College of Engineering
UNIVERSITY OF WISCONSIN–MADISON

Permeability of Base Aggregate and Sand
Project TPF 5(341)

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NRRA National Road Research Alliance
STRATEGIC IMPLEMENTATION THROUGH COOPERATIVE PAVEMENT RESEARCH

Statement of Problem

- Lack of proper pore water drainage is one of the main causes of geosystem failure (e.g., roadway base course, retaining wall backfills).

- Proper drainage required to minimize elevated pore pressure, minimize freeze-thaw damage.

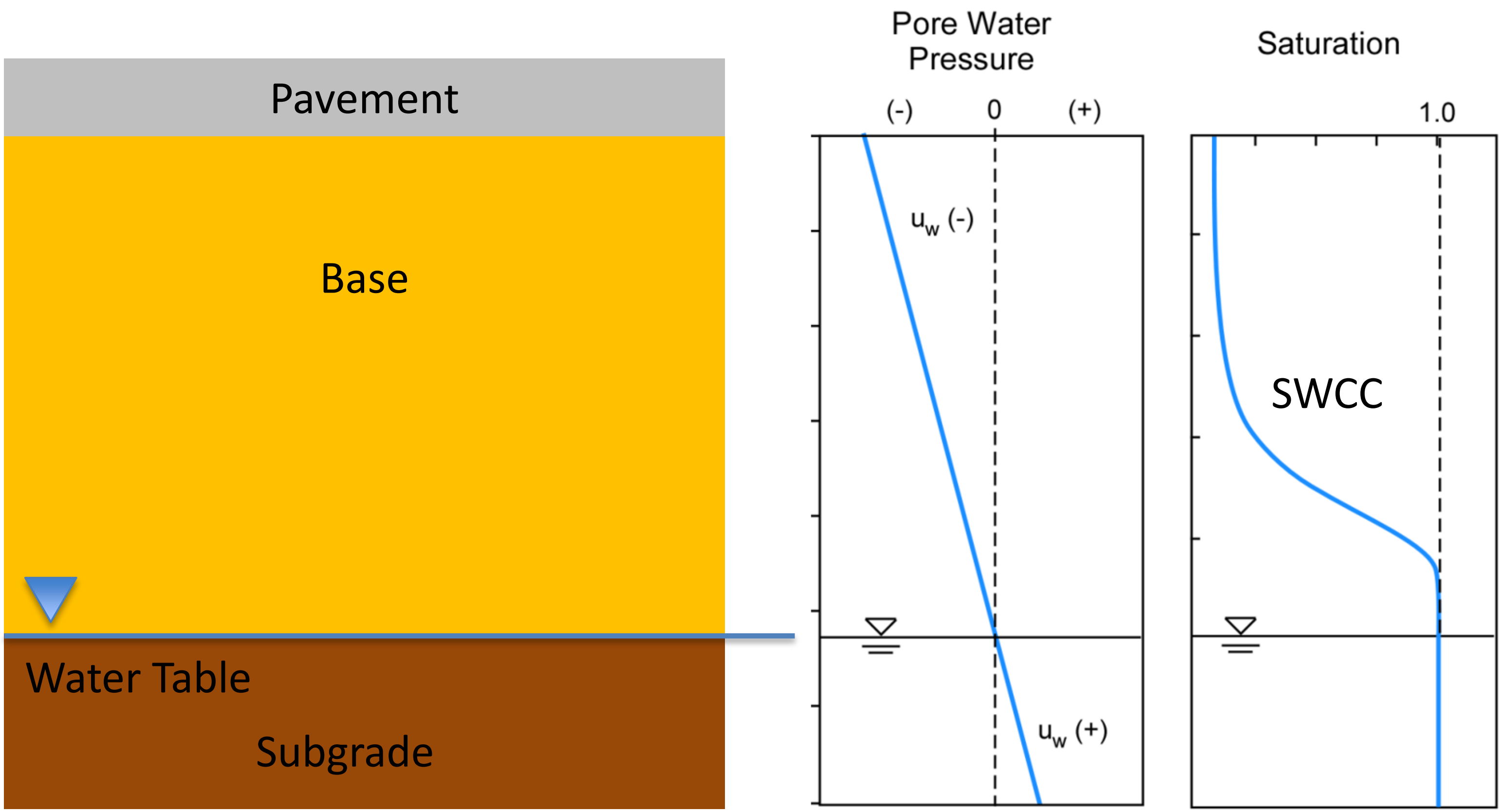
- Simple and reliable tools capable of estimating drainability values for common aggregate types will aid in material selection and design

  - Saturated hydraulic conductivity, K_{sat}
  - SWCC parameters

Project Objectives

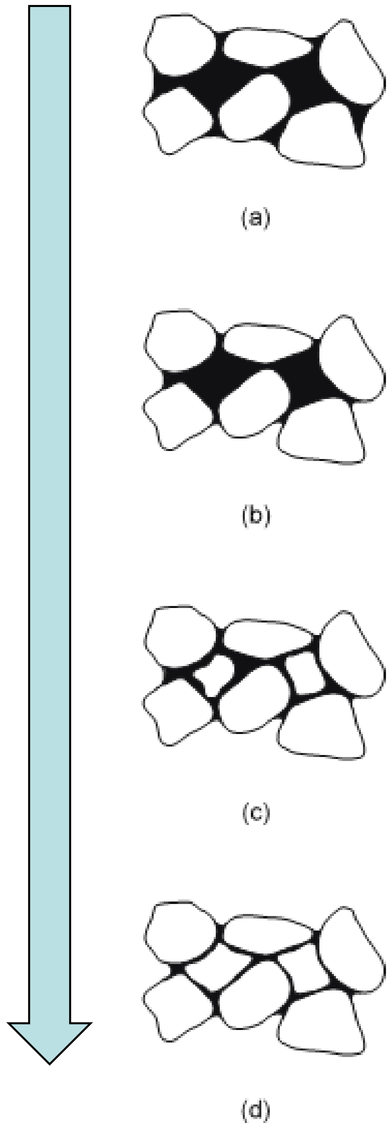
- Assess permeability of a wide range of coarse materials applicable to roadway construction.
- Conduct laboratory permeability and water retention tests on materials of different types, gradations, angularity, fine contents, and crushing percentages.
- Develop simple predictive tools that may be used to assess permeability/drainability from other properties (e.g., gradation, fines content, etc.)

