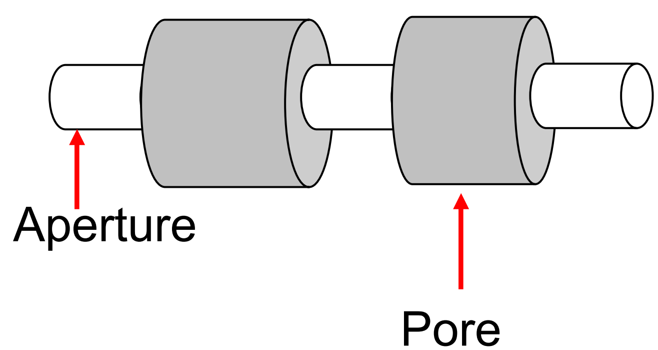
$$Z_n = z_o + \frac{1}{\frac{1}{Z_D} + \frac{1}{Z_{n-1}}}$$

$$\alpha = \frac{\frac{4R}{\rho_o c_o}}{(1 + \frac{R}{\rho_o c_o})^2 + (\frac{M}{\rho_o c_o})^2}$$

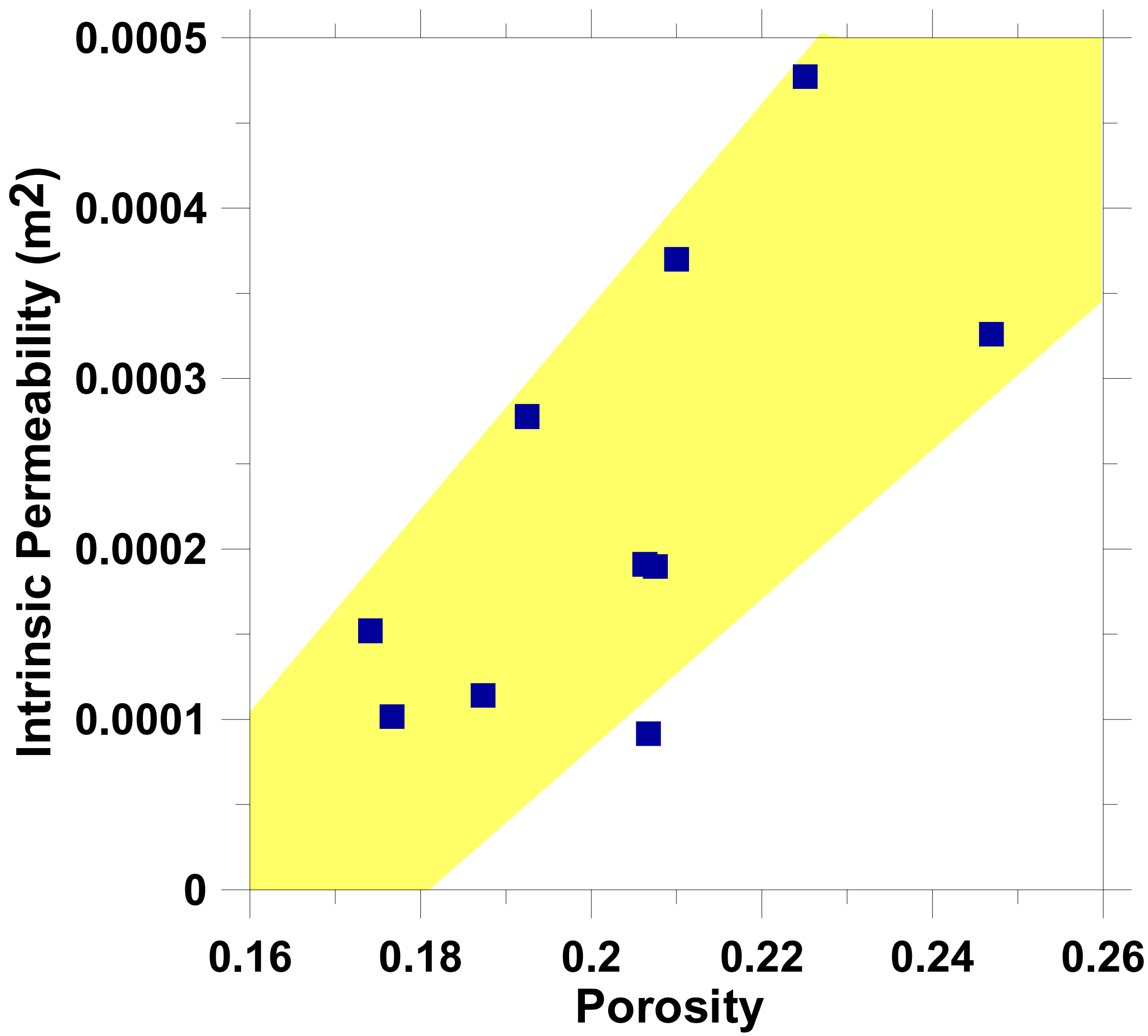
Using the Model to Determine the Optimal Pore Geometries

