Determining Pavement Design Criteria for Recycled Aggregate Base and Large Stone Subbase

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MnDOT Project TPF-5(341)

Monthly Meeting

October 3rd, 2019

Prepared by Sinan Coban, Bora Cetin, William Likos and Tuncer Edil

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AGENCY MEMBERS

- MnDOT
- Caltrans
- MDOT
- IDOT
- LRRB
- MoDOT
- WisDOT
- NDDOT
- Iowa DOT

ASSOCIATE MEMBERS

- Aggregate & Ready Mix of MN
- Asphalt Pavement Alliance (APA)
- Braun Intertec
- Infrasense
- Diamond Surface Inc.
- Flint Hills Resources
- International Grooving & Grinding Association (IGGA)
- Midstate Reclamation & Trucking
- MN Asphalt Pavement Association
- Minnesota State University - Mankato
- National Concrete Pavement Technology Center
- Roadscanners
- University of Minnesota - Duluth
- University of New Hampshire
- Mathy Construction Company
- Michigan Tech Transportation Institute (MTTI)
- University of Minnesota
- National Center for Asphalt Technology (NCAT) at Auburn University
- GSE Environmental
- Helix Steel
- Ingios Geotechnics
- WSB
- Cargill
- PITT Swanson Engineering
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- Collaborative Aggregates LLC
- American Engineering Testing, Inc.
- Center for Transportation Infrastructure Systems (CTIS)
- Asphalt Recycling & Reclaiming Association (ARRA)
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- BASF Corporation
- Upper Great Plains Transportation Institute at North Dakota State University
- 3M
- Pavia Systems, Inc.
- All States Materials Group
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- Caterpillar
- The Dow Chemical Company
- The Transtec Group
- Testquip LLC
- Hardrives, Inc.
- Husky Energy
- Asphalt Materials & Pavements Program (AMPP)
- Concrete Paving Association of MN (CPAM)
- MOBA Mobile Automation
- Geophysical Survey Systems
- Leica Geosystems
- University of St. Thomas
- Trimble

OUTLINE

- Follow-up
- Test cells & materials
- Task 4 – Laboratory testing
- Summary

FOLLOW-UP

- **Task 1** – Literature review and recommendations
- **Task 2** – Tech transfer “state of practice”
- **Task 3** – Construction monitoring and reporting
- **Task 4** – Laboratory testing
- **Task 5** – Performance monitoring and reporting
- **Task 6** – Instrumentation
- **Task 7** – Pavement design criteria
- **Task 8 & 9** – Draft/final report

Green – Completed
Red – In Progress

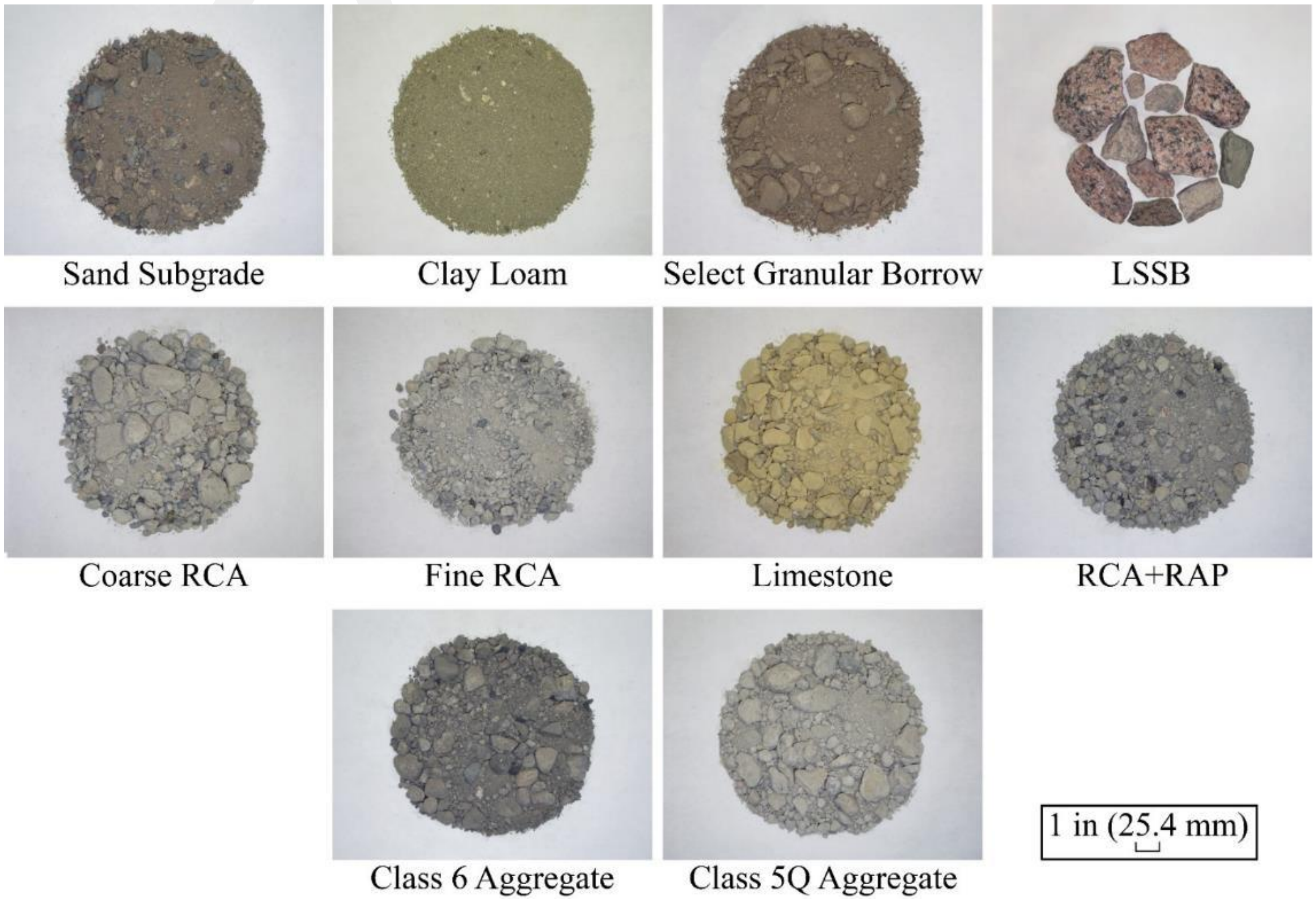
TEST CELLS

	Recycled Aggregate Base				Large Stone Subbase		Large Stone Subbase with Geosynthetics				
Cell	185	186	188	189	127	227	328	428	528	628	728
Surface	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave
Base	12 in Coarse RCA	12 in Fine RCA	12 in Limestone	12 in RCA+RAP	6 in Class 6 Aggregate	6 in Class 6 Aggregate	6 in Class 5Q Aggregate	6 in Class 5Q Aggregate	6 in Class 5Q Aggregate	6 in Class 5Q Aggregate	6 in Class 5Q Aggregate
Subbase	3.5 in S. Granular Borrow	3.5 in S. Granular Borrow	3.5 in S. Granular Borrow	3.5 in S. Granular Borrow	18 in LSSB (1 lift)	18 in LSSB (1 lift)	9 in LSSB TX	9 in LSSB TX+GT	9 in LSSB BX+GT	9 in LSSB BX	9 in LSSB
Subgrade	Sand	Sand	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam

S. Granular Borrow = Select Granular Borrow

TX = Triaxial Geogrid
BX = Biaxial Geogrid
GT = Nonwoven Geotextile

MATERIALS


Sand Subgrade
Clay Loam
Select Granular Borrow
LSSB
Coarse RCA
Fine RCA
Limestone
RCA+RAP
Class 6 Aggregate
Class 5Q Aggregate
1 in (25.4 mm)

TASK 4

Task 4 - Laboratory Testing

Green – Completed
Red – In Progress

Iowa State University

- Sieve analysis & hydrometer test
- Atterberg limits
- Proctor compaction
- Specific gravity & absorption
- Image analysis
- Asphalt & mortar content determination
- Gyratory compaction & percent crushing
- Contact angle measurement

University of Wisconsin-Madison

- Permeability
- Soil-water characteristic curve

TASK 4

Gyratory Compaction

- ASTM D6925
- 4500 g of each material
- 100, 300, and 500 gyrations

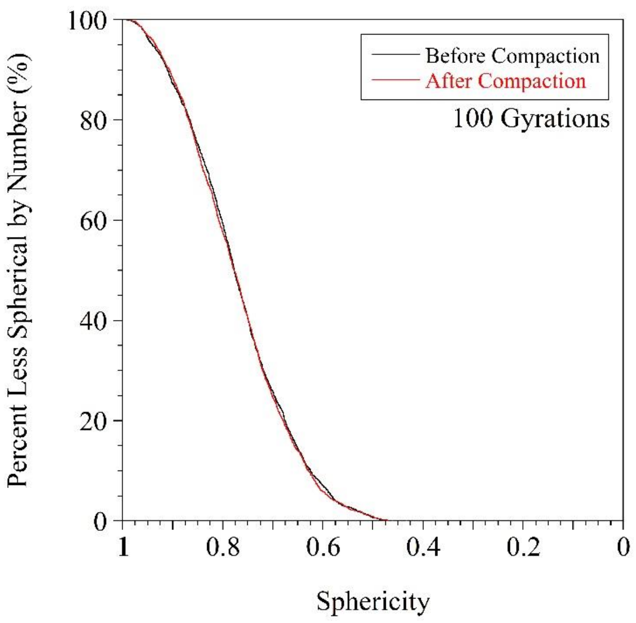
Parameter	Value
Compaction Mold Diameter	6 in (150 mm)
Specimen Height	6 - 7.25 in (150 – 185 mm)
Vertical Applied Pressure	12,530 psf (600 kPa)
Number of Gyrations	100, 300[a], 500[b]
Angle of Gyration	1.25° ± 0.02
Frequency of Gyration	30 ± 0.5 gyrations/min
Number of Dwell Gyrations	2

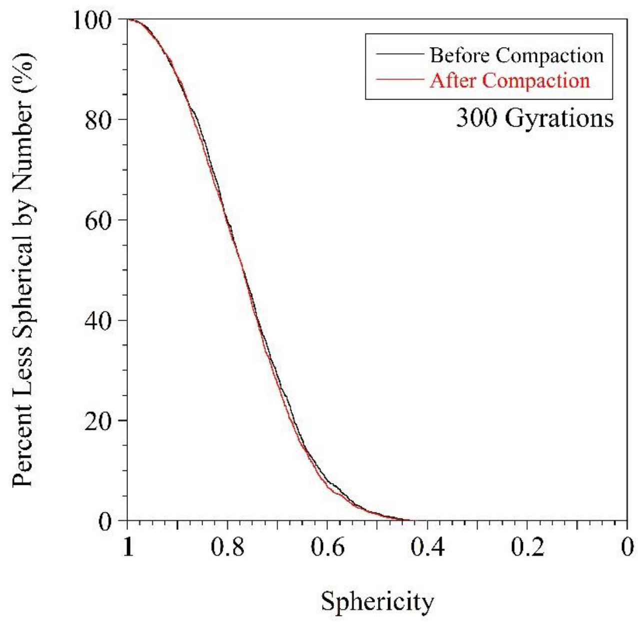
[a]In fact, 299 gyrations (maximum number of gyrations that can be applied per test) were applied. However, the number is rounded to 300 for simplicity.
[b]Applied in two consecutive tests with 250 gyrations each.