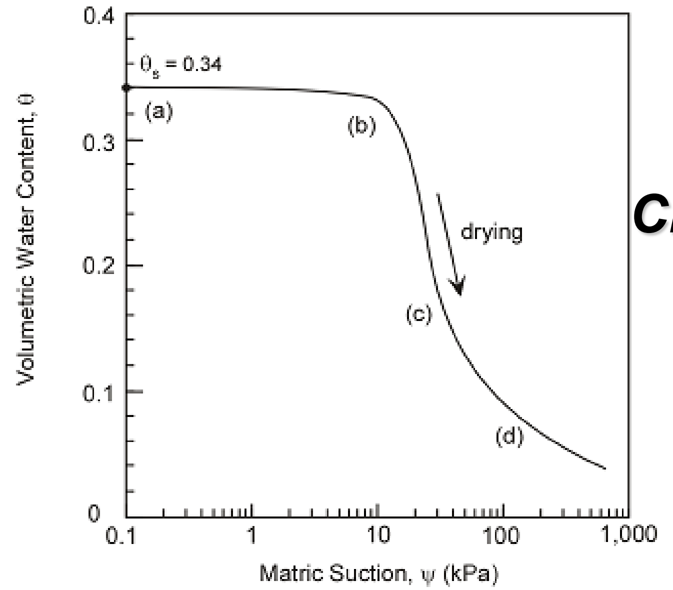
- Drainability -
An Unsaturated Soils Problem!



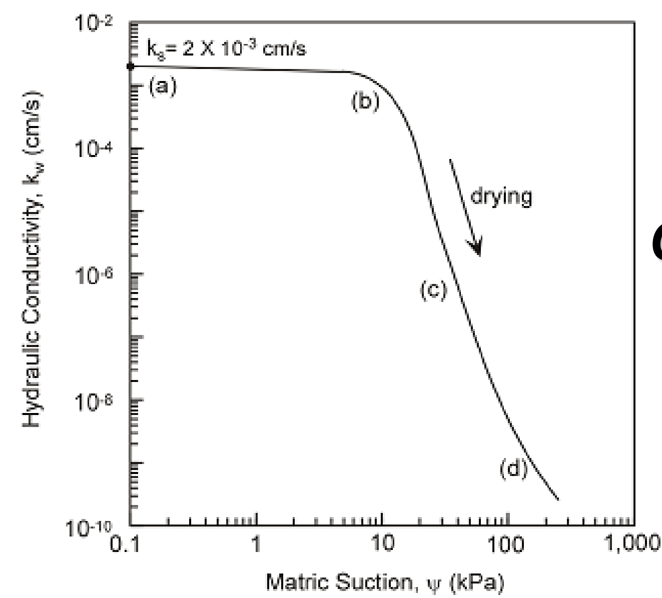
Permeability and Water Retention

Increasing Suction, Decreasing Saturation





Soil-Water Characteristic Curve (SWCC)



Hydraulic Conductivity Function (HCF)

(Lu and Likos, 2004)

Samples Obtained

Sample Number	Sample
1	3149 Super Sand (MnDOT)
2	MN Class 5 (MnDOT)
3	1007 Type 5 DGB (MoDOT)
4	1007 Type 7 DGB (MoDOT)
5	1010 Man. Sand (MoDOT)
6	MCC Freeborn West Quarry Crushed Stone (WisDOT)
7	Lannon Lisbon Pit (North Ave.) Structural Backfill (WisDOT)
8	Lannon Lisbon Pit (Mukwonago) Structural Backfill (WisDOT)
9	Lannon Stone Product Chips (WisDOT)
10	Super Aggregate Pit Granular Backfill (WisDOT)
15	Bryan Redrock Class 5, MnDOT Pit 70006
16	Bryan Redrock Ball Diamond material, MnDOT Pit 70006
A1	1¼'' Base (WisDOT)
A2	¾'' Washed (WisDOT)
A3	Manufactured Sand (WisDOT)
A4	¾'' Base Cs. (WisDOT)
A5	Breaker Run (limestone/dolomite) (WisDOT)