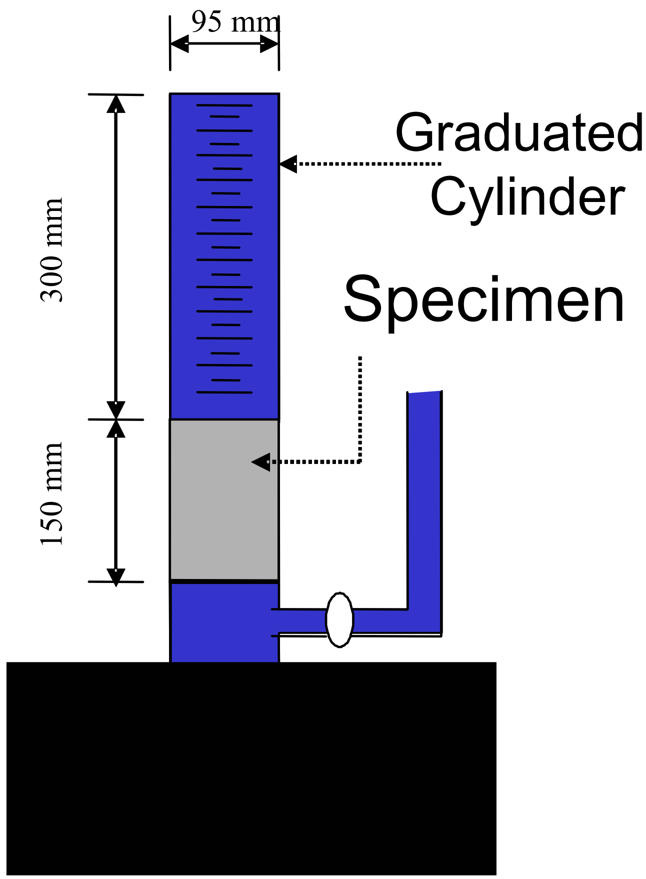


- Optimal D_p/D_a value for each D_p where α is max.
  - High Dp/Da: small aperture size, more energy reflected
  - Small Dp/Da: large aperture size, air trapped in pores



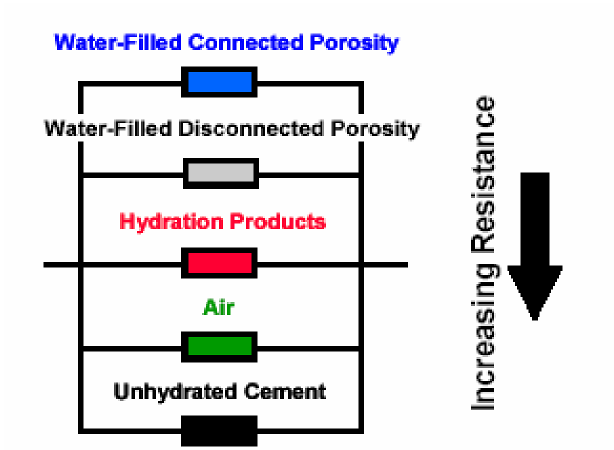
Water Permeability

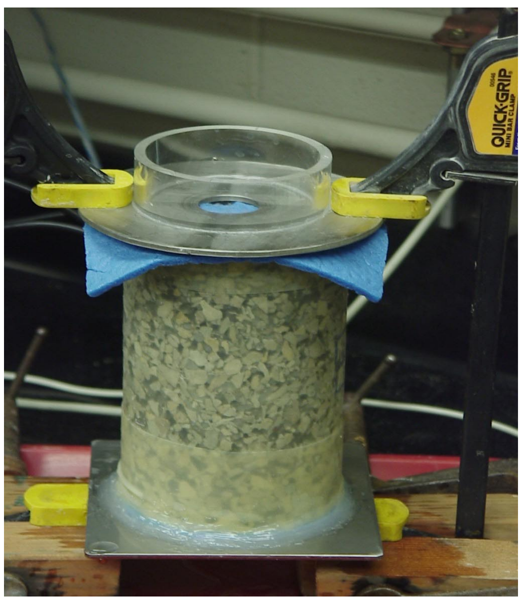




Characterizing the Pore Structure

- Electrical Impedance Spectroscopy
- Characterization of pore connectivity and tortuosity