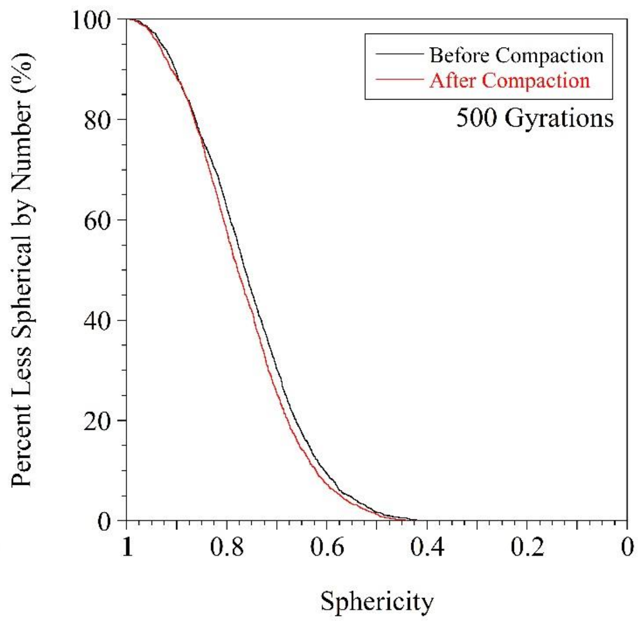
TASK 4

Gyratory Compaction

- Particle morphology change
- Example – Coarse RCA



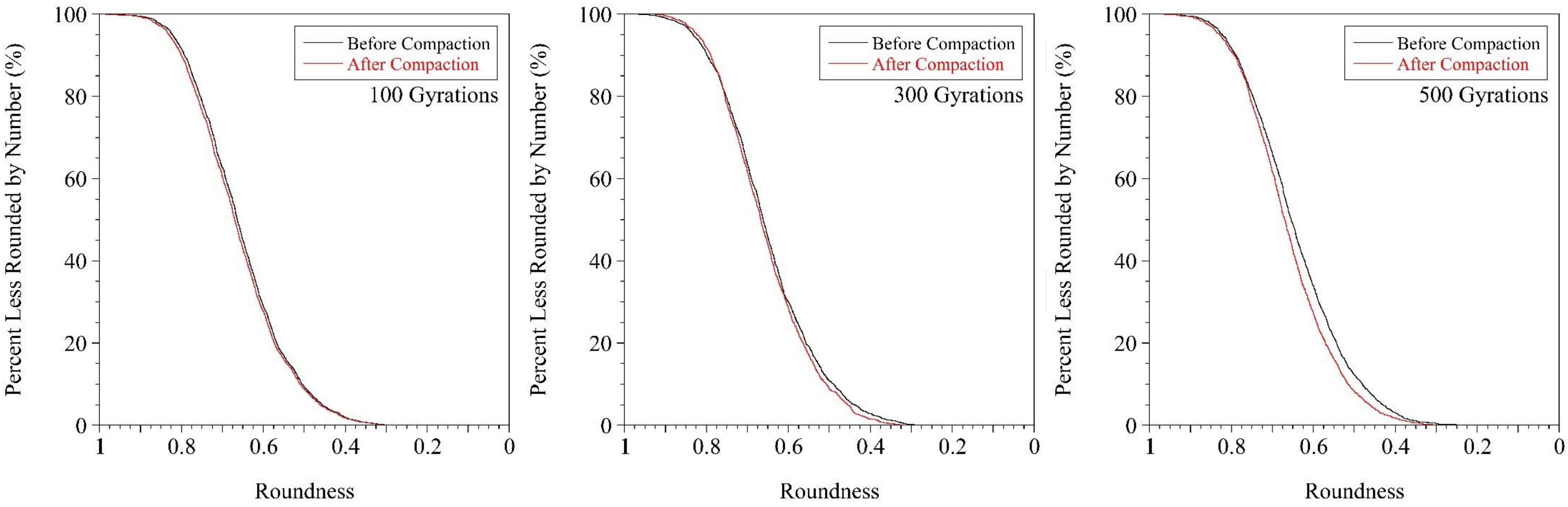




TASK 4

Gyratory Compaction

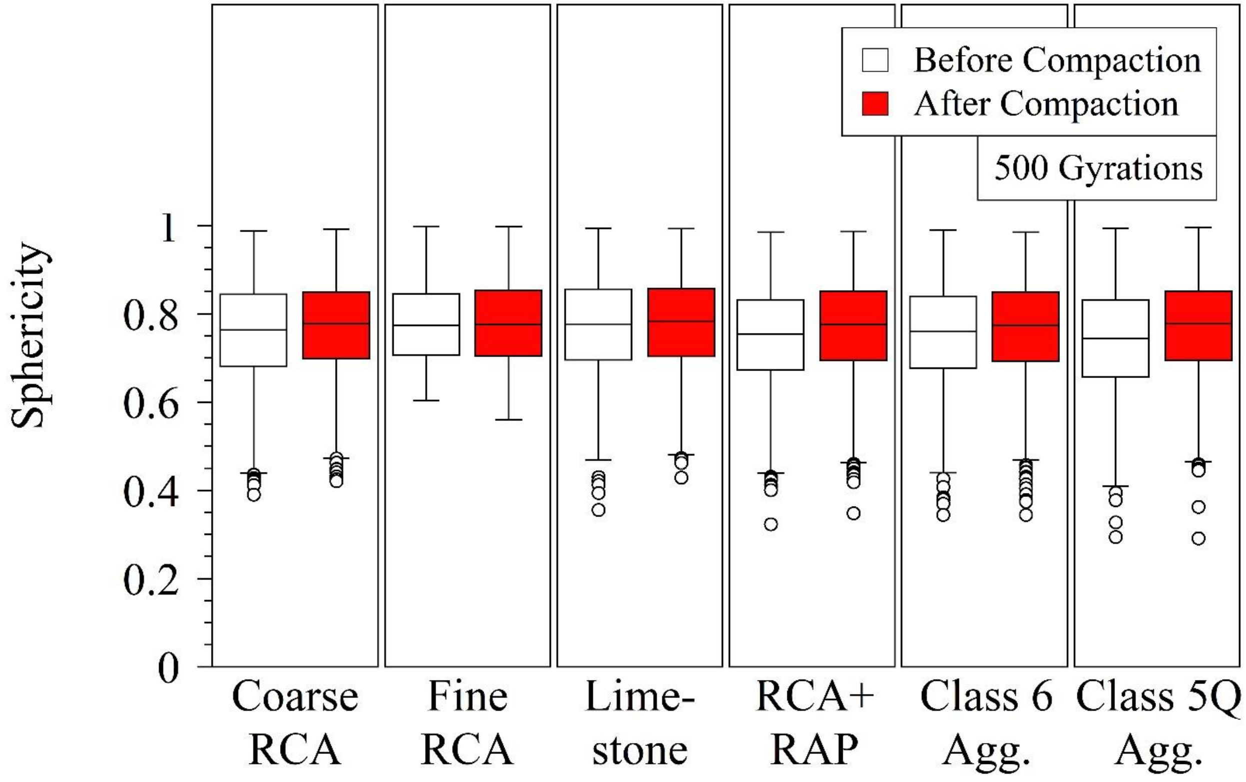
- Particle morphology change
- Example – Coarse RCA