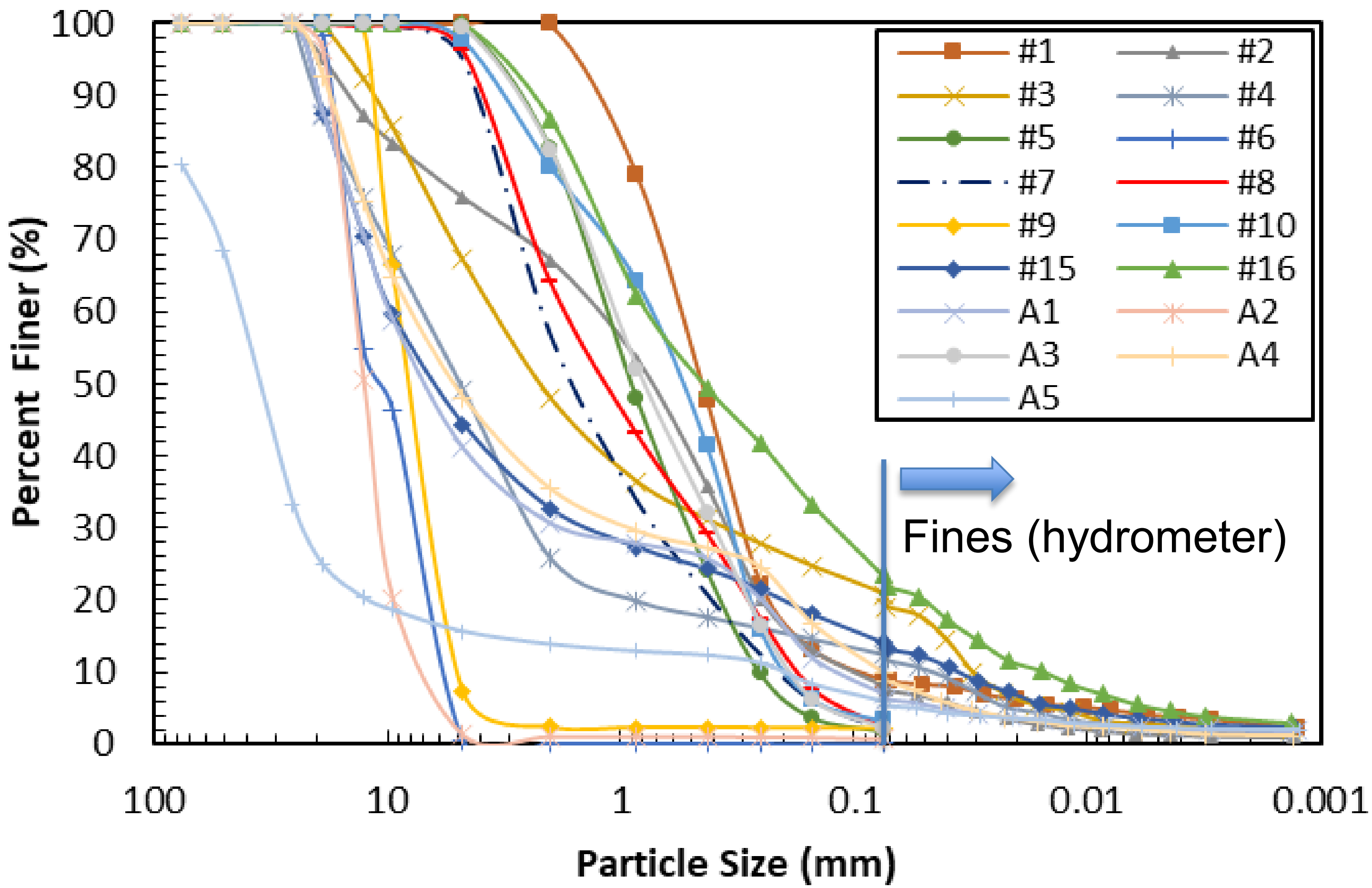
(1) 3149 Super Sand

(2) Mn Class 5

(3) 1007 Type 5 DGB

(4) 1007 Type 7 DGB

Particle Size Distribution



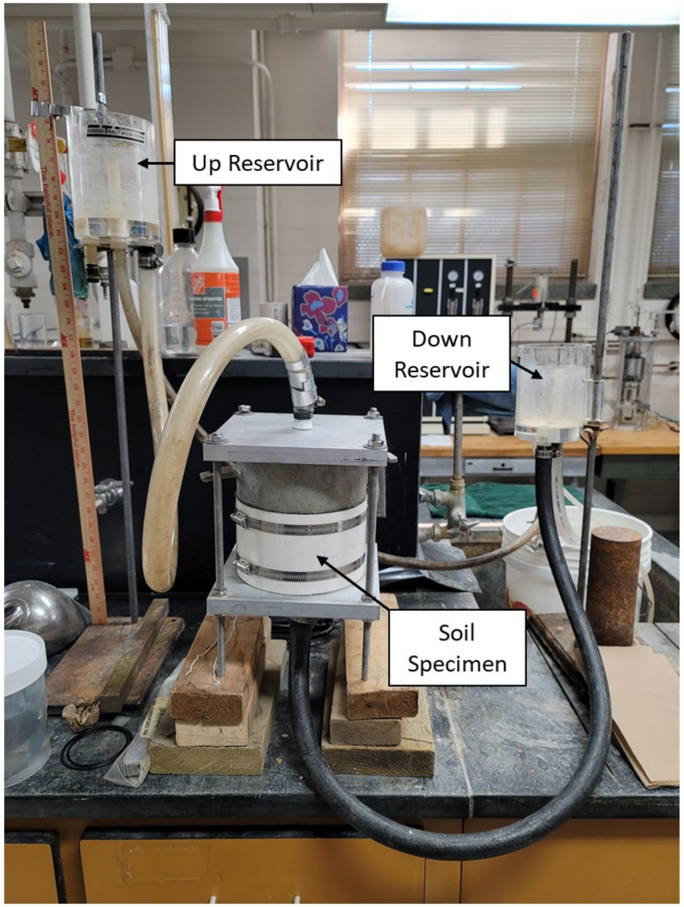
Indices and Classification

9 sands & 7 gravels; fines from ~0% to ~23%

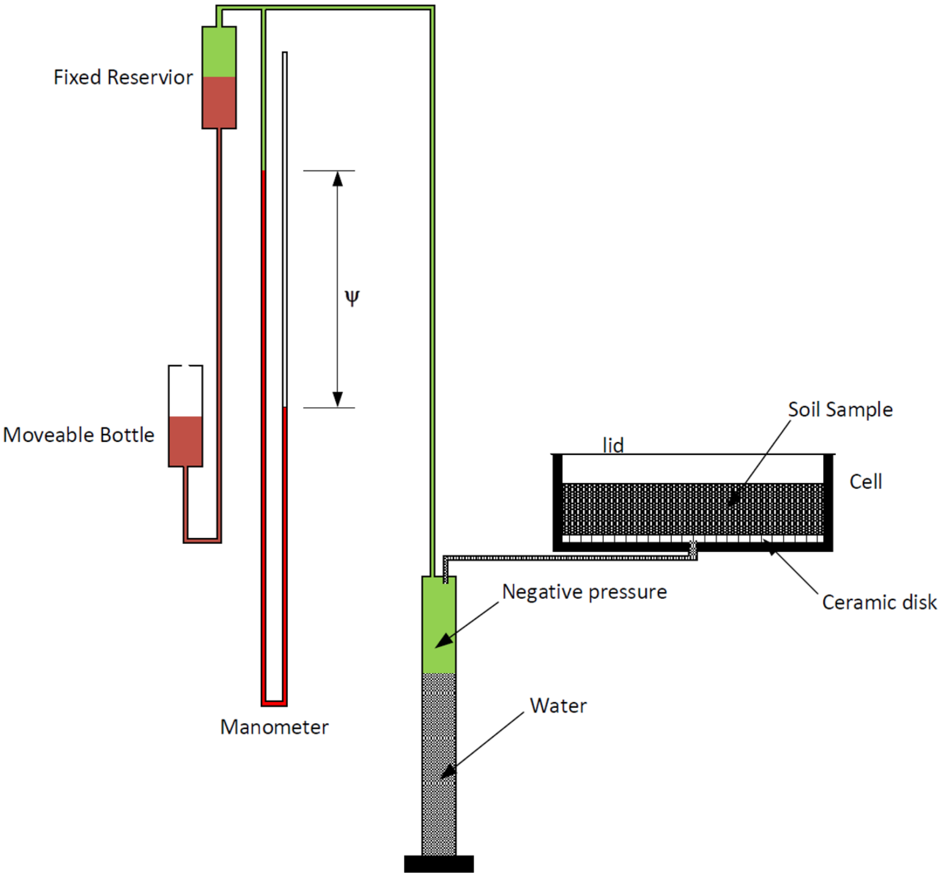
Sample	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	% Fines	% Gravels	γ_d (kN/m^3)	USCS
#1	0.09	0.30	0.46	0.55	5.91	8.82	100.00	18.57	SP-SM
#2	0.10	0.36	0.72	1.38	13.53	8.18	75.73	19.63	SW-SM
#3	0.03	0.36	2.28	3.65	114.78	20.8	67.18	17.76	SM
#4	0.05	2.50	4.90	7.09	154.13	12.5	49.24	17.80	GM
#5	0.27	0.52	0.90	1.26	4.75	1.89	99.75	15.91	SP
#6	5.85	7.70	10.9	14.0	2.39	0.19	0.59	16.22	GP
#7	0.22	0.72	1.70	2.20	10.09	2.03	95.17	18.65	SW
#8	0.18	0.45	1.30	1.82	10.11	2.39	96.40	20.10	SP
#9	5.00	6.60	8.05	8.95	1.79	2.17	7.37	16.57	GP
#10	0.20	0.33	0.53	0.72	3.60	3.24	97.72	18.26	SP
#15	0.04	1.58	6.35	9.50	256.76	14.1	44.37	18.66	GM
#16	0.02	0.13	0.44	0.79	46.90	23.4	99.88	17.69	SM
A1	0.13	1.82	7.00	9.92	76.31	7.05	41.03	18.63	GW-GM
A2	7.19	11.2	12.8	14.4	2.00	0.84	1.39	15.94	GP
A3	0.19	0.40	0.80	1.10	5.73	2.27	99.33	17.27	SP
A4	0.08	0.93	5.20	7.99	102.44	9.89	48.06	19.18	GW-GM