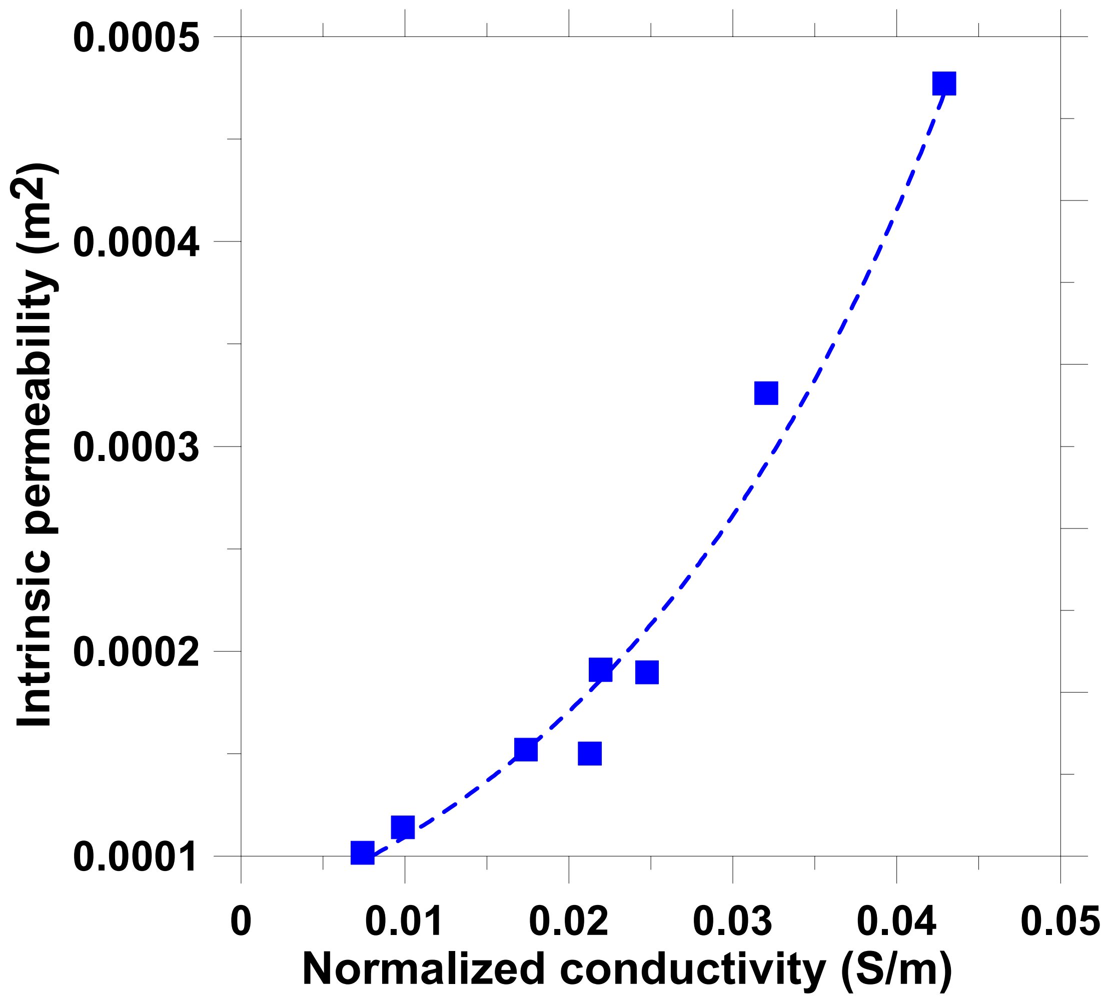


Permeability and Conductivity

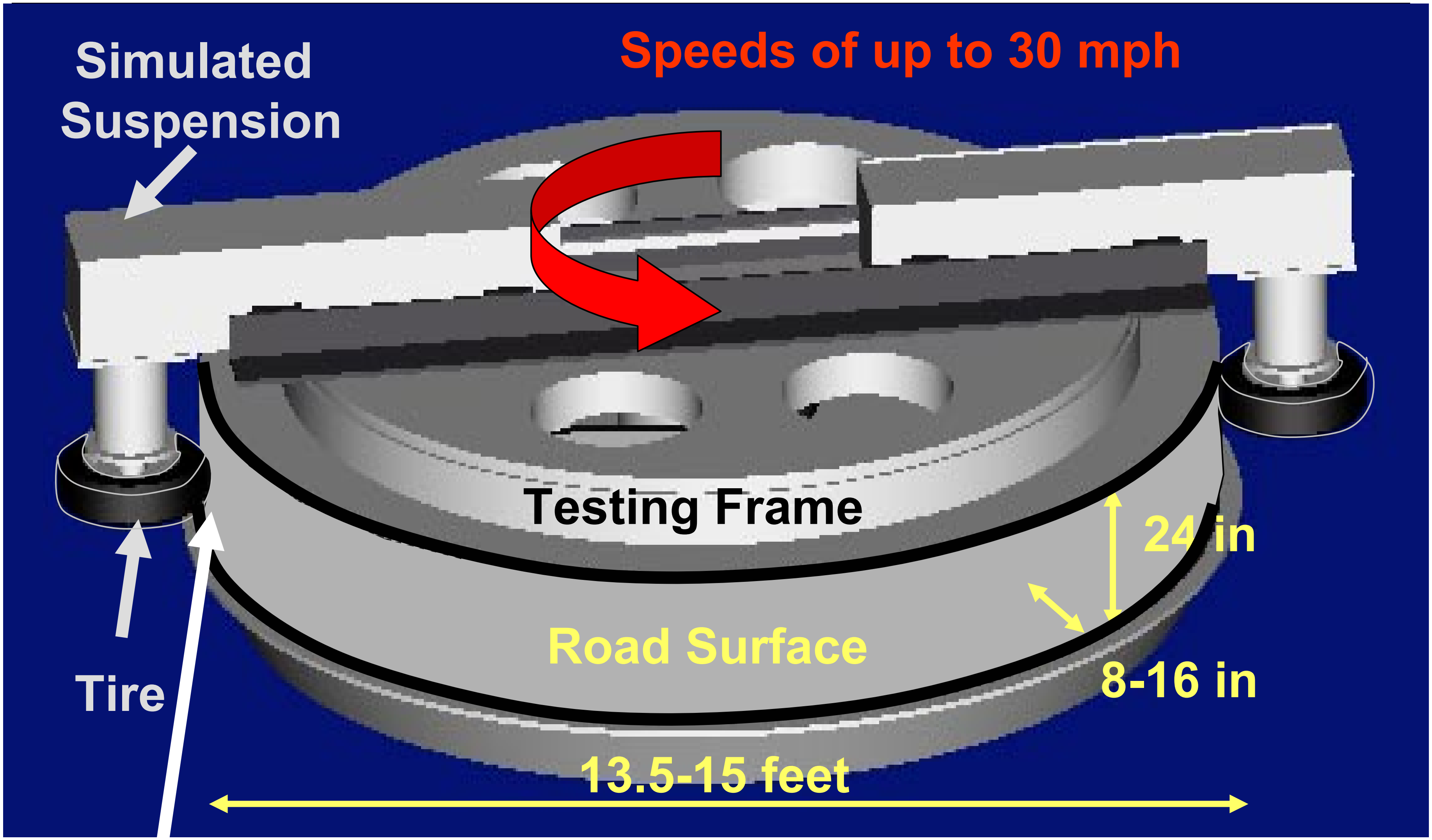
$$\beta = \frac{\sigma}{\sigma_0 \varphi}$$

$\frac{\sigma}{\sigma_0}$ Normalized conductivity

ϕ Porosity



Controlled Testing



Measure Sound Generated By Tire/Pavement Interaction

Summary and Conclusions

- Porous Concrete May Have Benefits – Sound Absorption and Drainage
- The “Structure of these Materials Influence Performance” (Impedance Tube, Porosity, Strength, Permeability)
- Blended Systems Appear to Show Optimal Performance
- Modeling Appears to Have A Promise to Help Us Optimize the Properties We Want
- Durability Testing is Beginning for F-T Climates