TASK 4

Gyratory Compaction

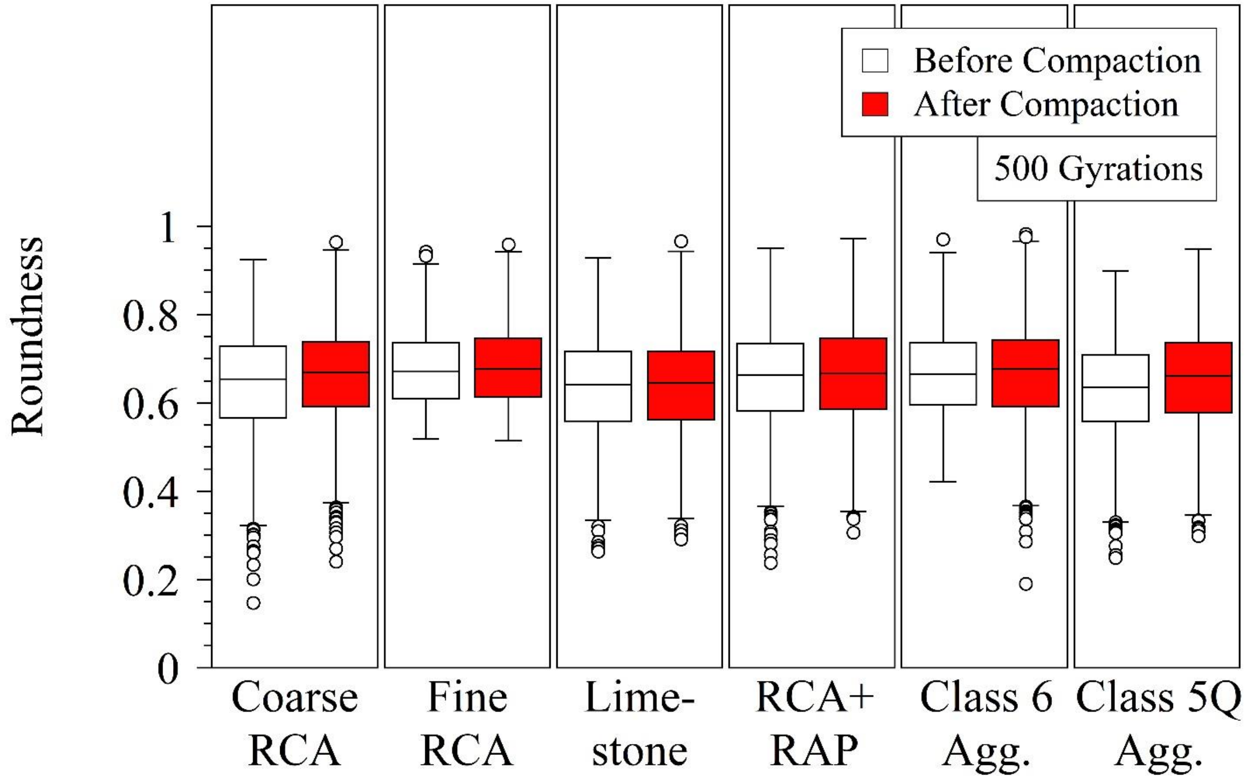
- Particle morphology change



TASK 4

Gyratory Compaction

- Particle morphology change



TASK 4

Mortar Content

- Freeze-thaw method developed by Abbas et al. 2008
- Test material (oven-dried)
  - 1-in and 3/4-in sieves ➔ 2000 g each
  - 3/8-in and No. 4 sieves ➔ 1000 g each
- 26 % (by weight) sodium sulfate solution for 24 hrs
- Five freeze-thaw cycles
  - Freezing at −17°C (1.4 °F) for 16 hrs
  - Thawing at 80°C (176 °F) for 8 hrs
- Washing over No. 4 sieve & oven drying

TASK 4

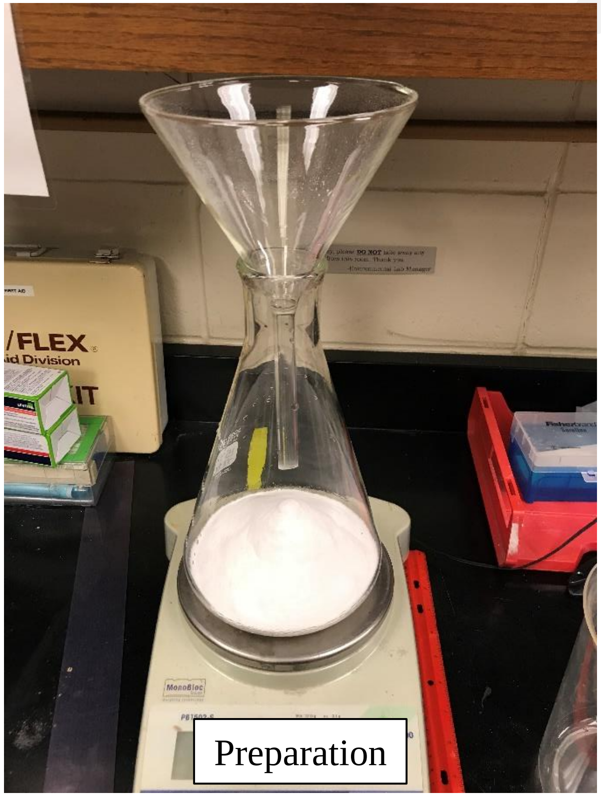
Mortar Content

- Test material
  - Example – Coarse RCA

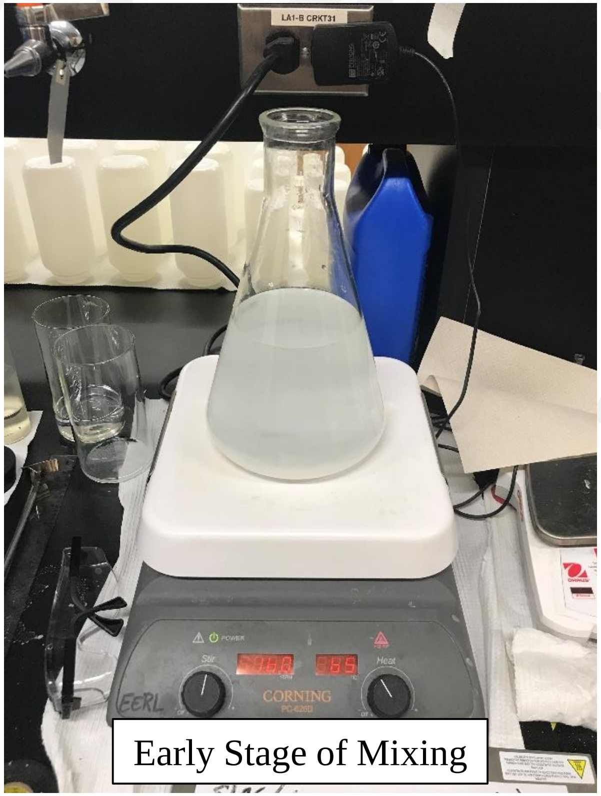
TASK 4

Mortar Content

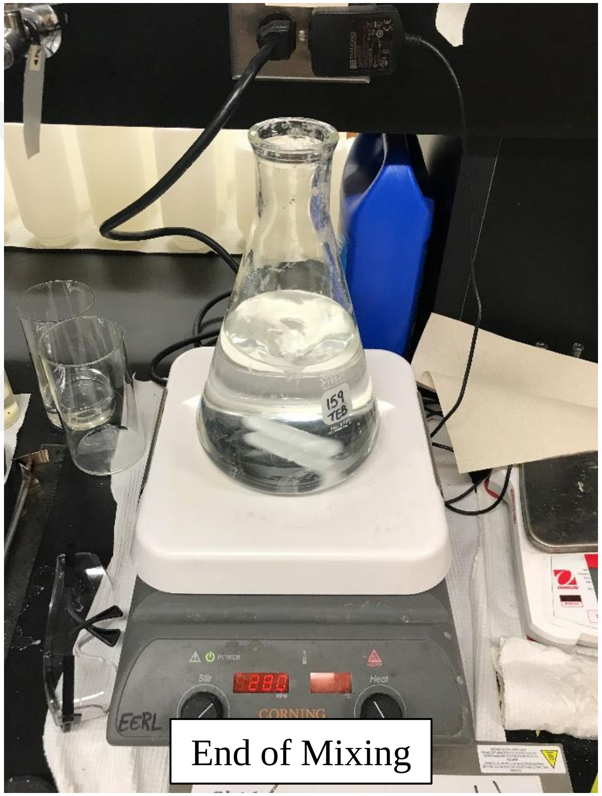
- 26 % (by weight) sodium sulphate solution
  - Saturated solution



Preparation



Early Stage of Mixing

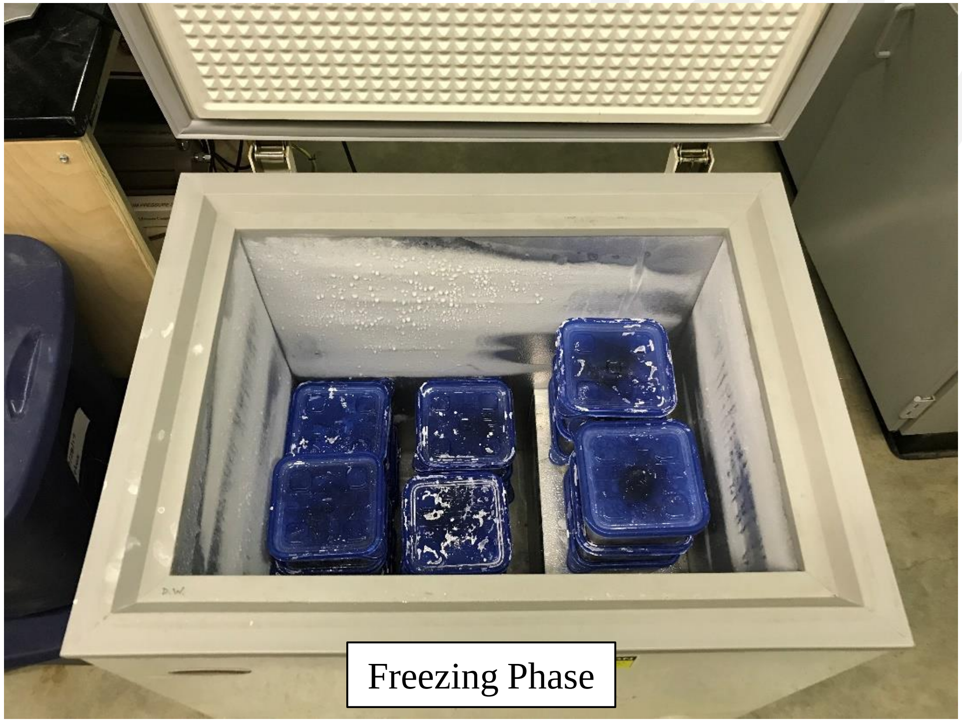


End of Mixing

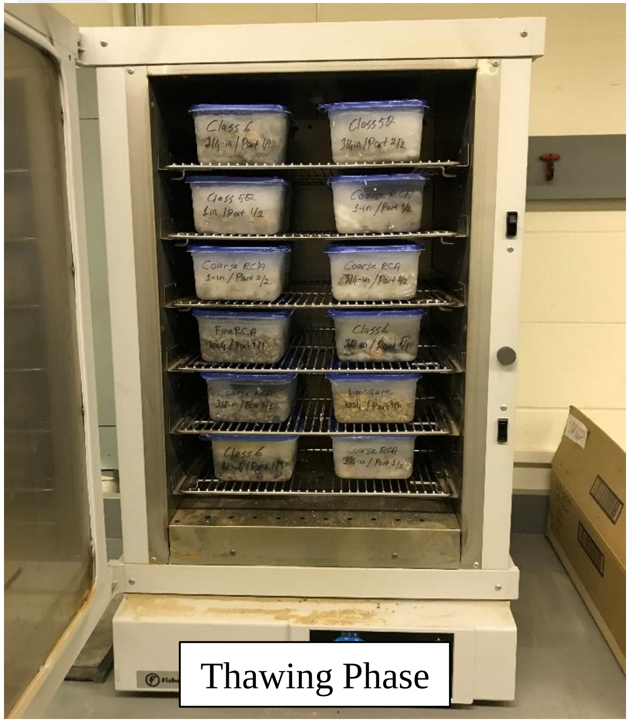
TASK 4

Mortar Content

- Five freeze-thaw cycles
  - Freezing at −17°C (1.4 °F) for 16 hrs
  - Thawing at 80°C (176 °F) for 8 hrs