Note: D_{10}, D_{30}, D_{50}, D_{60} = particle sizes corresponding to 10%, 30%, 50%, 60% finer, respectively, in particle-size distribution curve; C_u = coefficient of uniformity; C_c = coefficient of curvature; USCS = unified soil classification system

K_{sat} and SWCC Testing



Constant Head Apparatus (Ksat)

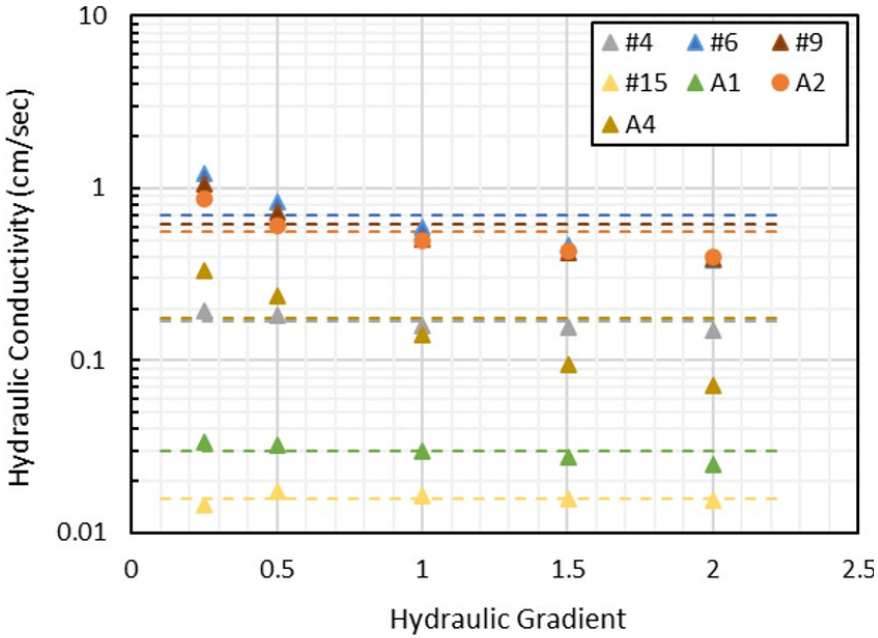


Hanging Column Apparatus (SWCC)

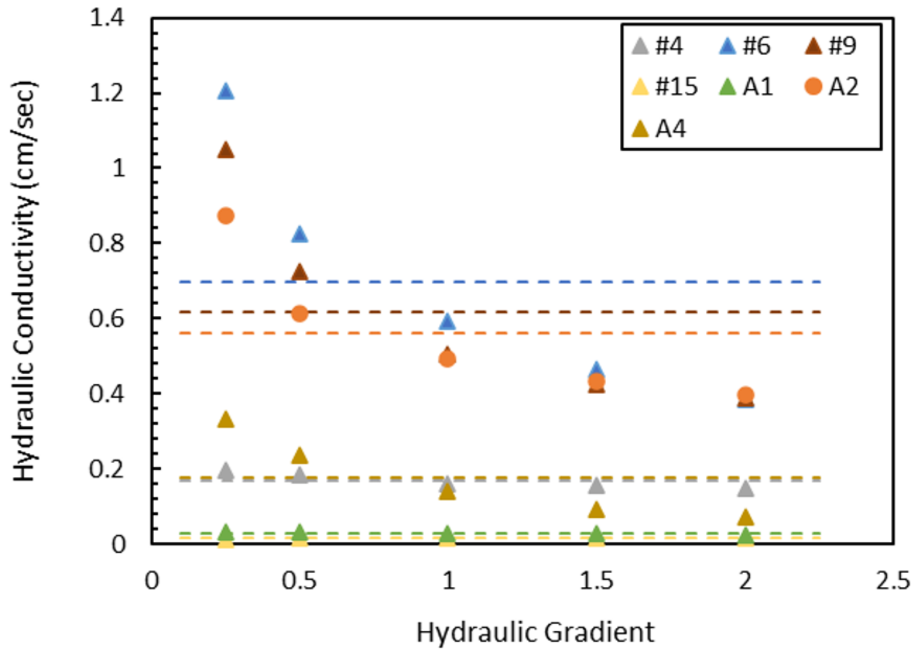
Compaction Density

Sample	Dry Unit Weight (KN/m^3)		% Difference
	K_{sat}	SWCC	
#1	18.6	18.5	0.54%
#2	19.6	19.6	0.00%
#3	17.8	17.8	0.00%
#4	17.8	17.8	0.00%
#5	15.9	16.0	0.63%
#6	16.2	16.3	0.62%
#7	18.7	18.6	0.54%
#8	20.1	20.1	0.00%
#9	16.6	16.6	0.00%
#10	18.3	18.3	0.00%
#15	18.7	18.7	0.00%
#16	17.7	17.7	0.00%
A1	18.6	18.7	0.54%
A2	15.9	16.0	0.63%
A3	17.3	17.3	0.00%
A4	19.2	19.2	0.00%

K_{sat}: Effect of Hydraulic Gradient



(Sands)



(Gravels)

- Potential fines migration
- Turbulent flow regime (gravels?)

$$Q = kiA$$

Summary of K_{sat}

Gravel average = 0.324 cm/s   Sand average = 0.014 cm/s

Sample	Hydraulic Conductivity (cm/sec)			Standard Deviation	Coefficient of Variation
	Minimum	Maximum	Average		
#1	0.0019	0.0023	0.0021	0.0001	0.0553
#2	0.0026	0.0030	0.0027	0.0002	0.0579
#3	0.0068	0.0075	0.0073	0.0003	0.0367
#4	0.1498	0.1960	0.1693	0.0180	0.1063
#5	0.0479	0.0499	0.0489	0.0007	0.0148
#6	0.3869	1.2072	0.6957	0.2960	0.4255
#7	0.0206	0.0253	0.0236	0.0018	0.0758
#8	0.0047	0.0052	0.0050	0.0002	0.0411
#9	0.3889	1.0499	0.6196	0.2452	0.3957
#10	0.0101	0.0108	0.0104	0.0002	0.0225
#15	0.0147	0.0173	0.0159	0.0009	0.0564
#16	0.0004	0.0005	0.0004	0.0000	0.0527
A1	0.0251	0.0339	0.0298	0.0031	0.1043
A2	0.3957	0.8741	0.5618	0.1725	0.3070
A3	0.0187	0.0303	0.0224	0.0045	0.2030
A4	0.0716	0.3327	0.1759	0.0972	0.5528

