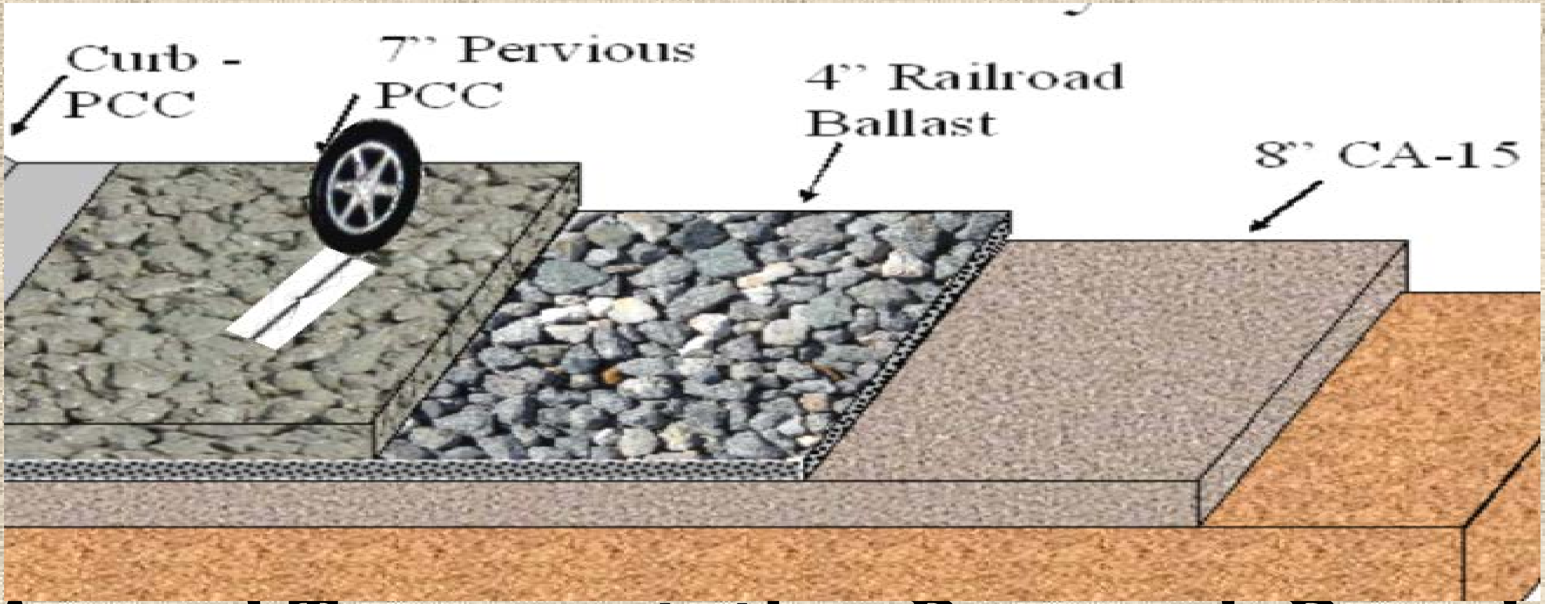
Maintenance and Evaluation of Porous Pavement Infrastructure in Minnesota

Bernard Igbafen Izevbekhai, P.E.
Mark Maloney, P.E.



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Raison D' Etre

- Pervious concrete is a stormwater management solution

- Due to the larger cavities clogging tends to occurs

- Does clogging compromise acoustic and hydraulic conductivity characteristics ?

- Do clogging agents impact Pervious concrete variously?

- Can acoustic properties and conductivity properties be partly or fully restored by maintenance practices.

- How does clogging affect tortuosity?

Definition

A pervious Pavement Consists of a Concrete, Bituminous or Aggregate surfacing with sufficient porous structure to facilitate the direct ingress of surface run-off.

Implications:

- **A porous base structure for storage (detention and retention) (Except a porous overlay)**
- **A granular subgrade for infiltration;**
- **Semi-porous: Air voids content between 10 and 15 %**

  Porous > 15% void content (Sandberg and Ejsmont (2002)

Pervious Concrete- Definitions

- **Regular concrete is permeable to 10^{-3}in/hour**
- **A porous structure through the entire layer designed to a specified flood level**
- **Facilitates Direct ingress of stormwater through the pavement : implies HC > 30 in/minute base and subbase of equal or greater hydraulic conductivity than the surface.**
- **Non-Pervious Concrete: Air voids are held in the paste. Pervious Concrete : Cavities are outside the paste.**
- **Air Entrained Concrete is not pervious.**

CLOGGING AND PAVEMENT QUIETNESS

Pervious Concrete Clogging Concept

- OBSI is a function of the initial Sound Absorption coefficient, degree of Clogging and Ravelling Intensity

$OBSI_{(frequency)} = f((\alpha 0_{frequency}, \gamma \; \phi)$

$OBSI = G((\gamma \; \phi)$

$\alpha 0$ Average was poorly correlated to OBSI Average

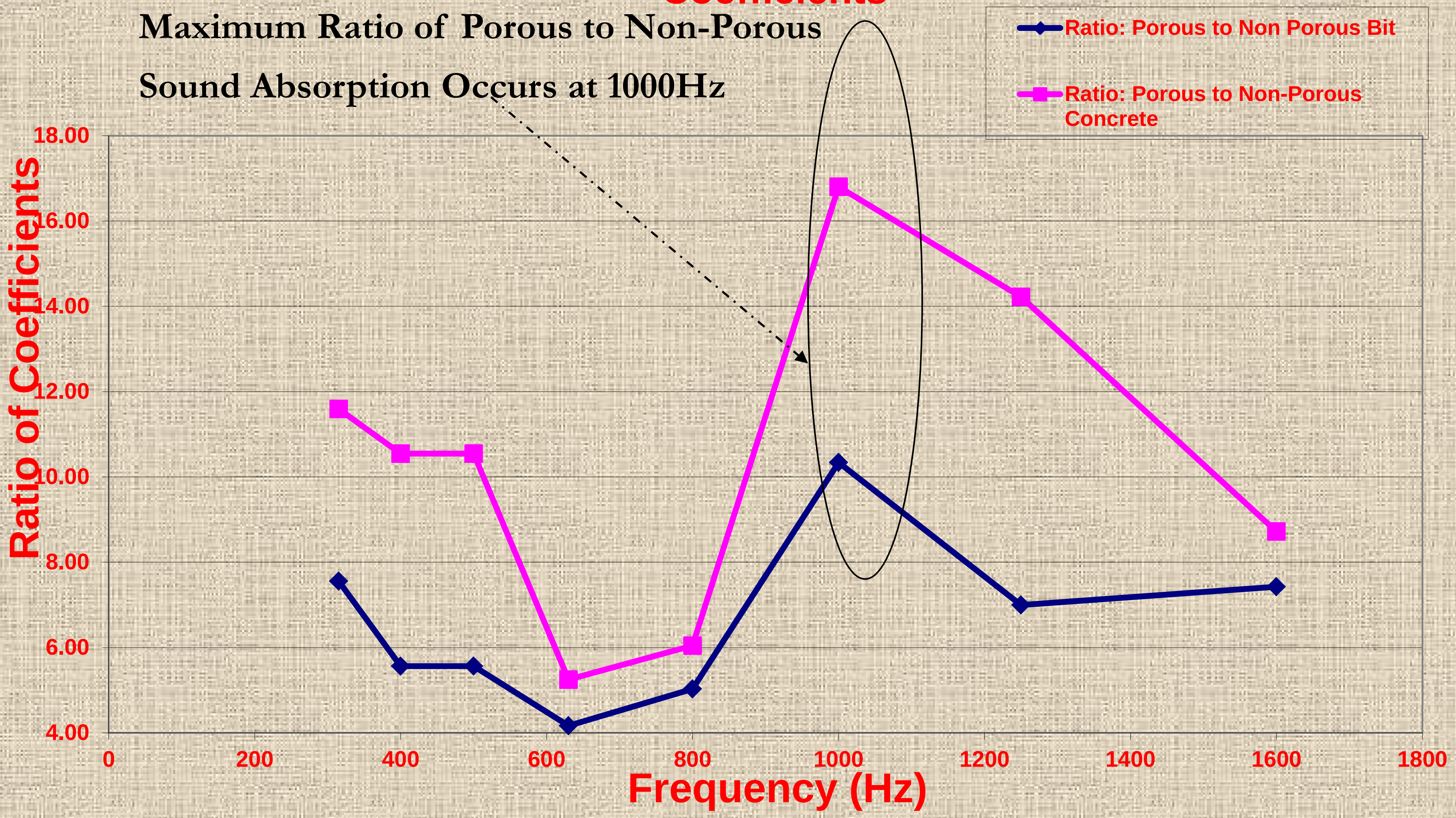
$R^2 = 0.0018$

$\alpha 0_{frequency}$ was better correlated to $OBSI_{frequency}$ $R^2 = 0.4$

  - Where $\alpha 0$ is initial sound absorption
  - γ is a raveling function ranging from zero non-existent to 1 severe (can be dislodged without mechanical effort). This is a surface function and ϕ is the degree of clogging.