Freezing Phase

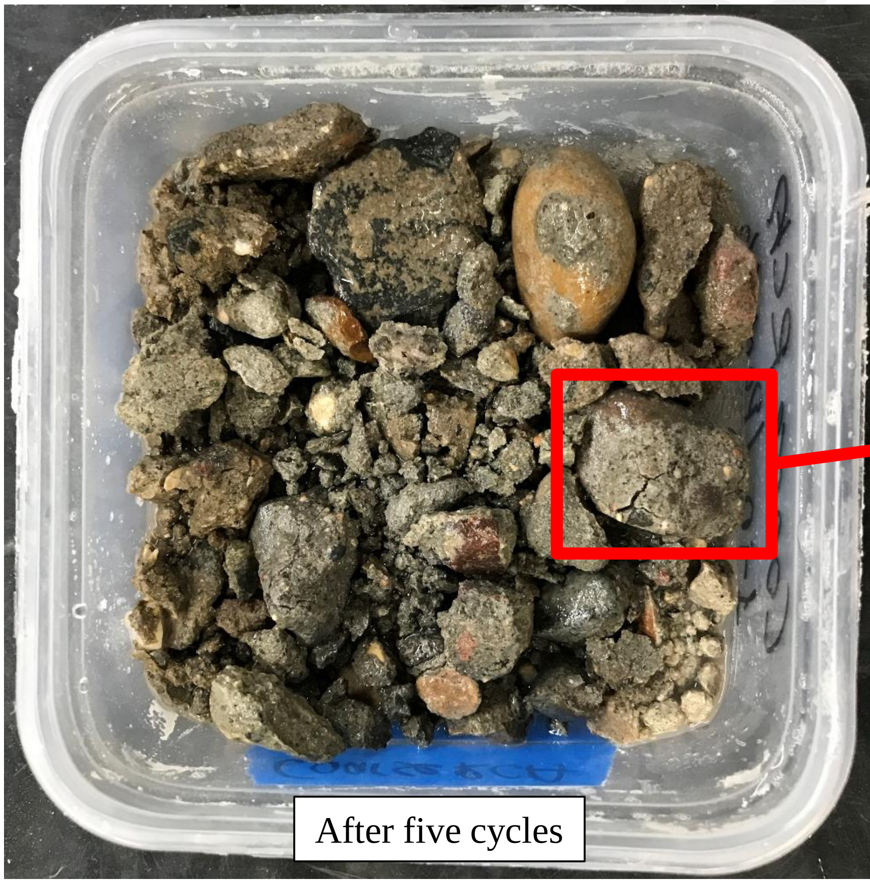


Thawing Phase

TASK 4

Mortar Content

- Five freeze-thaw cycles



After five cycles

Disintegration of Mortar

TASK 4

Mortar Content

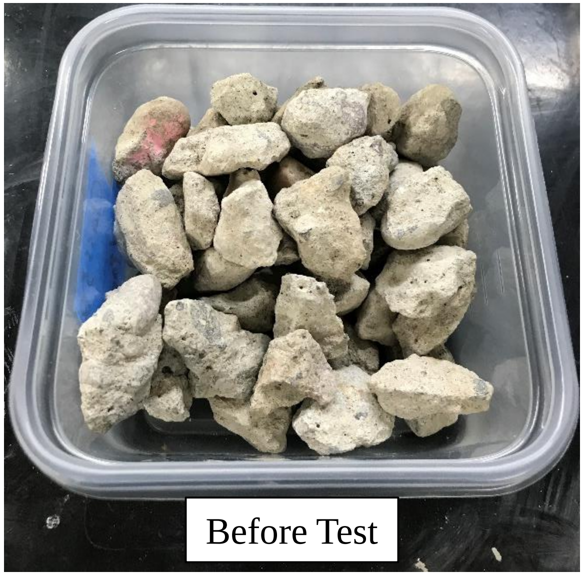
- Washing over No. 4 sieve & oven drying

Mixture of Disintegrated Mortar and Aggregates

TASK 4

Mortar Content

Material	Mortar Content (%)
Coarse RCA	33.4
Fine RCA	29.6
Limestone	1.3
RCA+RAP	20.1
Class 6 Aggregate	25.6
Class 5Q Aggregate	37.1



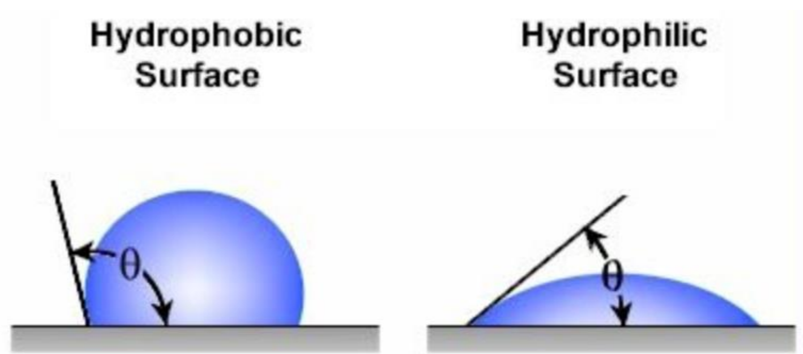
Before Test

After Test

TASK 4

Water Repellency

- Apparent water contact angle (°)
  - At zero energy state of water
- Water drop penetration time (WDPT)
  - Time required for a water drop to completely infiltrate the material



http://www.ramehart.com/contactangle.htm

Water repellency	WDPT (s)	Apparent contact angle (°)
Wettable	<5	0
Slightly to moderately repellent	5–60	67
Strongly water-repellent	60–600	90
Severely water-repellent	600–3600	98
Extremely water-repellent	>3600	122

The WDPT test consists of randomly applying water drops (100 ± 5 μl) onto the soil surface and measuring the time (in sec) it takes to infiltrate the soil.

(Mandal and Jayaprakash 2009)

TASK 4

Water Repellency

Coarse RCA

Fine RCA

Limestone

TASK 4

Water Repellency

RCA+RAP

Class 6 Aggregate

Class 5Q Aggregate

TASK 4

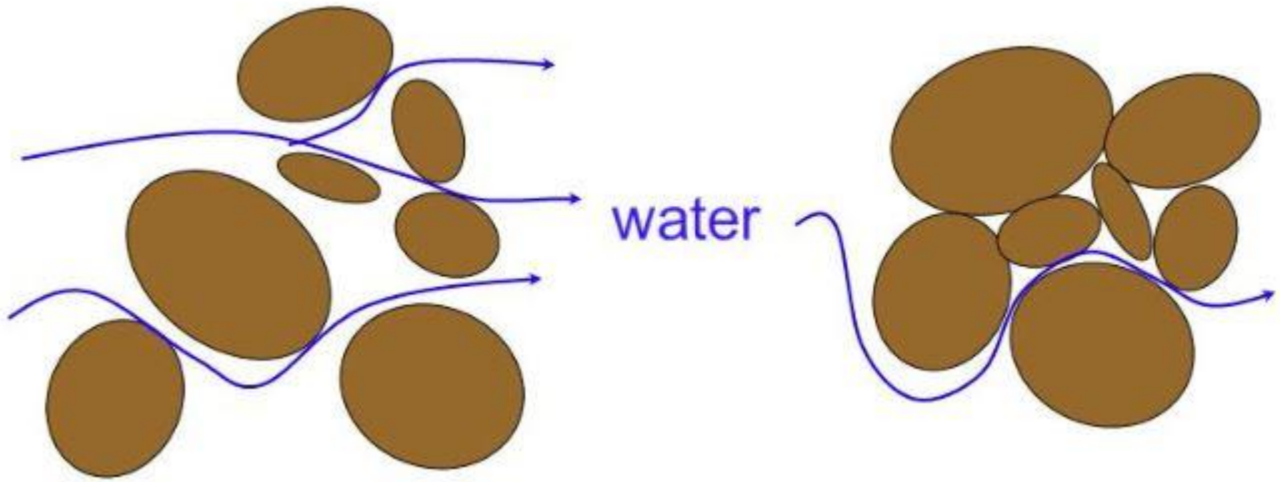
Water Repellency

Material	Apparent Contact Angle (°)	Water Drop Penetration Time (WDPT) (s)	Water Repellency
Coarse RCA	~ 0	< 5	Wettable (Hydrophilic)
Fine RCA	~ 0	< 5	Wettable (Hydrophilic)
Limestone	~ 0	< 5	Wettable (Hydrophilic)
RCA+RAP	~ 83	> 3600	Water Repellent (Hydrophobic)
Class 6 Aggregate	~ 86	> 3600	Water Repellent (Hydrophobic)
Class 5Q Aggregate	~ 0	< 5	Wettable (Hydrophilic)

TASK 4

Permeability Test

- ASTM 5084 – Flexible wall permeameter
  - Constant head permeability test (method A)
  - Falling head permeability test (method C)