(% Fines)

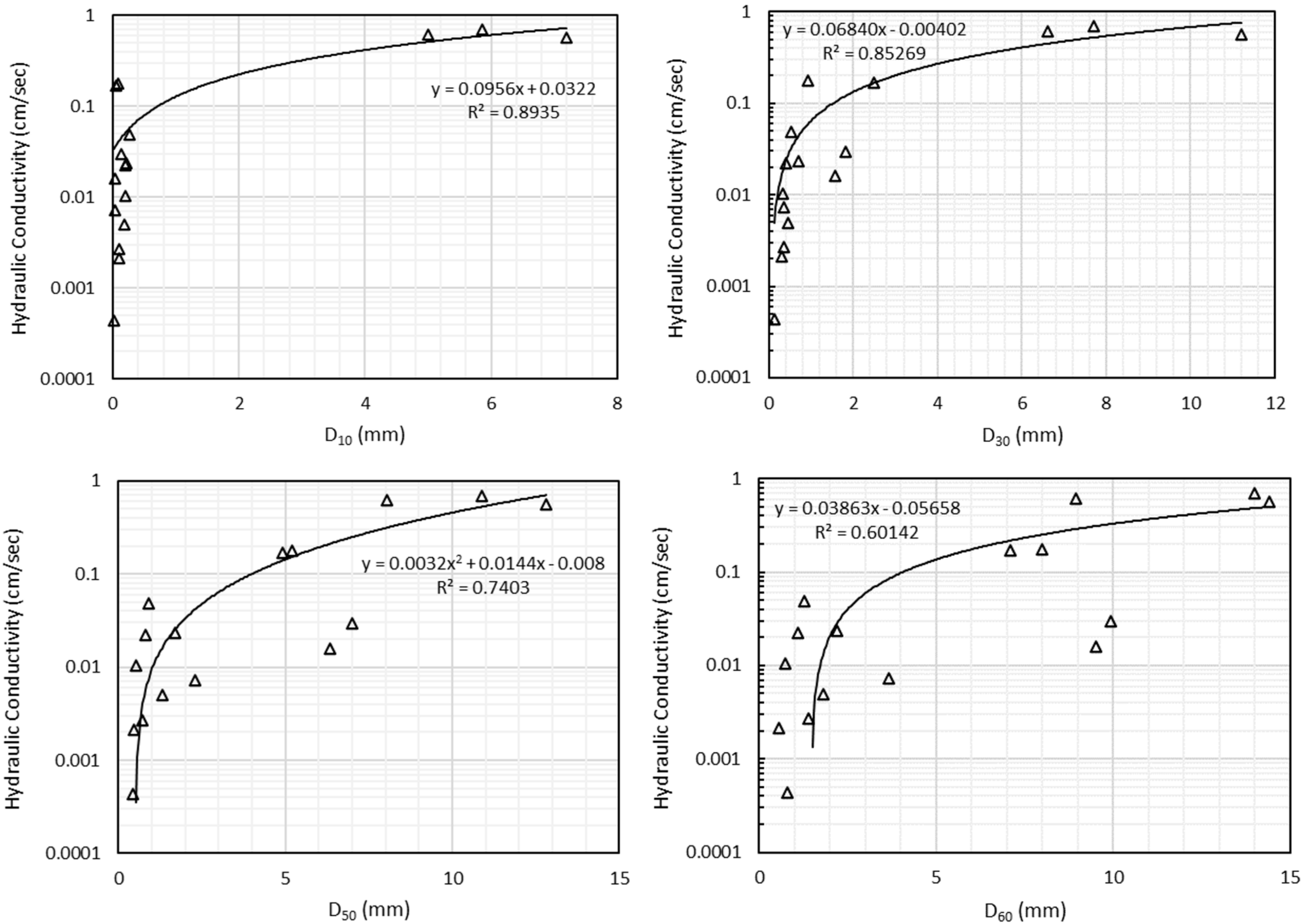
← #6: GP (0.19)

← #9: GP (2.17)

← A2: GP (0.84)

← A4: GW-GM (9.89)

$(K_{sat})_{avg}$ correlation with grain size



Existing Empirical Equations for K_{sat}

Literature search was conducted to summarize equations for predicting saturated hydraulic conductivity from grain size, compaction indices, ad fluid properties (e.g., d10, porosity, viscosity)

The equations used in this study were as follows:

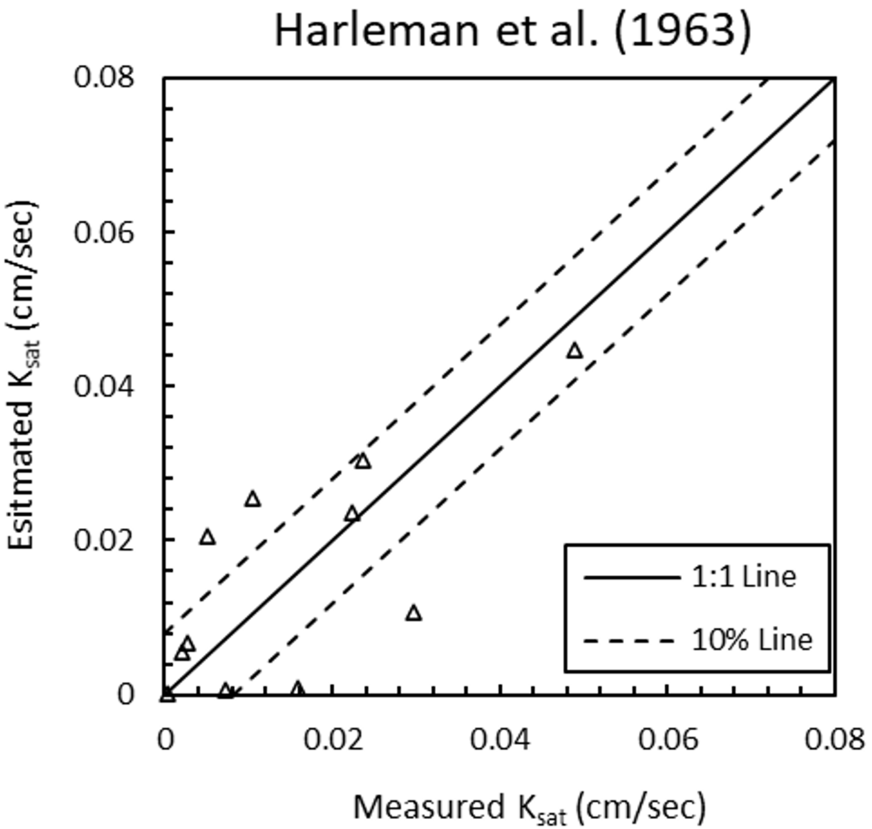
Alyamani and Sen (Equation B.21)
Beyer (Equation B.12)
Harleman et al. (Equation B.11)
Original Hazen (Equation B.1a)
Modified Hazen (Equation B.1b)
Kozeny (Equation B.9)
Kozeny-Carman (Equation B.10)
Sauerbrei (Equation B.19)
Slichter (Equation B.3)
Terzaghi (Equation B.5)
U.S. Bureau of Reclamation (Equation B.20)
Salarashayeri and Siosemarde (Equation B.25)
Chapuis (Equation B.28)