WHAT DO WE SEEK TO RESTORE BY MAINTENANCE

Ratio of Porous to Non-Porous Sound Absorption Coefficients

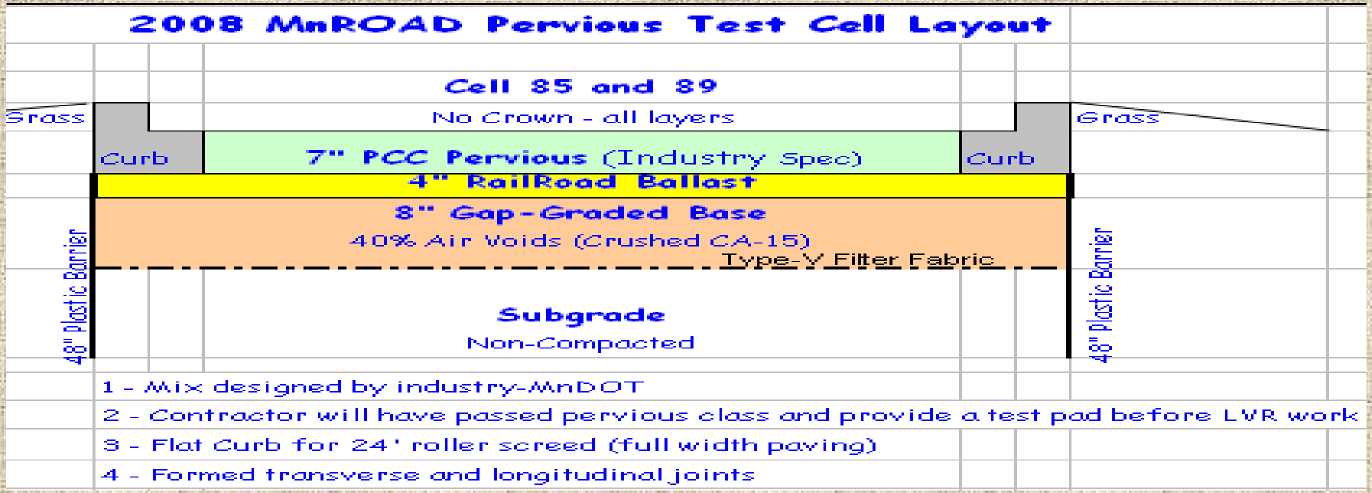


AN IMPORTANT DISCOVERY: ACOUSTIC BENEFIT OF PERVIOUS PAVEMENT IS MAXIMUM AT ROADWAY FREQUENCY OF 1000Hz

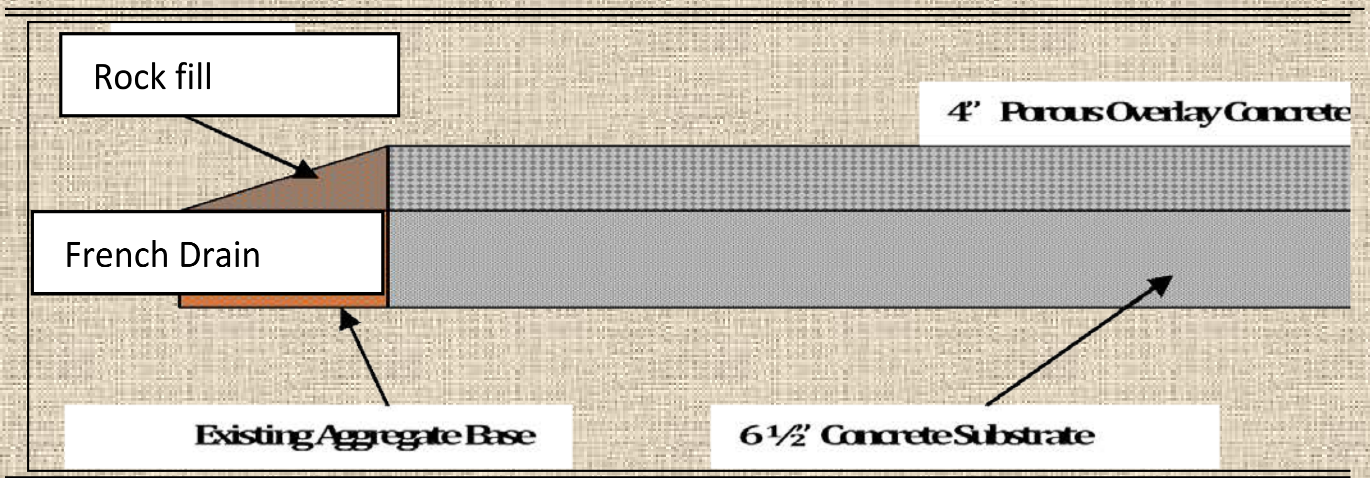
POROSITY TARGETS

PSC CODE	FINISHING	Cell/ Location Allocation	Performance Specification
Perv C	Pervious Concrete	85, 89	Porosity shall be 18 to 22 % and communicating void ratio shall be 20 to 25%. The surface shall be void of laitance or slurry and should guarantee uniform porosity through the depth of the concrete. The matrix should be resistant to undesirable raveling and weathering. This shall be established during the trial mixing process. Unit weight may not exceed 120 pcf unless if by improved practice or otherwise, contactor achieves desired porosity while attaining 7-day flexural strength of 300psi. Mix design Modification: 6 % Sand
PERV OL	Pervious Concrete Overlay	39	Specified by Iowa State University. Unique Porous mix Contains Fibers and 6% sand. Mixture is self consolidating and slip-formable Poly Olefin / Polypropylene Fibers + cellulosic fibers included.
NON PERV BC	Pervious Control cell	87	Non- Porous HMA