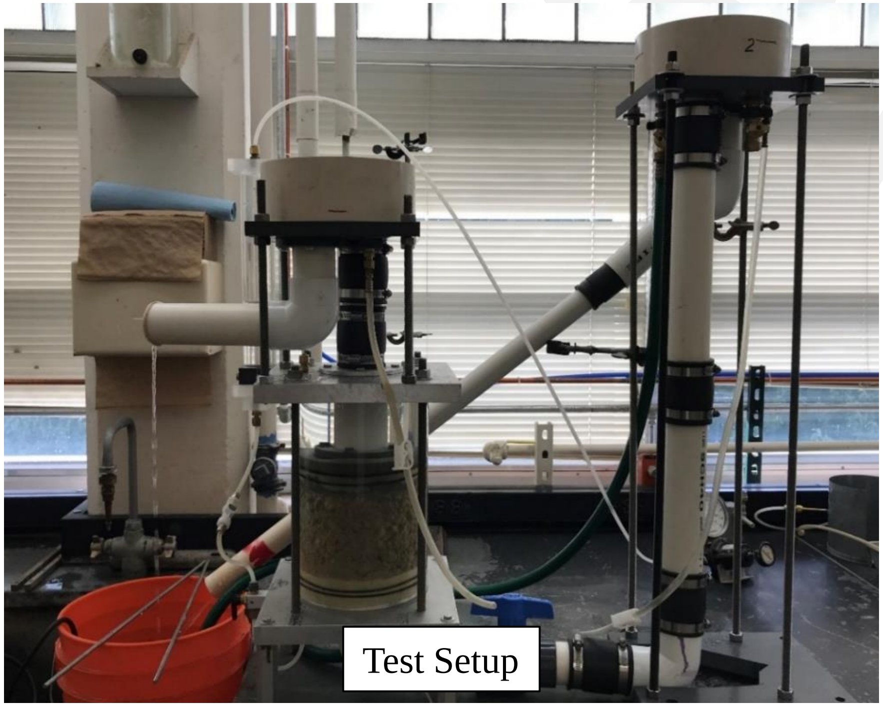


https://slideplayer.com/slide/6104388/

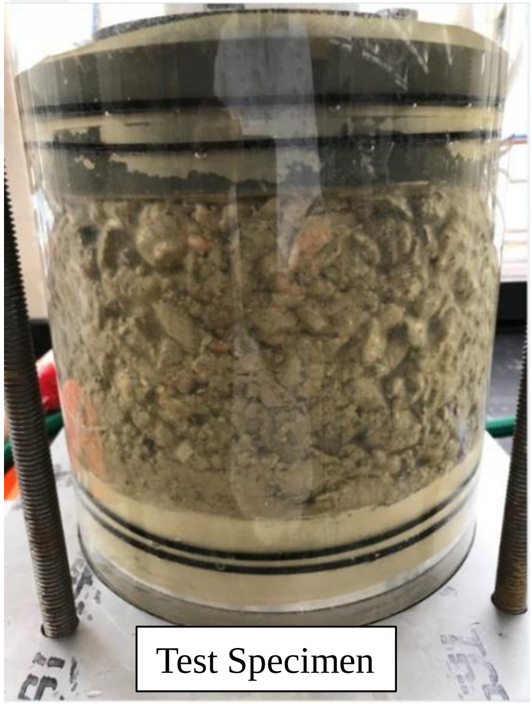
TASK 4

Constant Head Permeability Test

- 6-in diameter and 4-in height specimens
  - Materials passing 3/4-in sieve
- In the membrane by light hammering