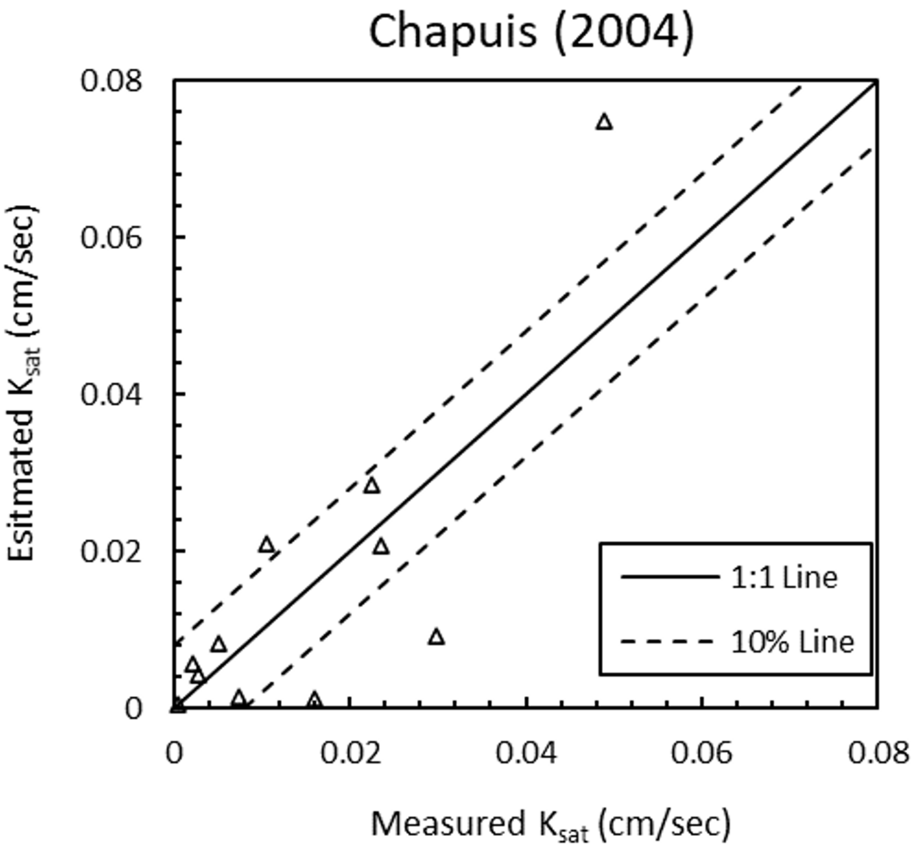
$$K[m/s] = \beta \frac{g}{v} \log \frac{500}{C_u} d_{10}^2$$

(Beyer, 1964)

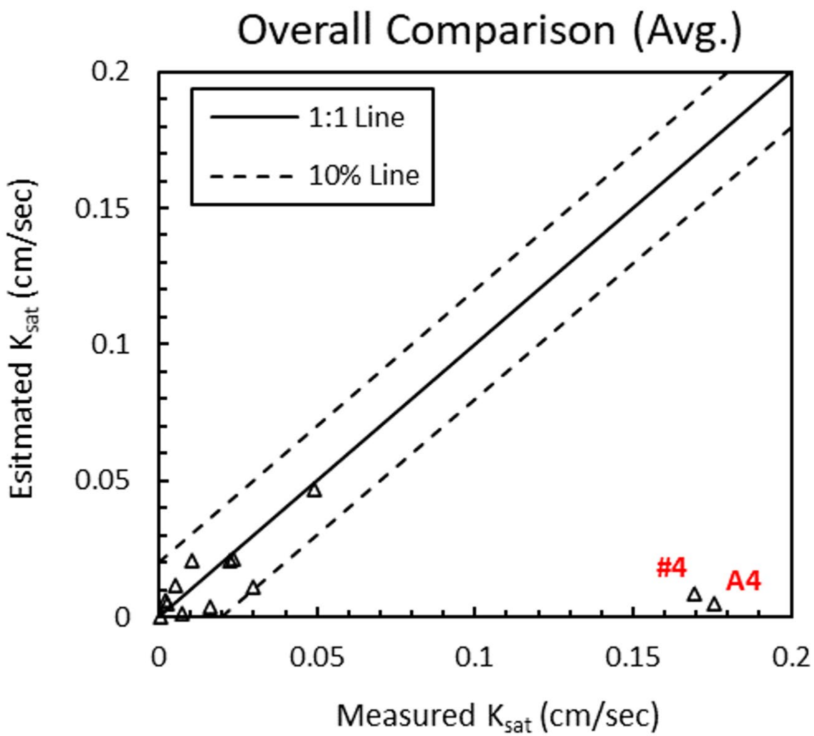
Empirical Equation Performance

(Gravels excluded)