TEST SECTION CROSS SECTIONS

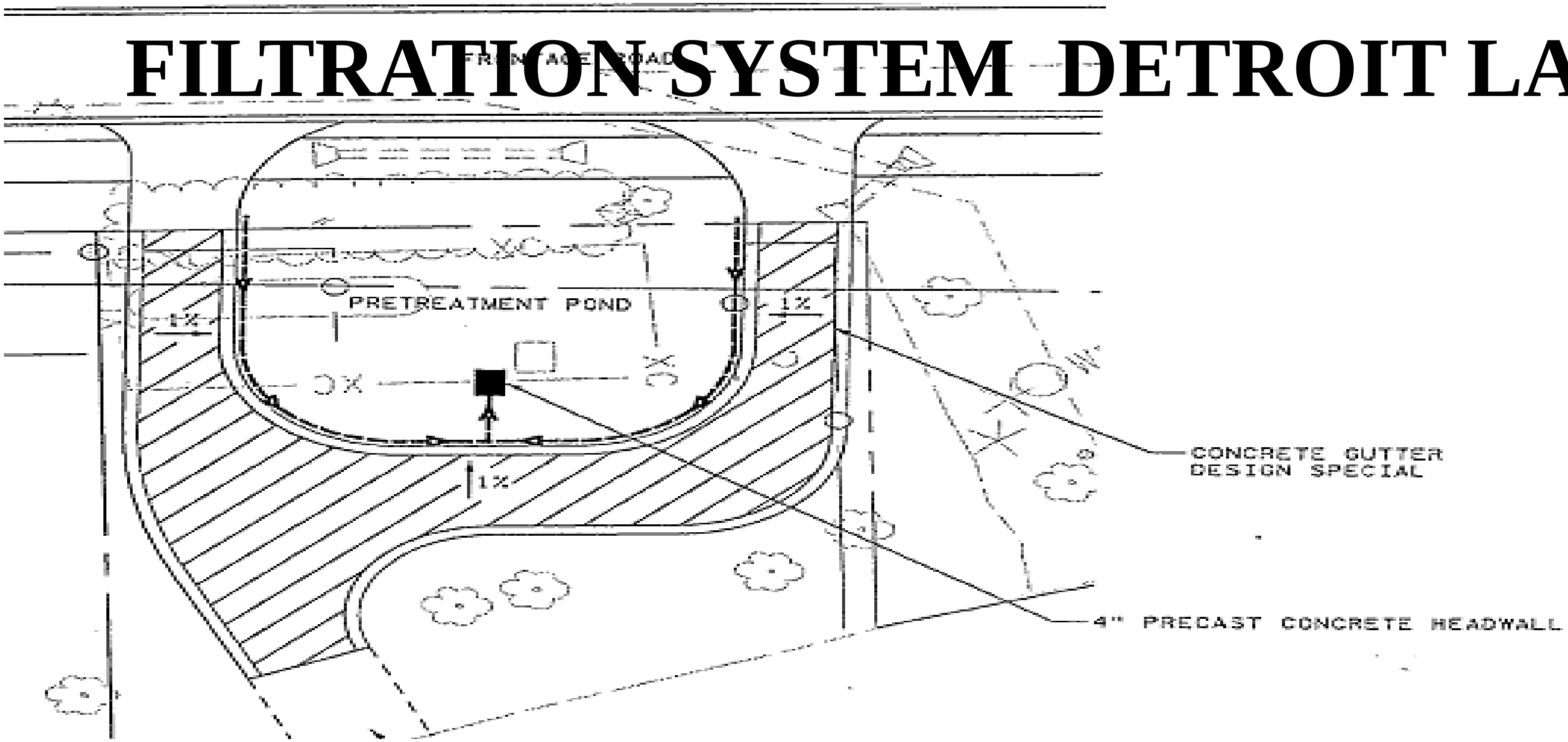


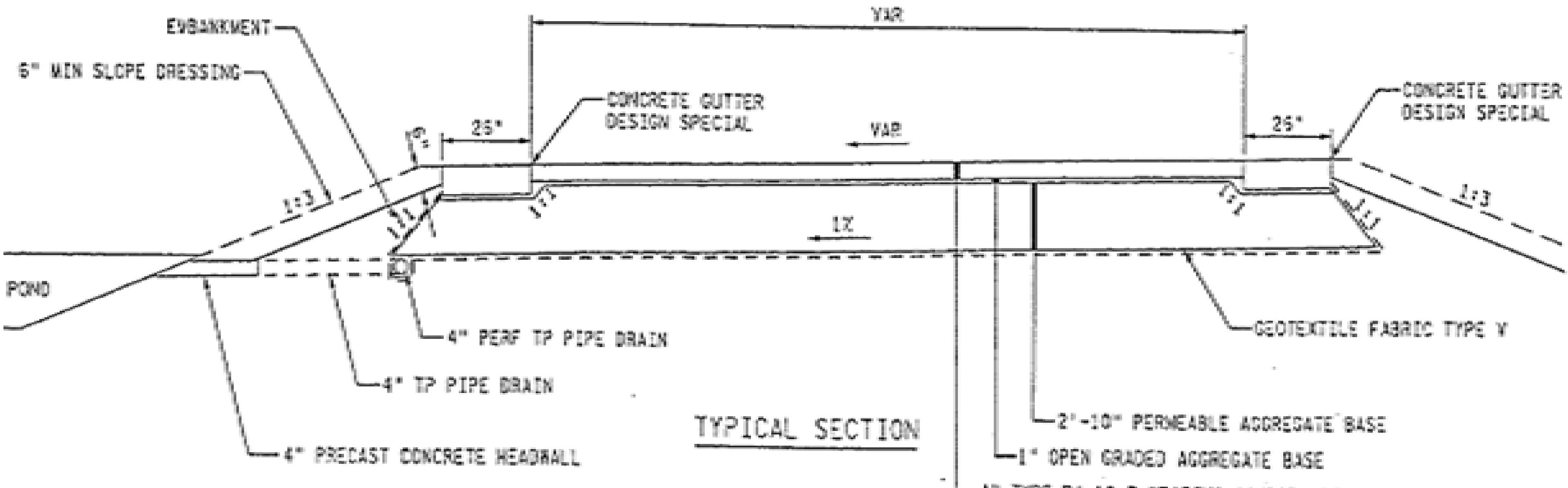
Pervious cells 85 Sand Subgrade ; 89 (Clay Subgrade)



Schematic Section Through the Pervious Concrete Overlay Cell 39. (French Drains at 100-ft Intervals)

PERVIOUS CONCRETE BOAT RAMP FILTRATION SYSTEM DETROIT LAKES





MnROAD PERVIOUS CELL LAYOUT

7 inches	Pervious PCC
	12" Drainable Base
Sand Clay	

Pervious HMA on Sand (Cell 86)

Pervious PCC on Sand (Cell 85)

Pervious Control (Cell 87)

Pervious PCC on clay (Cell 89)

Pervious HMA on Clay(Cell 88)

PAVING PROCESS

ROLLER SCREED FIXED FORM PLACEMENT

CURING

SURFACE CURED WITH "CONFILM", A BIO-ENVIRONMENTALLY FRIENDLY ALTERNATIVE TO CONVENTIONAL AMS CURING COMPOUND

MUNICIPAL MAINTENANCE PRACTICES

CITY OR AGENGY	PERVIOUS PROJECT	MAINTENANCE			MONITORING		
		SNOW AND ICE	VACUUM	OTHERS	FLOW TIME	POROSITY	ACOUSTIC
DETROIT LAKES	Boat Landing & Treatment System	None	Once as month	Snow and Ice Groomed for Snowmobile Trail	Qualitative (Empty 5 gallon Bucket)	Proposed By DOT	Sound Absorption ASTM E-1050
MINNEAPOLIS	Cul-de-sac at 10th street & Lake Street	Plow as needed	Once as month		Sand Cone Apparatus for Discharge Time	Qualitative Indicated by Discharge Time	None
SHOREVIEW	3000ft (900m) Of City Streets Near Lake Owasso	Plow as needed	Once as month	Educational Campaign to Residents	(Empty 5 gallon Bucket) & measure spread	Qualitative Indicated by Discharge Time	Sound Absorption ASTM E 1050

Mn/DOT TEST CELLS MAINTENANCE PRACTICES

CITY OR AGENGY	PERVIOUS PROJECT	MAINTENANCE			MONITORING		
		SNOW AND ICE	VACUUM	OTHERS	FLOW TIME	POROSITY	ACOUSTIC
MINNESOTA DOT	Pervious Concrete Driveway Cell 64	Plow as needed	None	Example of Unmaintained System	Mn/DOT's Infiltrometer	Nuclear Density	Sound Absorption ASTM E-1050
MINNESOTA DOT	Pervious Concrete Full-depth Cells 85 and 89	Plow as needed	2/3 times a year	Inspect and maintain Flouts	Mn/DOT's Infiltrometer	Nuclear Density	OBSI AASHTO TP 7609 and Sound Absorption ASTM E-1050
MINNESOTA DOT	Pervious Concrete Overlay Cell 39 on Concrete substrate	Plow as needed	2/3 times a year	Inspect and Repair French Drains	Mn/DOT's Infiltrometer	Nuclear Density	OBSI and Sound Absorption ASTM E 1050
MINNESOTA DOT	Sidewalk at MnROAD	Plow as needed	2/3 times a year	Replace portion destroyed by freeze thaw	Mn/DOT's Infiltrometer	Nuclear Density	Sound Absorption ASTM E-1050
MINNESOTA DOT	Driveway at MnROAD	Plow as needed	2/3 times a year	Inspect and maintain flow at outlet of subsurface pervious pipe	Mn/DOT's Infiltrometer	Nuclear Density	Sound Absorption ASTM E 1050