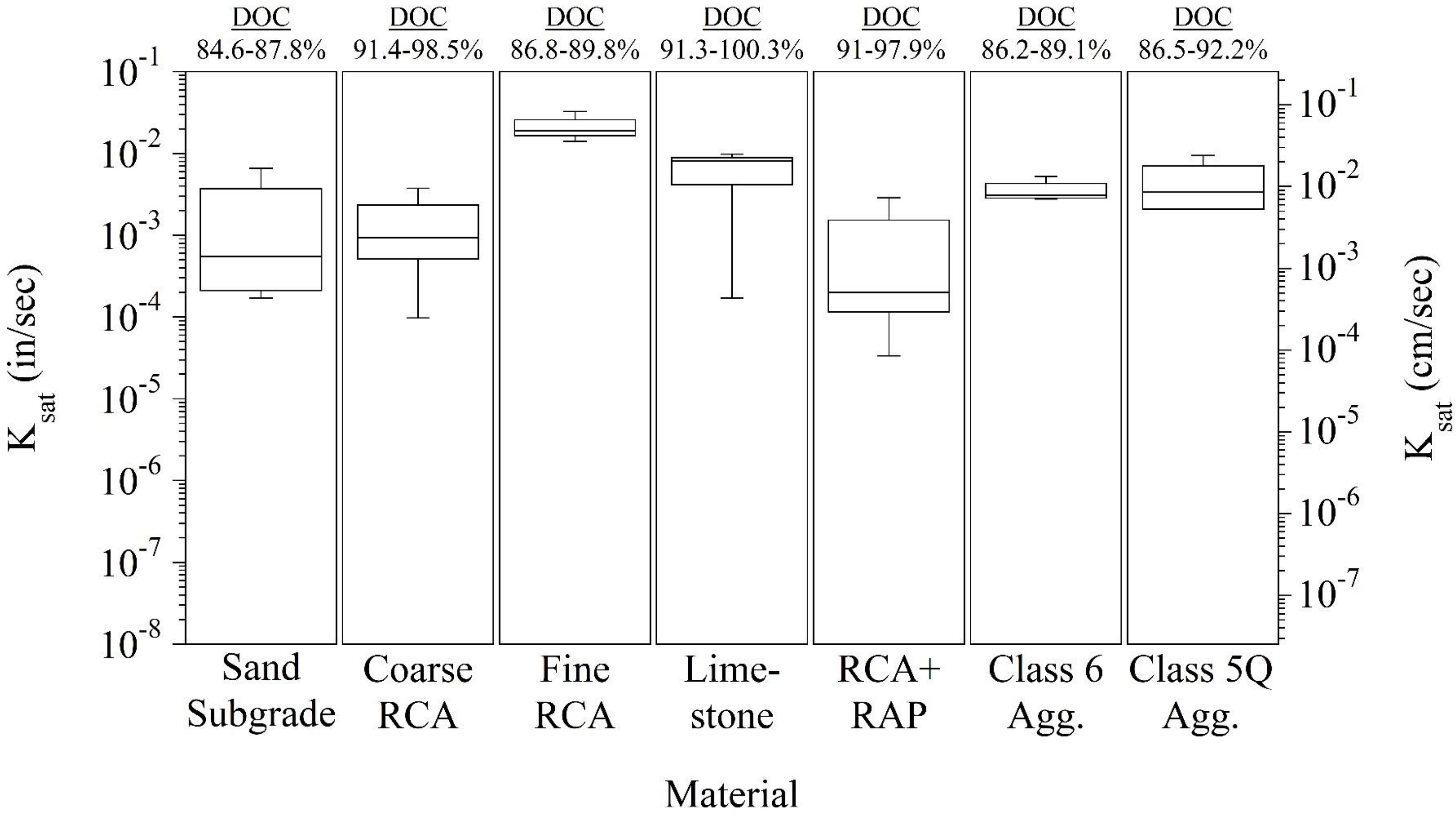
Test Setup



Test Specimen

TASK 4

Constant Head Permeability Test



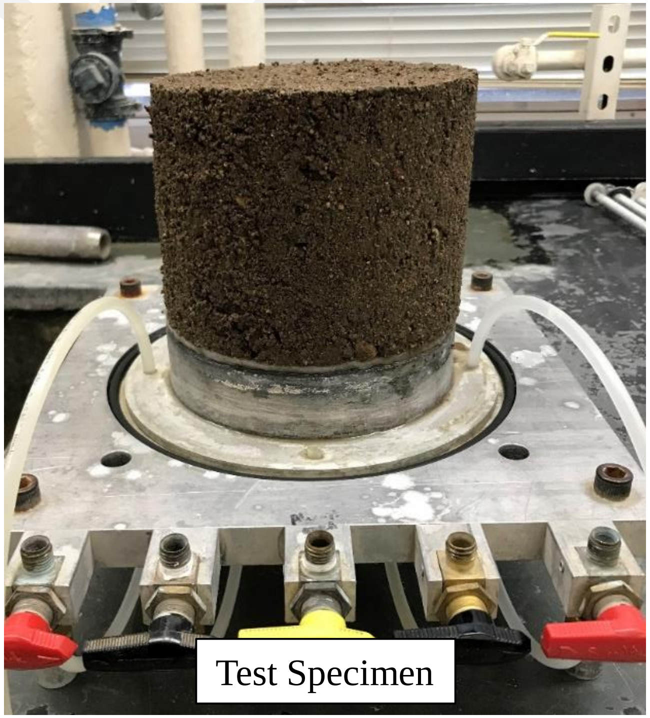
DOC = Degree of compaction

TASK 4

Falling Head Permeability Test

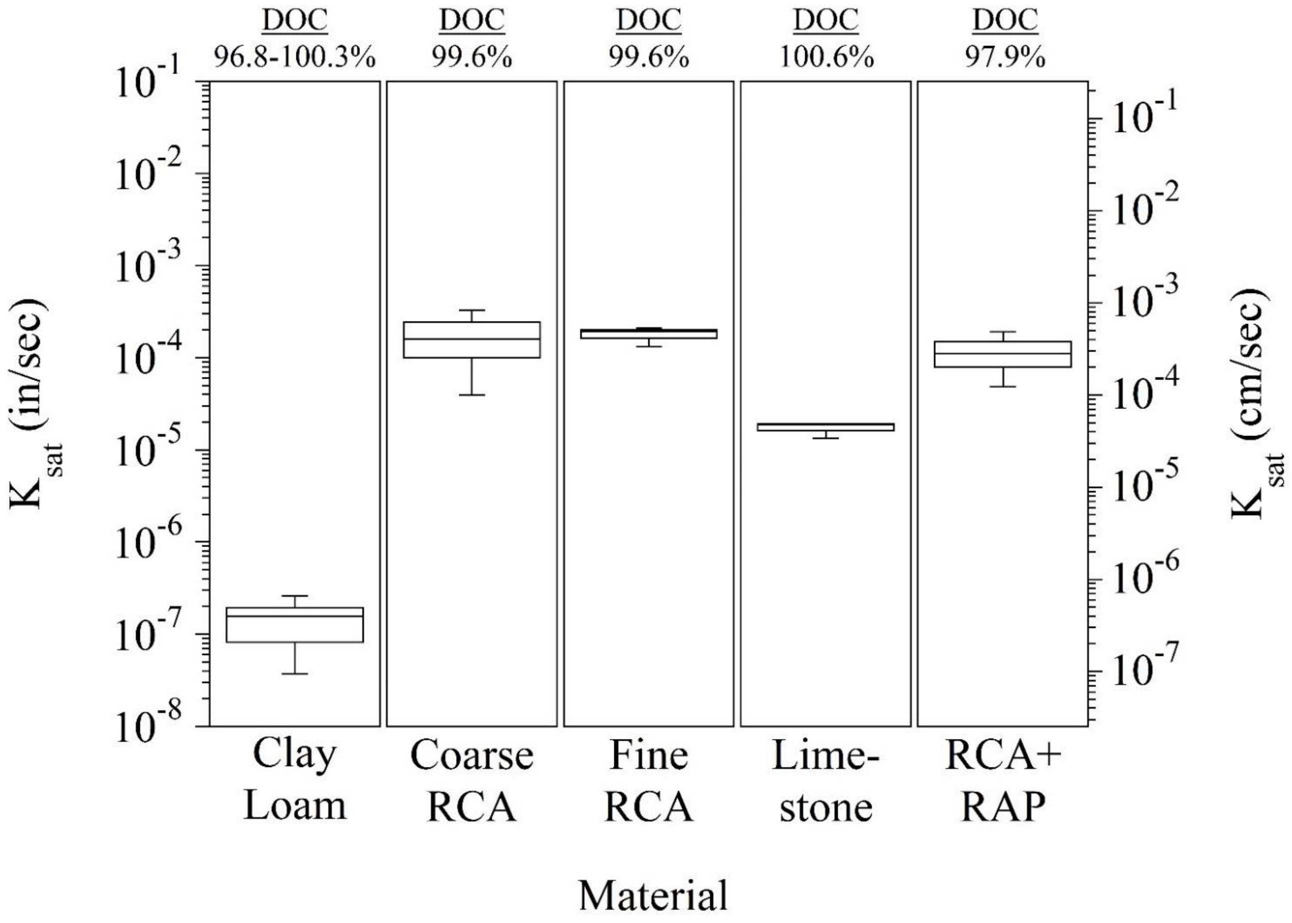
- 6-in diameter and 4-in height specimens
  - Materials passing 3/4-in sieve
- In the compaction mold (5 layers)


Test Setup


Test Specimen

TASK 4

Falling Head Permeability Test

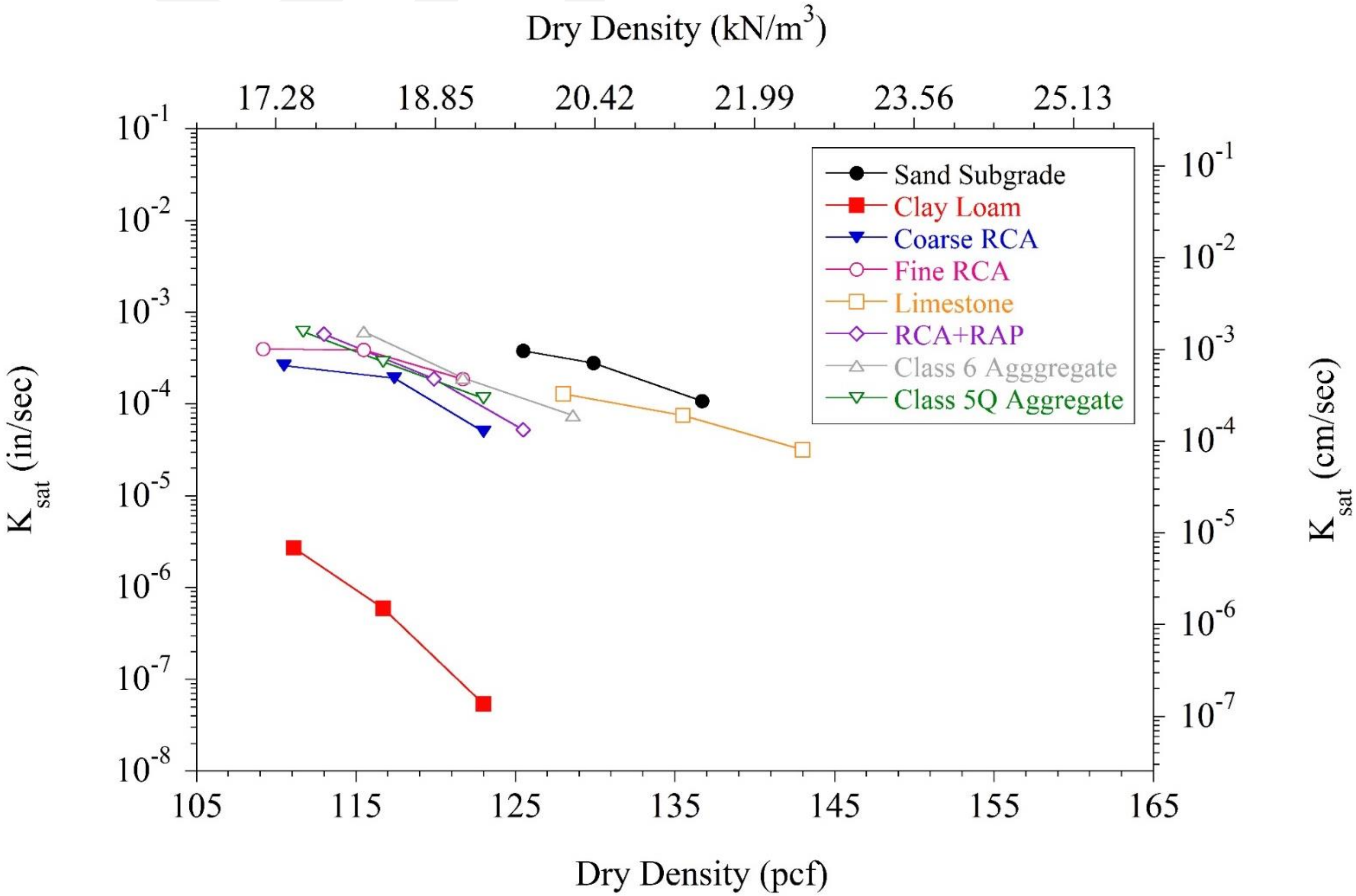


DOC = Degree of compaction

TASK 4

Falling Head Permeability Test

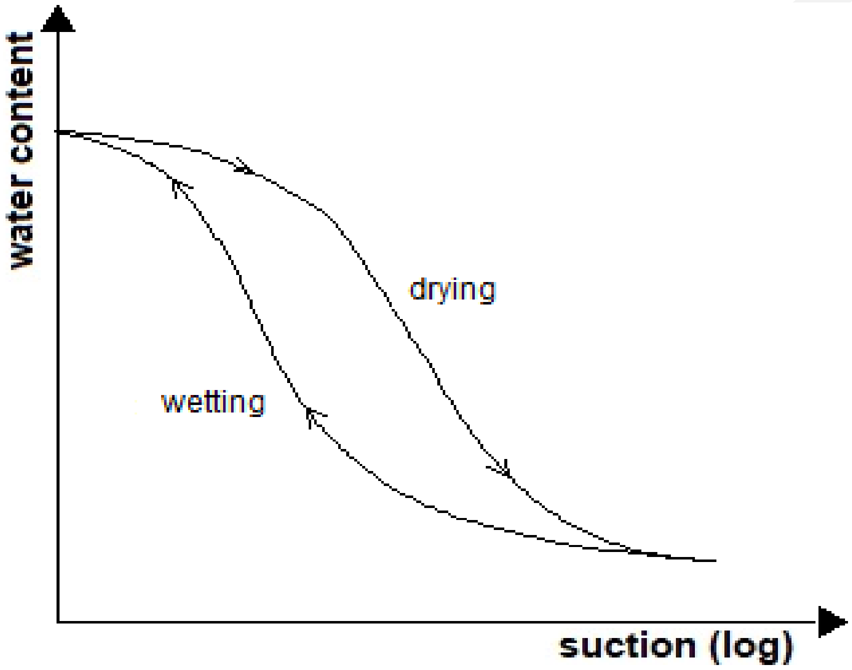
- Degree of compaction

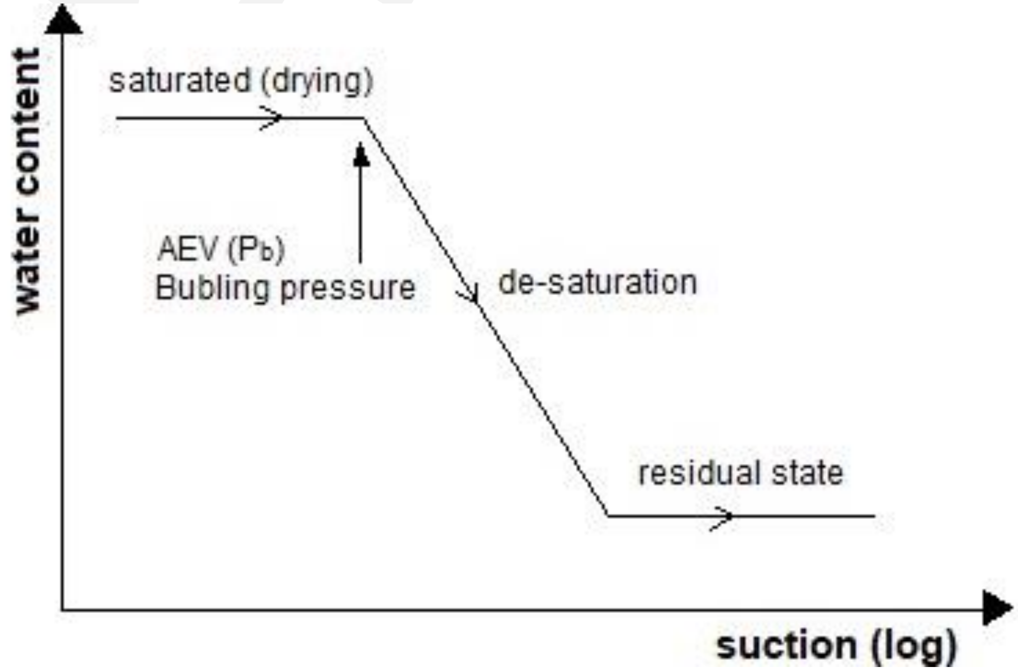


TASK 4

Soil-Water Characteristic Curve (SWCC)