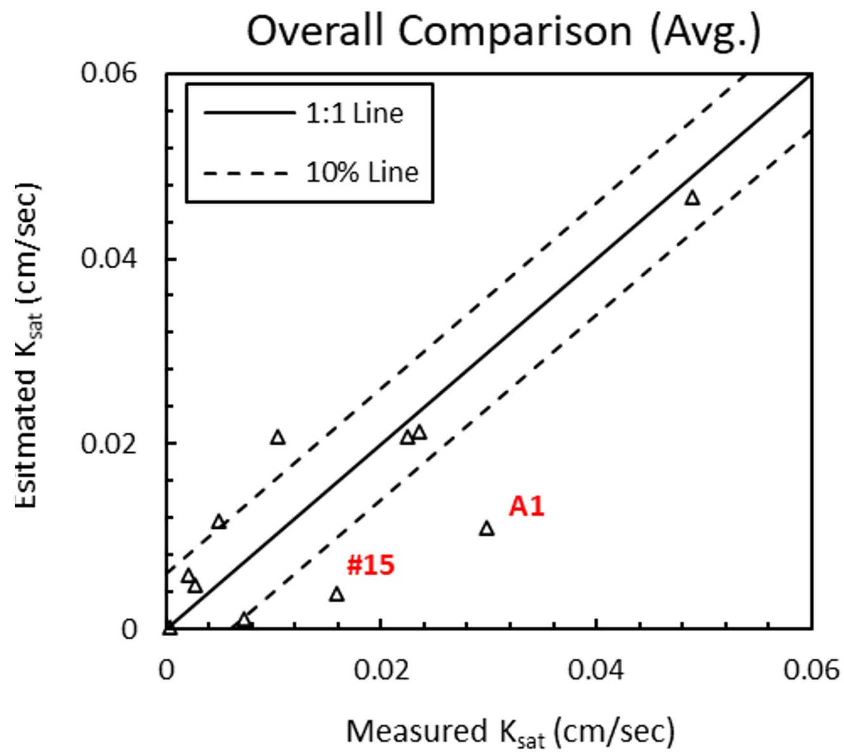




Empirical Equation Performance



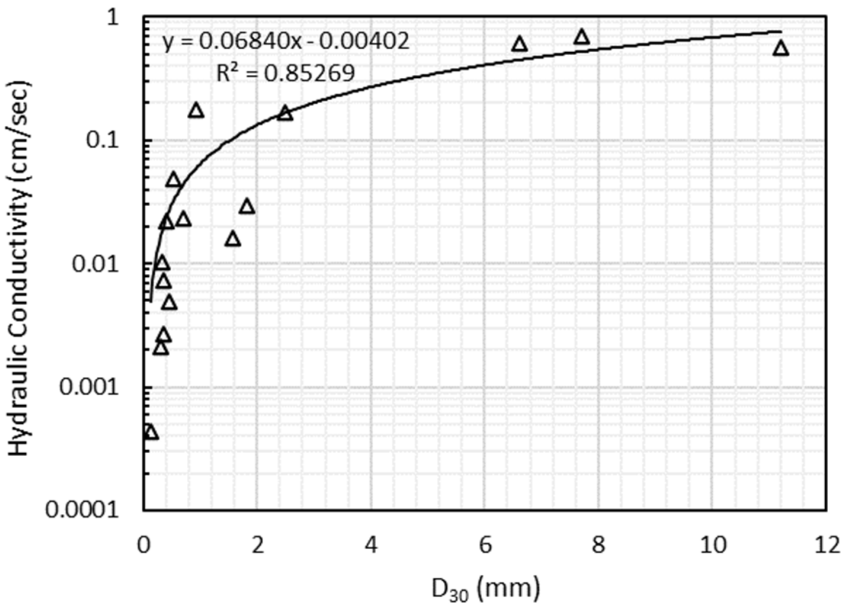
(All Samples)

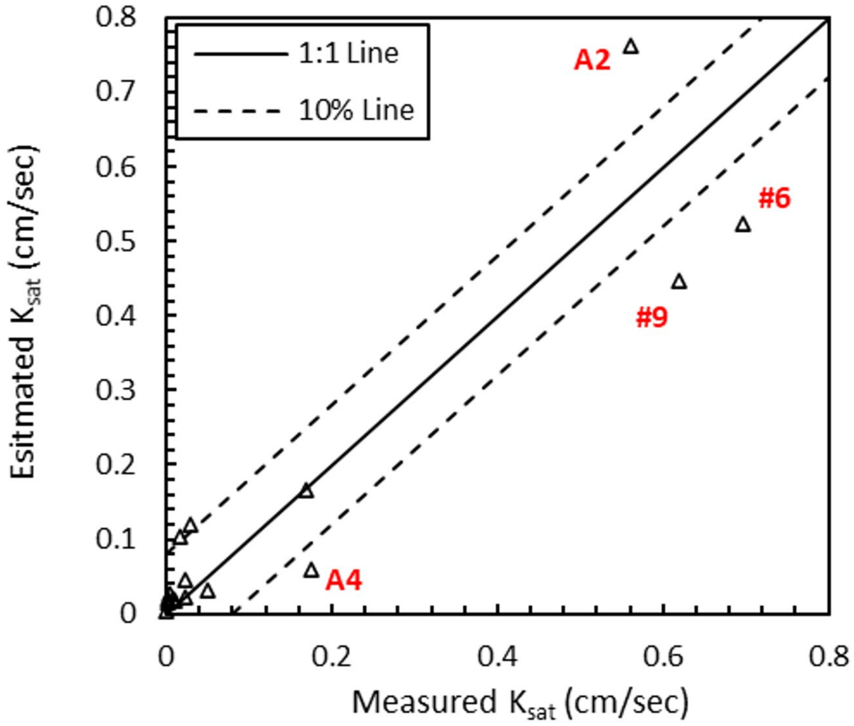


(Gravels Excluded)

Dataset Specific Estimations

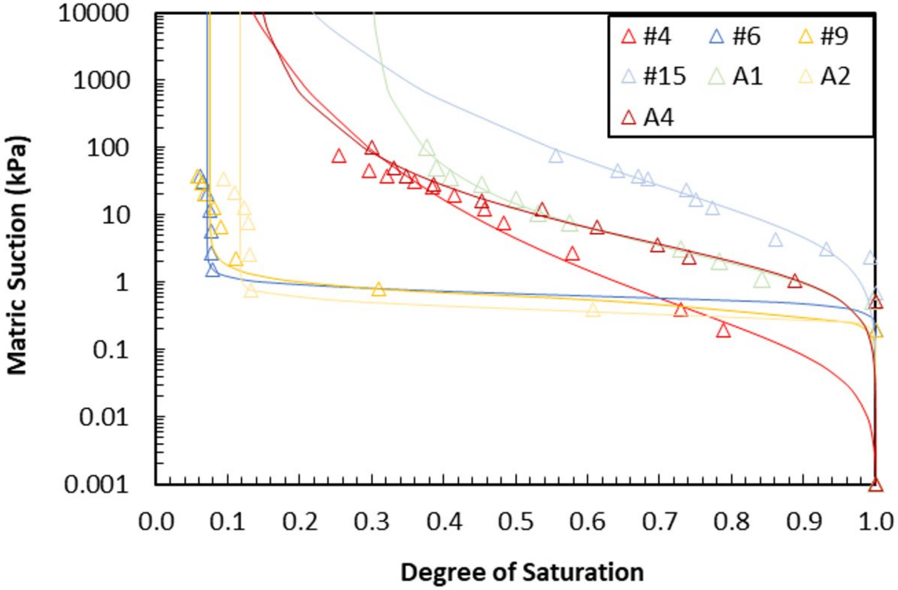
(Example using D30)