MAINTENANCE EVALUATION

❑**<u>CLOGGING EFFECT</u>**

- **Pervious concrete driveway VS Cell 89 Non-Clogged MnROAD.**
- **Clogged Location VS Non Clogged Location in Shoreview**

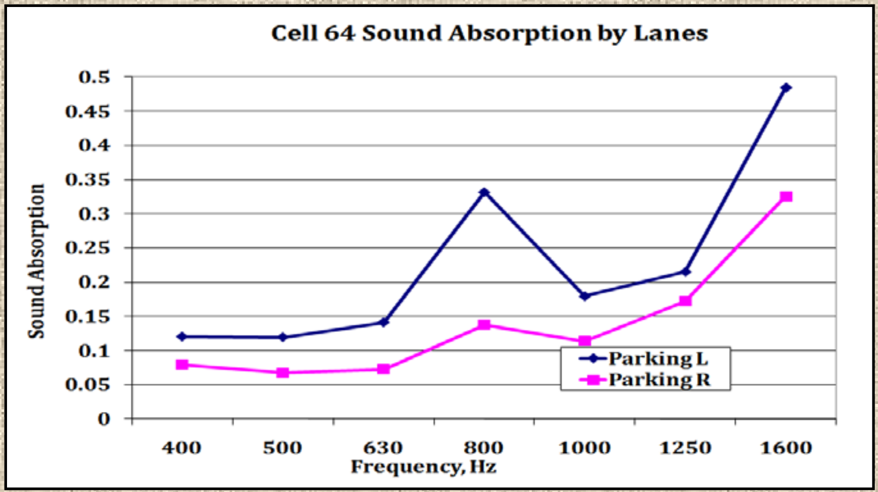
❑**EVALUATION BEFORE AND AFTER VACUUMING**

❑**<u>ACCELERATED CLOGGING TEST (Cell 89) 10ml Increments</u>**

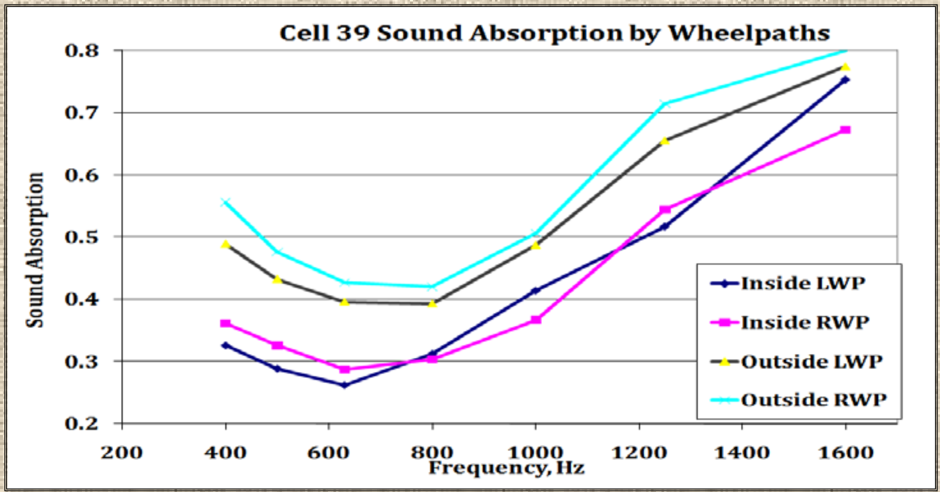
- **<u>Ottawa sand</u>**
- **<u>Glass Beads</u>**
- **<u>Clay</u>**

Seamans Nuclear Gauge Infiltrometer, Impedance Tube, Accelerated Clogging

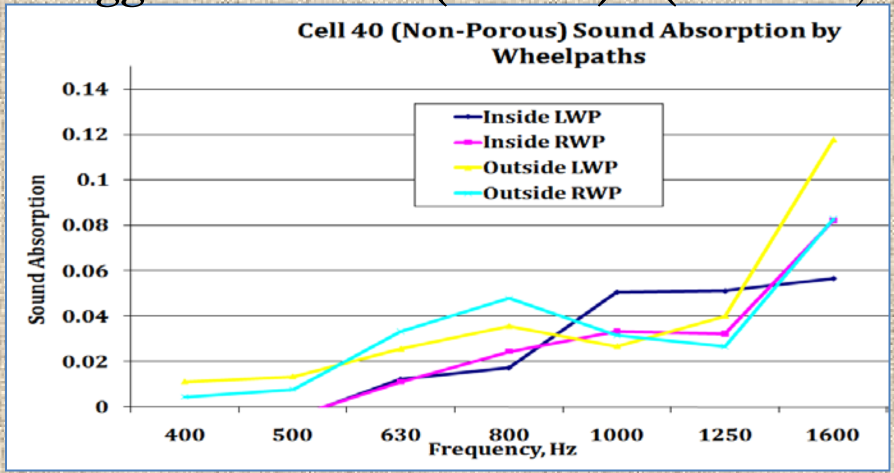
SOUND ABSORPTION COEFFICIENTS



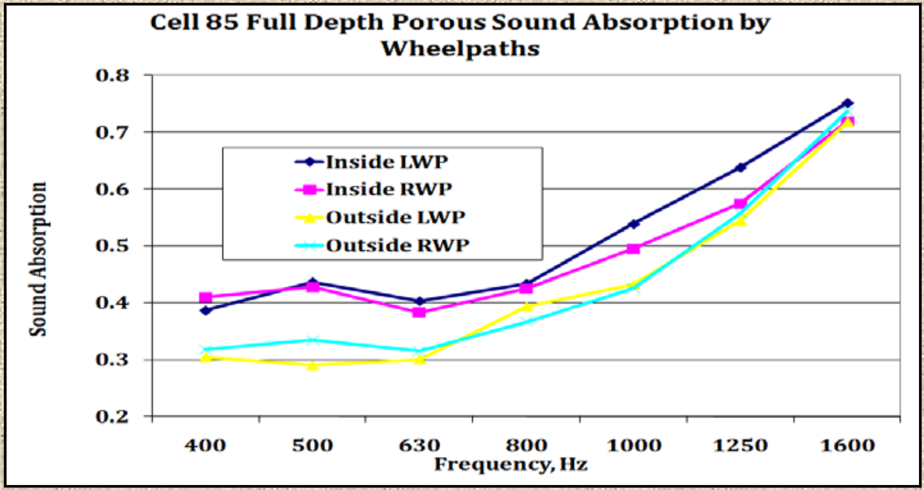
Clogged Porous SA (1000Hz)= (0.12 -0.18)



Porous Overlay SA (1000Hz)= (0.35 -0.50)