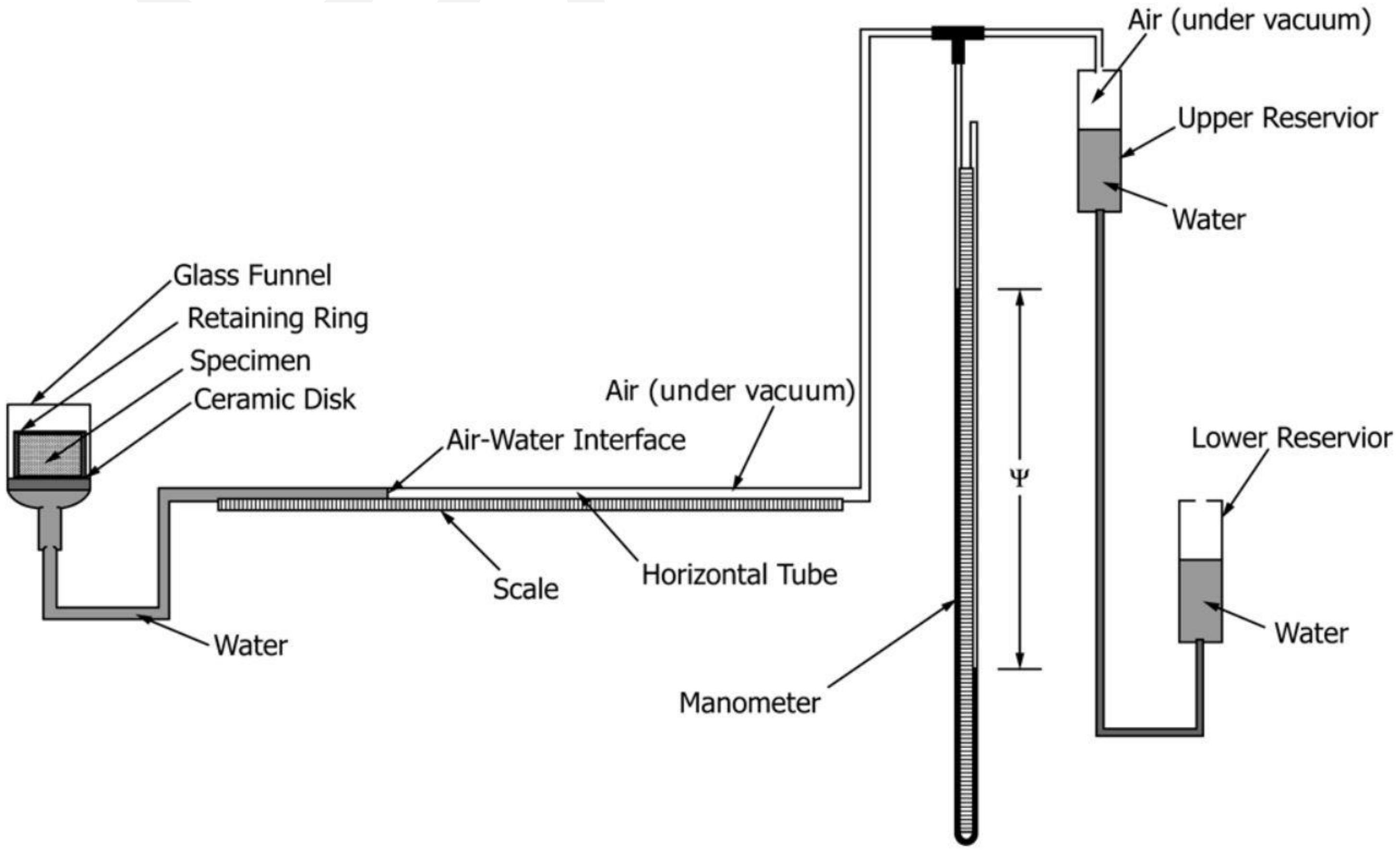
- ASTM D6836
  - Hanging column test
  - Pressure plate and activity meter test





TASK 4

Hanging Column Test



TASK 4

Hanging Column Test

Glass Funnel

Horizontal Tube

Manometers

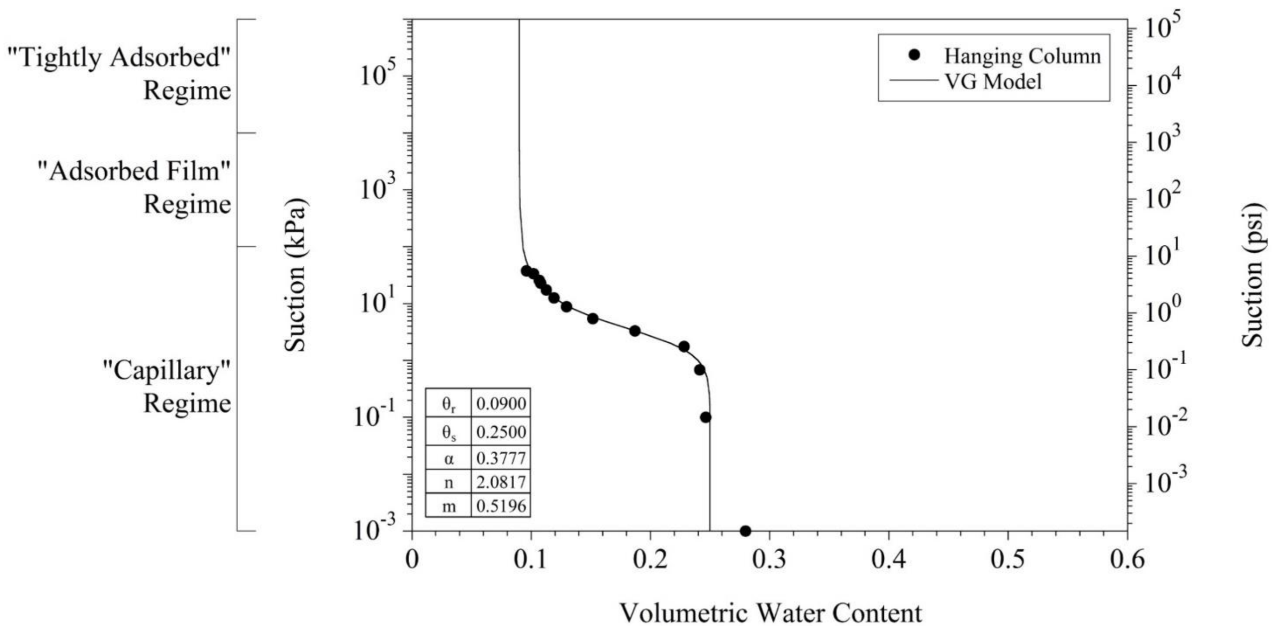
TASK 4

Hanging Column Test

- van Genuchten (1980) model

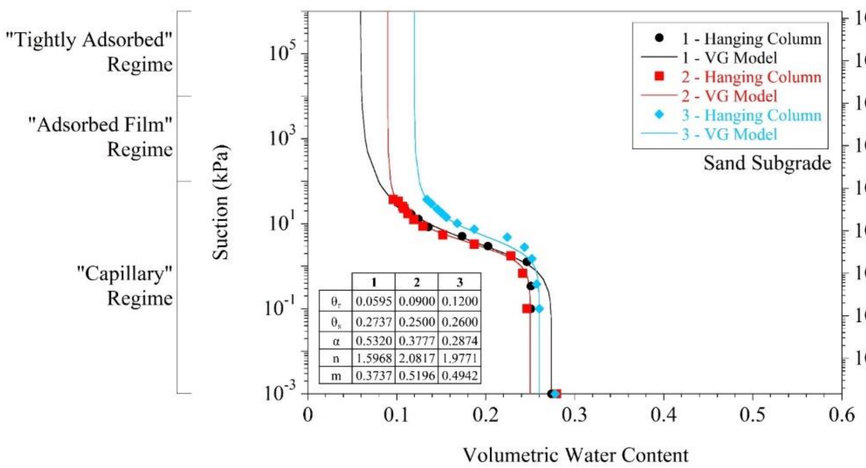
$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[\frac{1}{1 + (\alpha\psi)^n}\right]^m$$

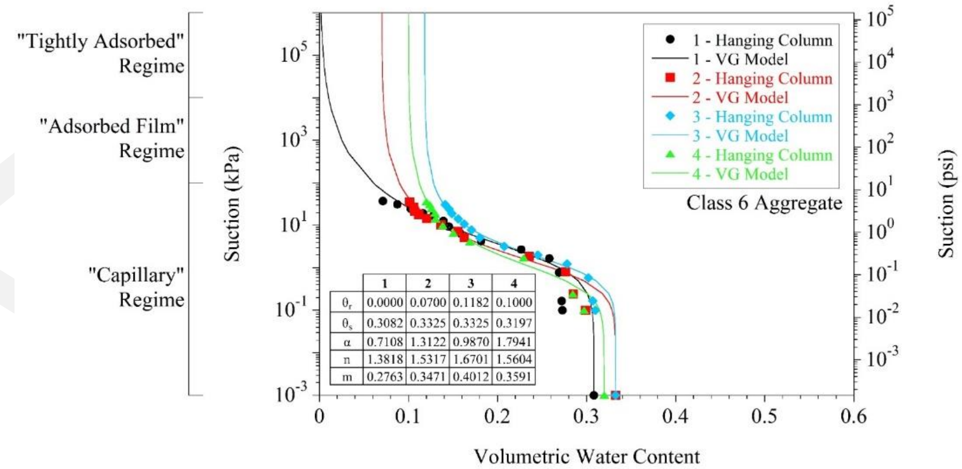
Θ = Normalized volumetric water content
θ = Soil volumetric water content
θ_r = Residual volumetric water content
θ_s = Saturated volumetric water content
Ψ = Matric suction
α, n, and m = van Genuchten fitting parameters