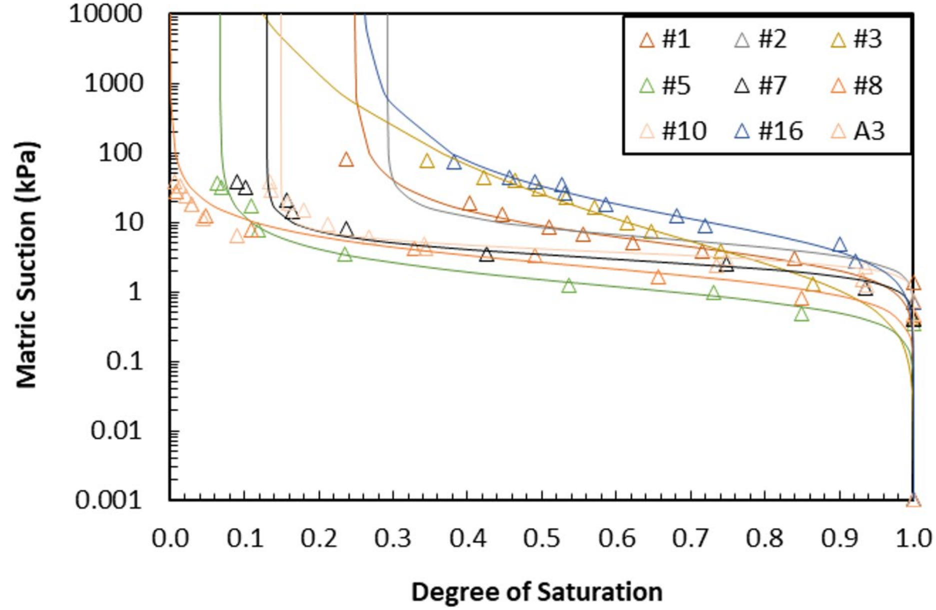


Soil-Water Characteristic Curves

(Gravels)



(Sands)



$$\Theta = S_e = \left[\frac{1}{1+(a\psi)^n}\right]^m$$

Van Genuchten (1980) Model

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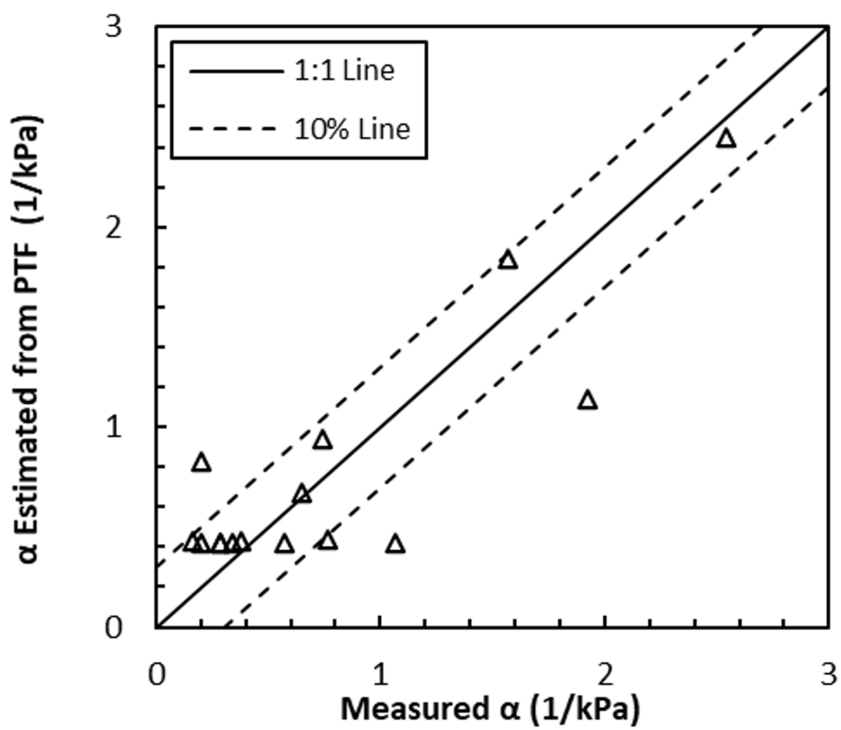
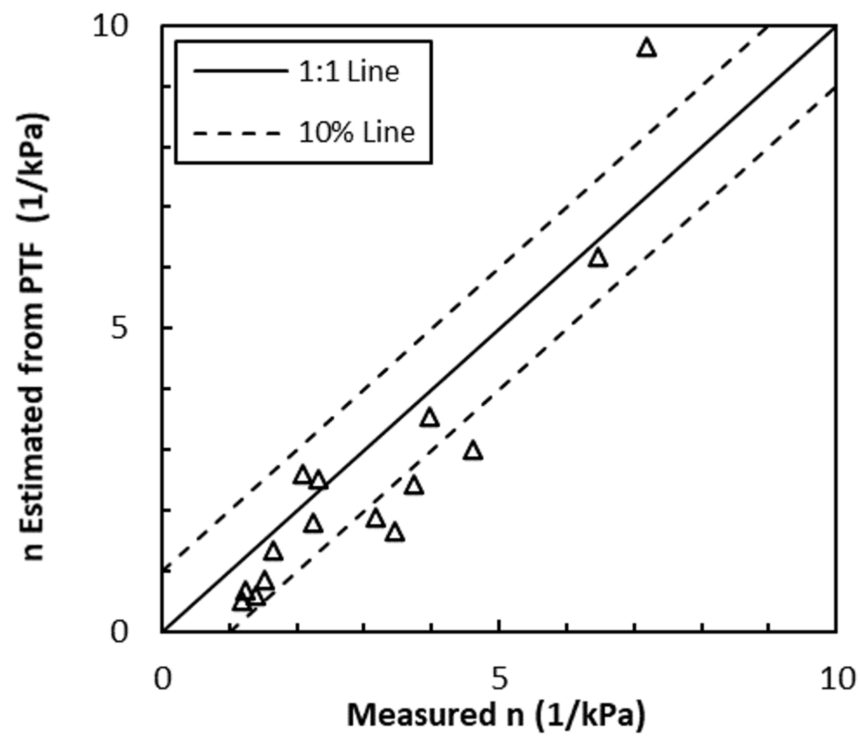
Estimations of van Genuchten SWCC parameters (preliminary)



α parameter estimated using D50



n parameter estimated using D50

Ongoing Efforts

- Continue data analysis (K_{sat} and VG parameters)
- Expand empirical database with applicable literature
- Final report (draft June 30, 2021)

Task Durations

	2020												2021							
Months:	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**
Task 1			X	X	X	X	X													
Task 2			X	X	X	X	X													
Task 3									X	X	X	X	X							
Task 4														X	X	X	X	X	X	X
Task 5														X	X	X	X	X	X	X