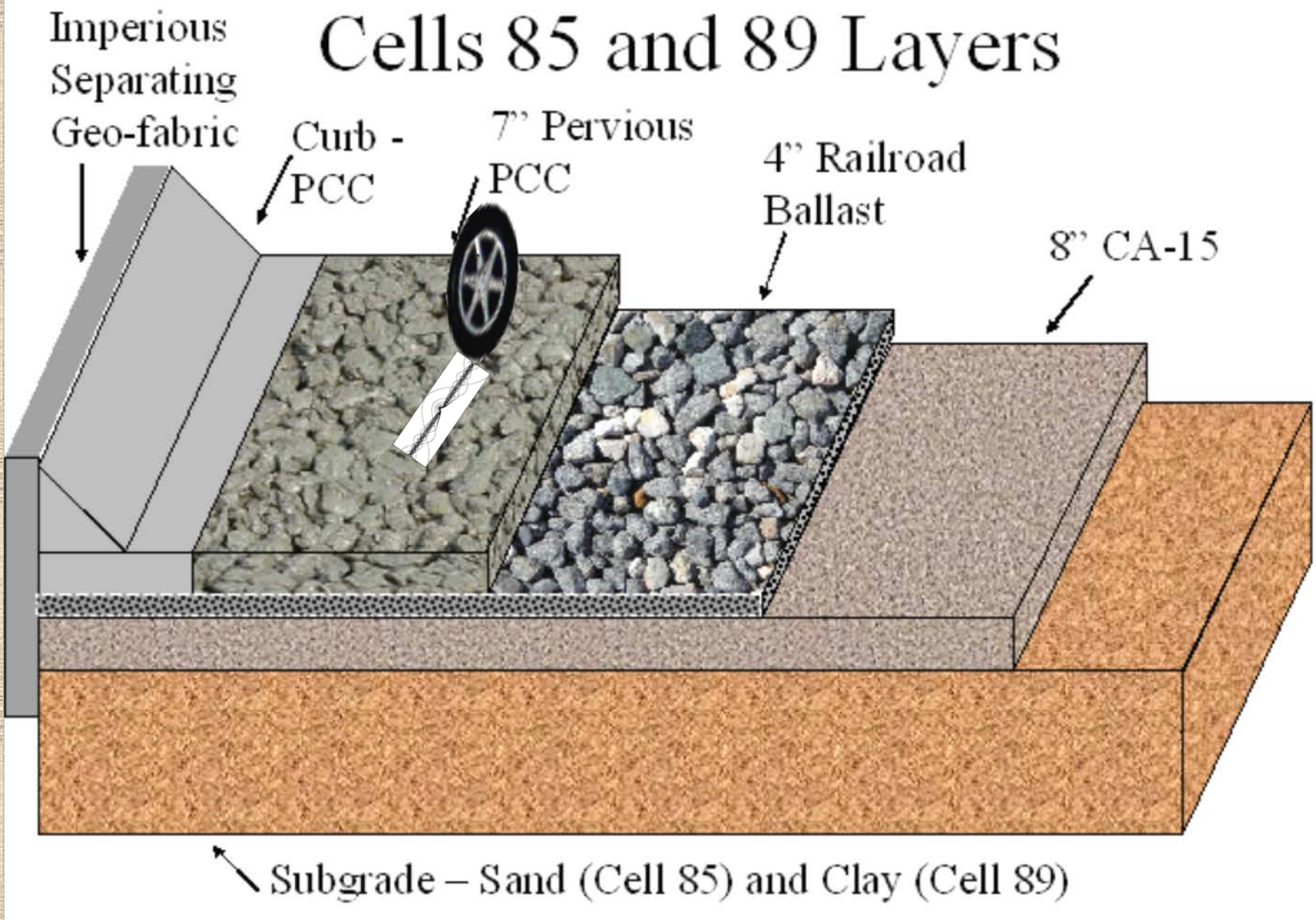


Non-Porous SA (1000Hz)= (0.02 -0.04)



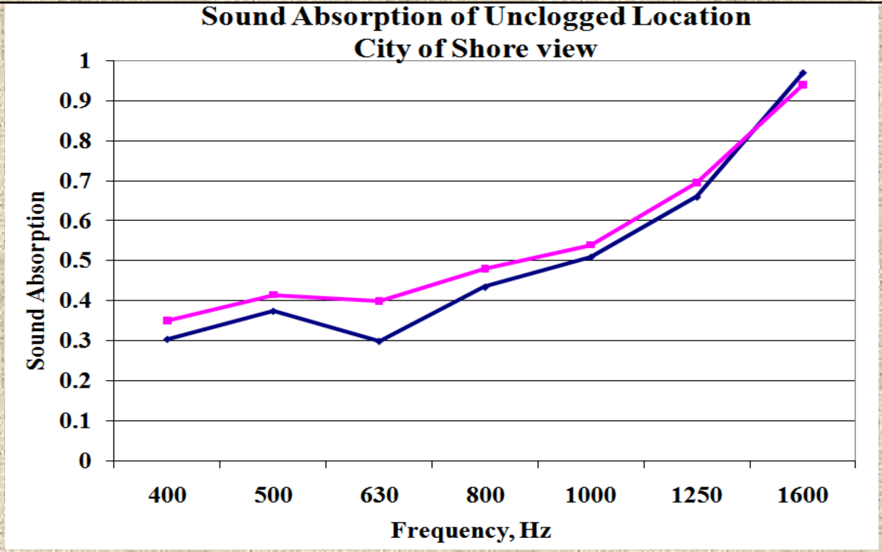
Porous Pavement SA (1000Hz)= (0.35 -0.42)

PERVIOUS CONCRETE ATTENUATES SOUND BY AIR PRESSURE RELIEF



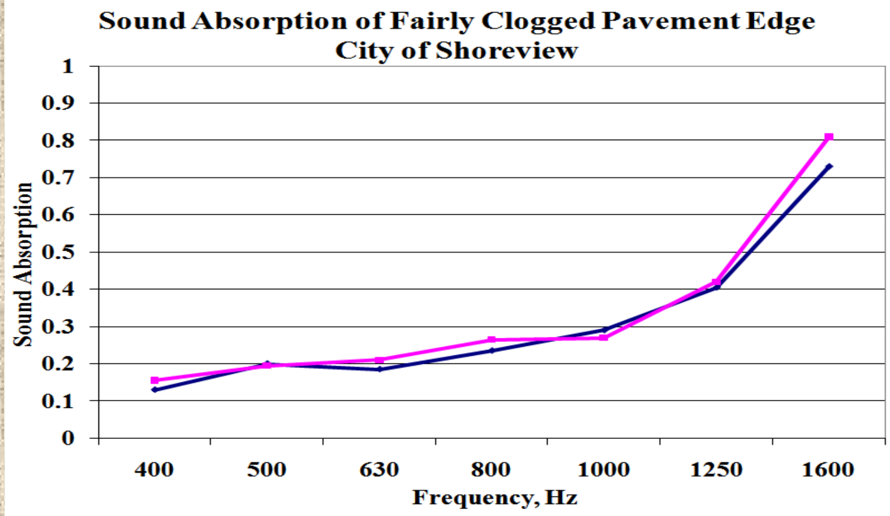
TYPICAL MAINTENANCE EVALUATION

Unclogged Location



Sound Absorption of Unclogged Location

Fairly Clogged Location



Sound Absorption of Fairly Clogged Location

Figure Sound Absorption of Clogged and Unclogged Locations in City of Shoreview

TYPICAL MAINTENANCE EVALUATION

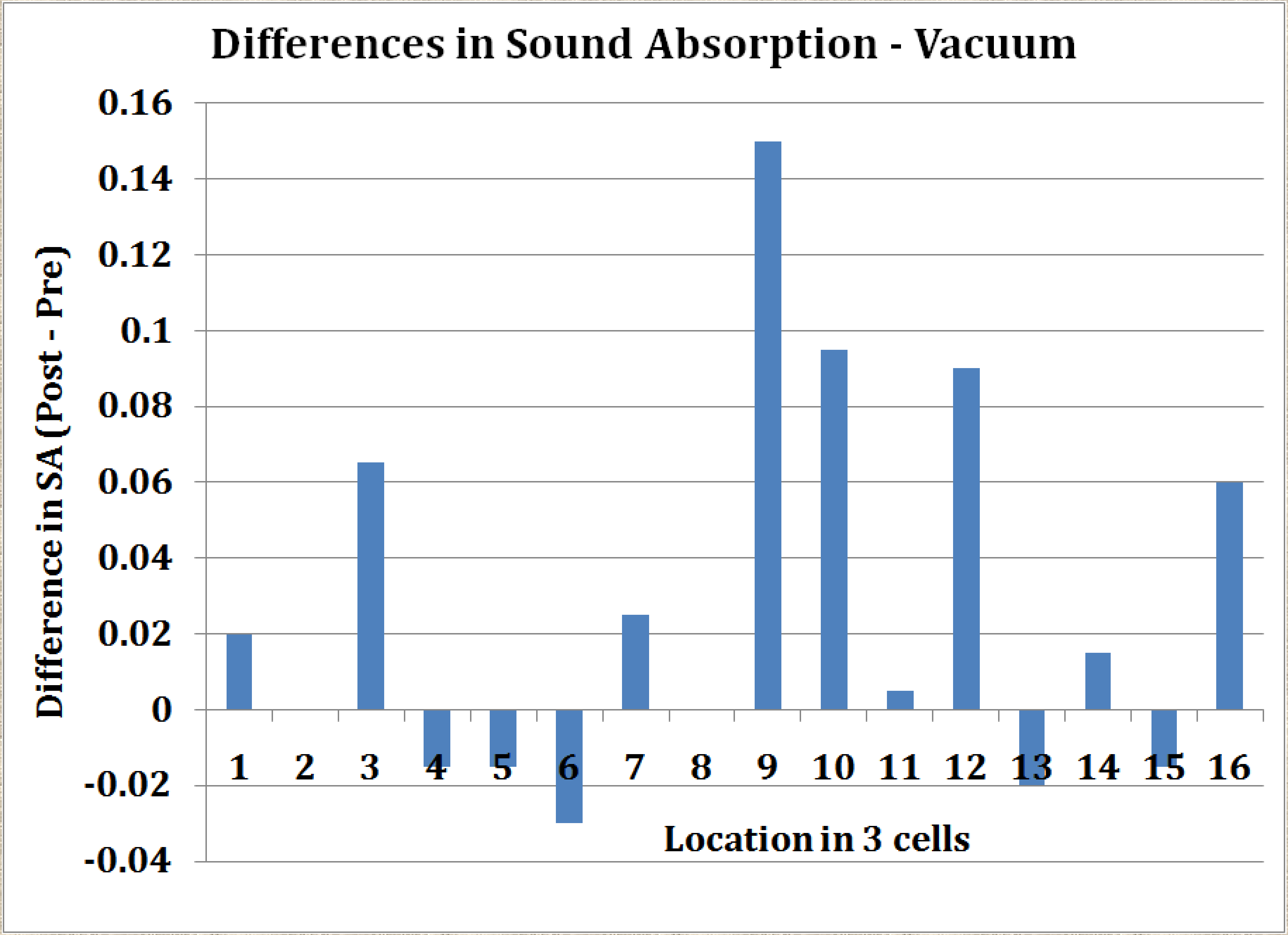
a) Regenerative Air Vacuum

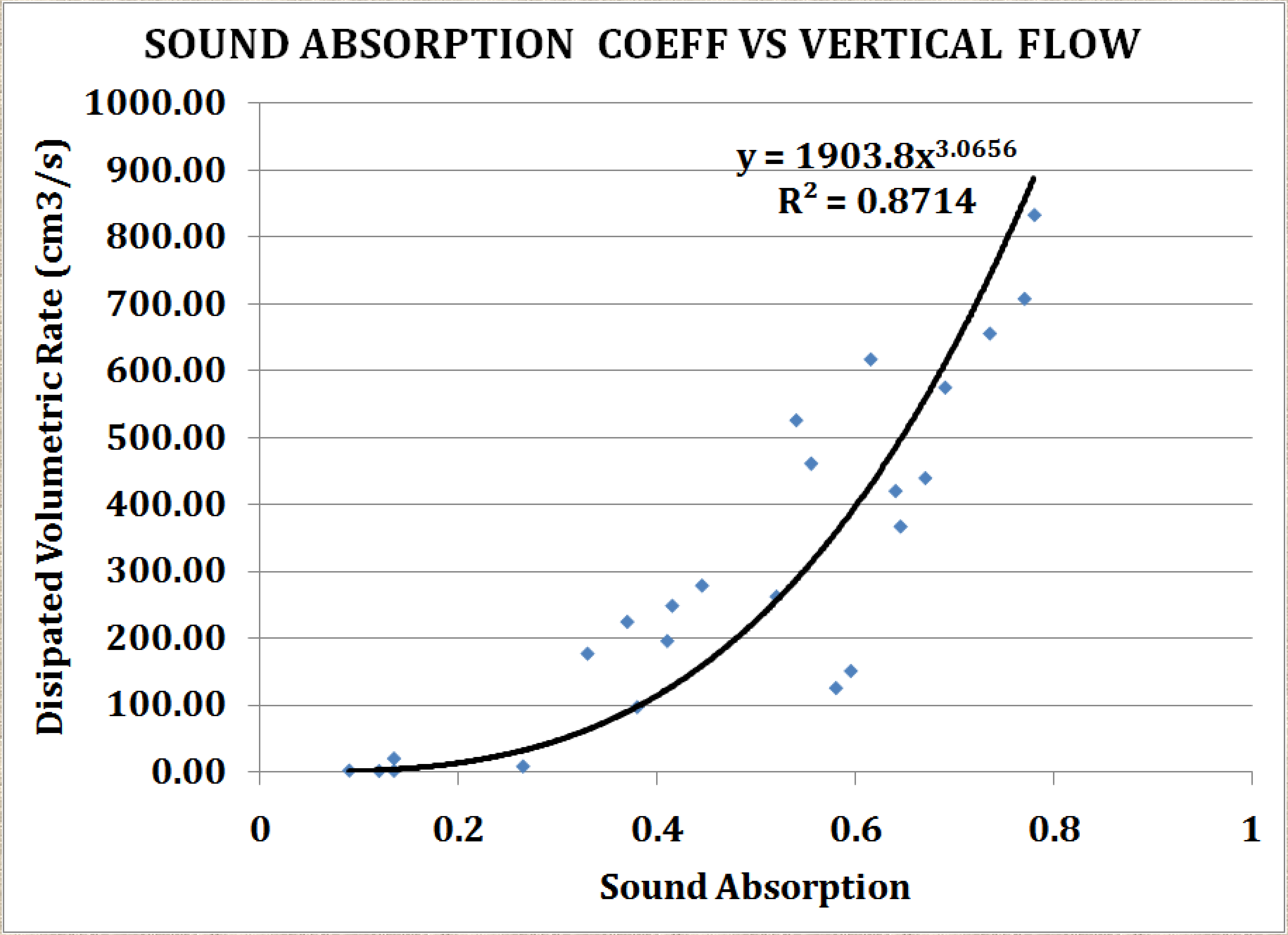
b)Agents Vacuumed from MnROAD Pervious Pavements

Mn/DOT Infiltrometer Test

a) Infiltrometer

Cell #	Before Time (s)	Time After (s)	% Change
85	6.0	6.0	0
89	17.0	15.5	-9


Differences in Sound Absorption - Vacuum
Difference in SA (Post - Pre)
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
-0.04
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Location in 3 cells


SOUND ABSORPTION COEFF VS VERTICAL FLOW
y = 1903.8x^3.0656
R² = 0.8714
Dissipated Volumetric Rate (cm3 /s)
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
0.2
0.4
0.6
0.8
1
Sound Absorption

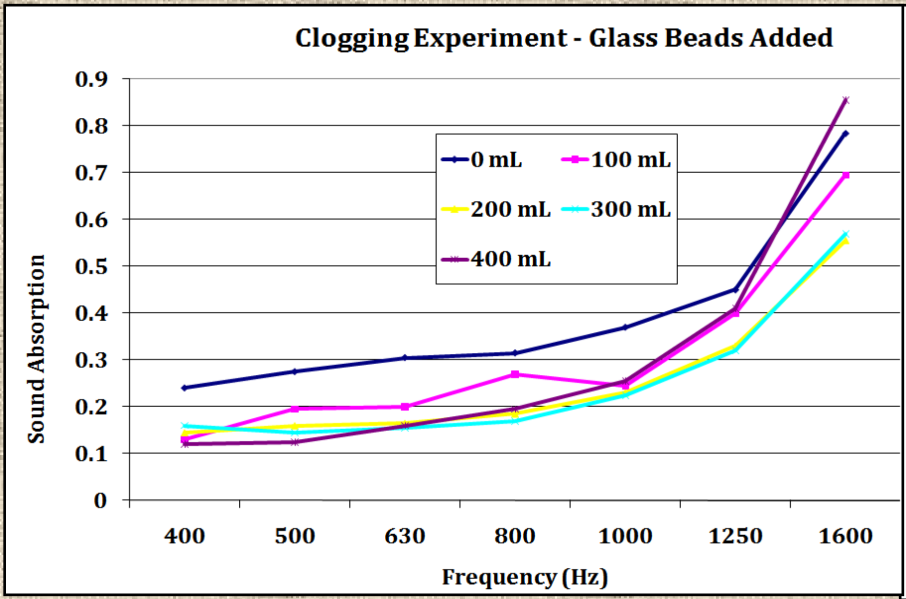
ACCELERATED CLOGGING TEST

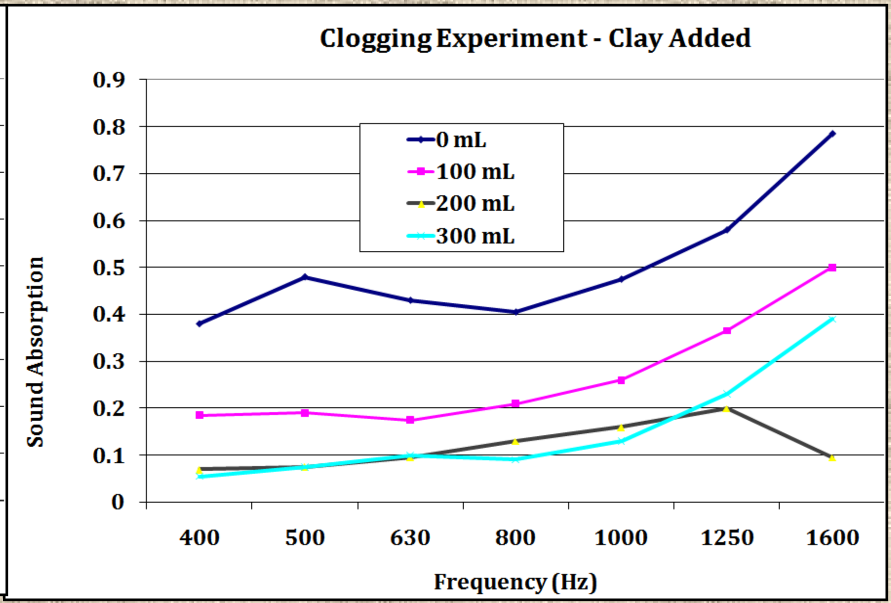
Sound Absorption Tests

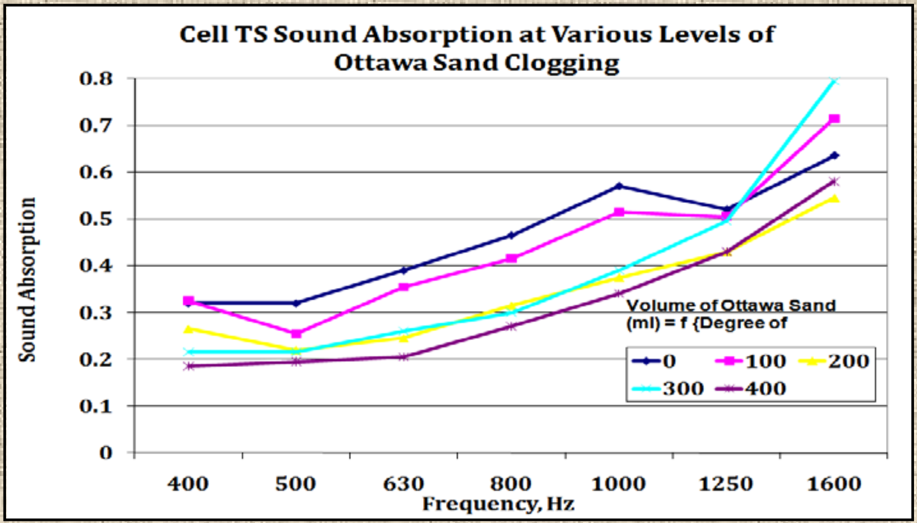
Glass Beads Clogging

Clay Clogging

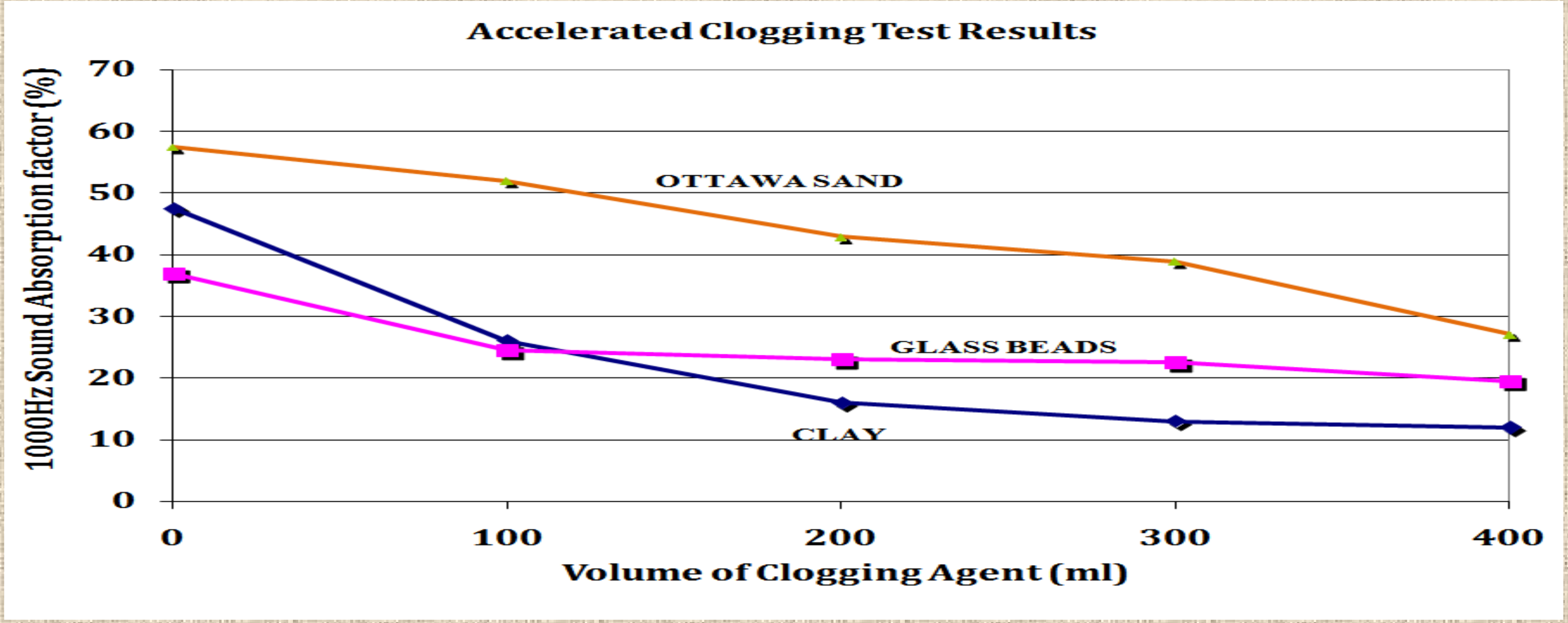
ACCELERATED CLOGGING EXPERIMENT





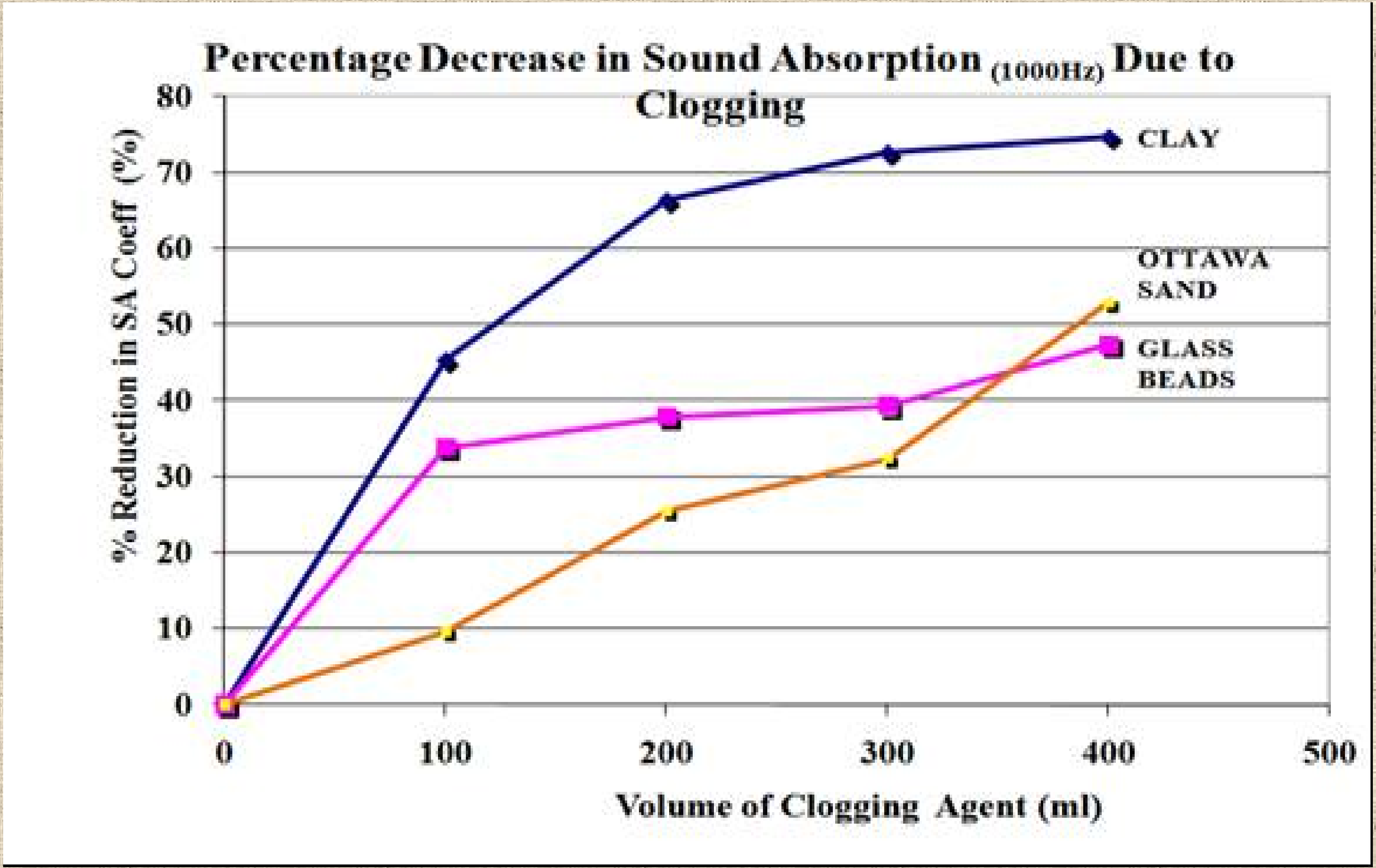


ACCELERATED CLOGGING TEST RESULT

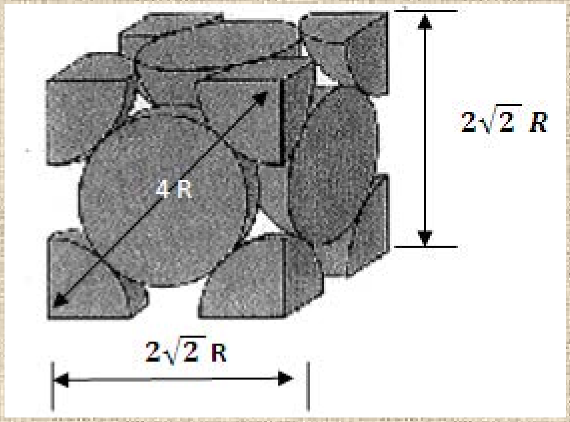


- **Clay was the most effective Clogging agent (72 % reduction) Ottawa Sand (52%) and Glass beads (48%) validates Effective porosity Lemma.**
- **Clogged Pavements are better sound absorbers than Non-Porous Pavements**
- **Clogging Affects Acoustic Properties of Porous Pavements**
- **Variability in Porosity due to initial construction**

ACCELERATED CLOGGING TEST RESULT



POROSITY AND TORTUOSITY EFFECTS OF CLOGGING

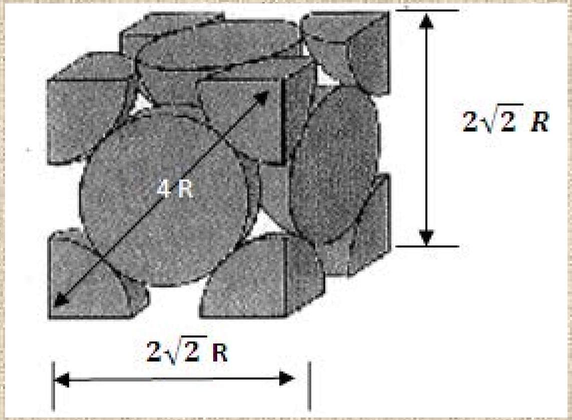


Consider a fully clogged matrix of total volume V and pore / cavity system Vp

The clogging agent introduces a void system Va into the cavities

The natural porosity of the agent = Va/Vp
Porosity before clogging = Vp/V
Porosity after clogging = Va/V= (Va/Vp) (Vp/V)
n (clogged)= n agent * n (unclogged concrete)

POROSITY AND TORTUOSITY EFFECTS OF CLOGGING



- Packing Efficiency = $\frac{\pi\sqrt{2}}{6} \cong 0.74.$
- Maximum Porosity ≈ 0.26
- Max Surface Porosity ≈ $(1-\frac{\pi}{4})$= 0.21
- Simple tortuosity of unclogged matrix is

$$\frac{(2\sqrt{2}\ R - 2R + \pi R)}{2\sqrt{2}\ R} \cong 1.4$$

If the void is clogged by stacking n layers of clogging agent of radius r, additional path due to clogging agent is nr(n -2) which is always positive.

Tortuosity of clogged matrix =
S/L (clogged)

$$\frac{(2\sqrt{2}\ R - 2R + \pi R + nr\,(\pi - 2))}{2\sqrt{2}\ R} \gg 1.4$$

CONCLUSIONS

Clogging reduces the acoustic absorption properties of pervious pavements

Pervious concrete is a quiet pavement solution with maximum ratio SA (pervious/ SA non pervious) occurring at 1000Hz where it is most needed.

Pervious concrete left to clog will also experience ravelling and general deterioration.

Hydraulic conductivity of pervious concrete decreases very rapidly but is polynomially correlated to sound absorption.

CONCLUSION

- **Effective porosity of a clogged system can be deduced from the porosity of the unclogged system and that of the clogging agent**
- **Clogging increases tortuosity of pervious concrete.**
- **Accelerated clogging tests found clay to be a more detrimental clogging agent than Ottawa sand and Glass beads. Sodding should be avoided unless best practices against silt/ clay migration are in place in Pervious concrete projects.**
- **Restoration attempts on extremely clogged pervious systems proved futile. Preventative and routine maintenance is recommended.**