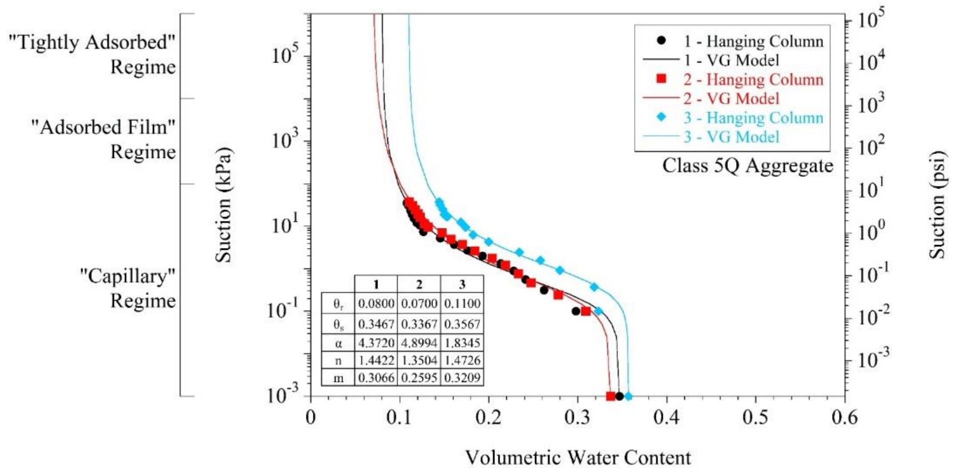


TASK 4

Hanging Column Test

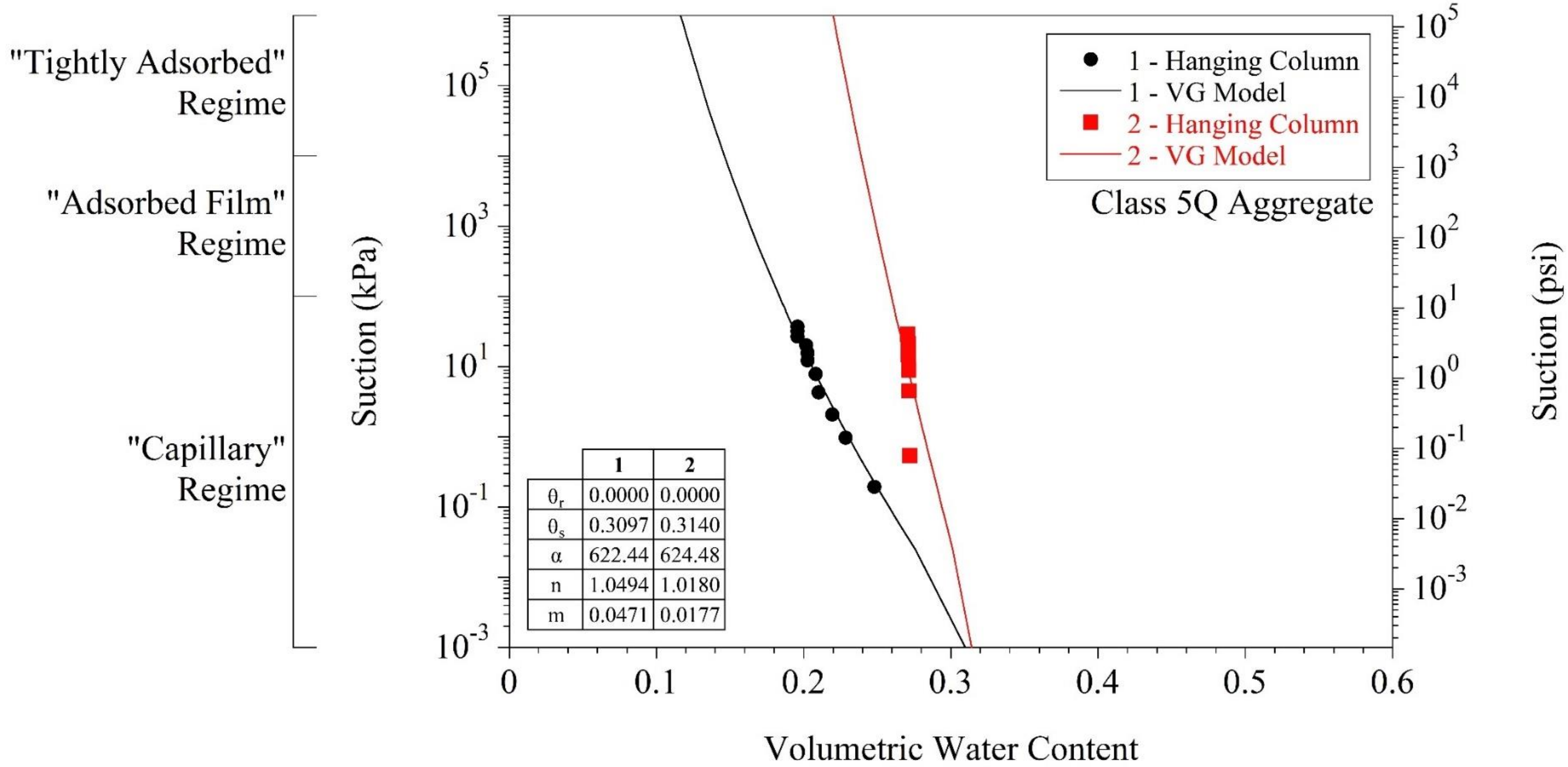






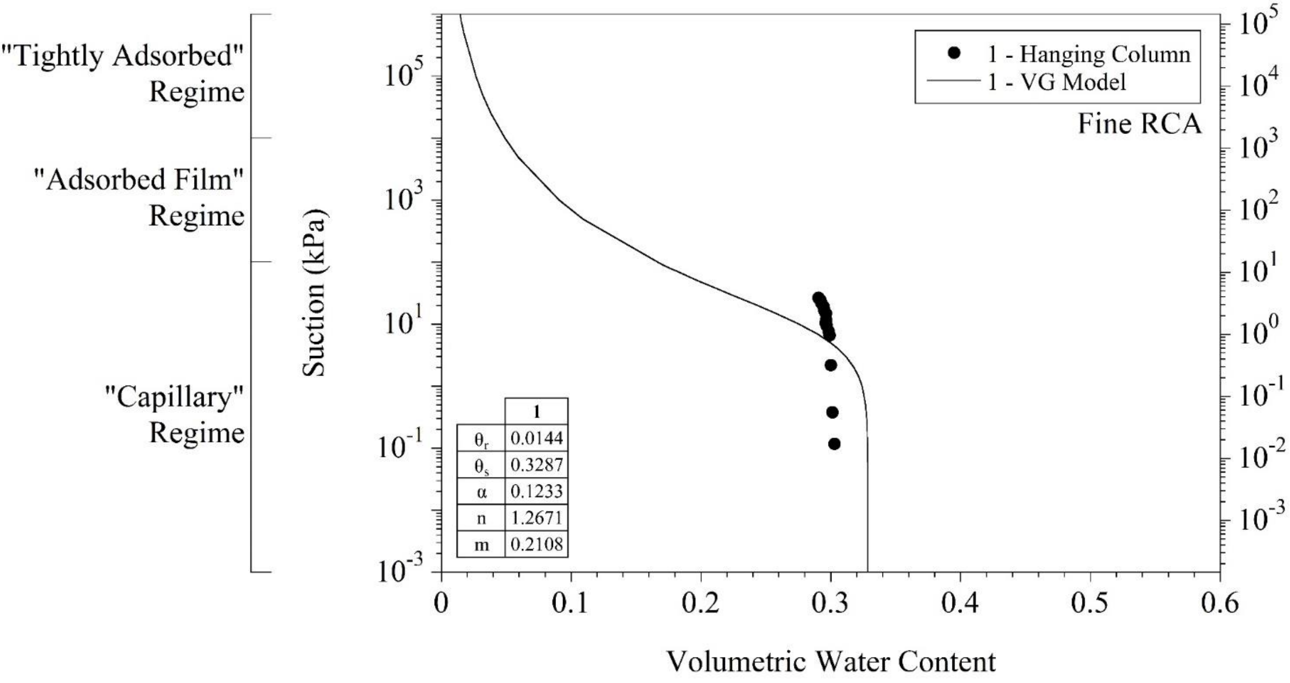
TASK 4

Hanging Column Test



TASK 4

Hanging Column Test



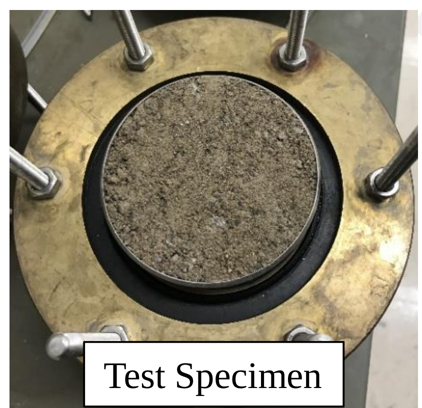
Cementation of Fine RCA

TASK 4

Pressure Plate and Activity Meter Test

- Pressure Plate
  - 3-in diameter and 1-in height specimens
  - Materials passing 3/8-in sieve
  - Suction values up to 220 psi (1500 kPa)
- Activity Meter
  - Materials passing No. 10 sieve
  - Higher suction


Single-Specimen Pressure Chambers


Test Specimen

Activity Meter Device

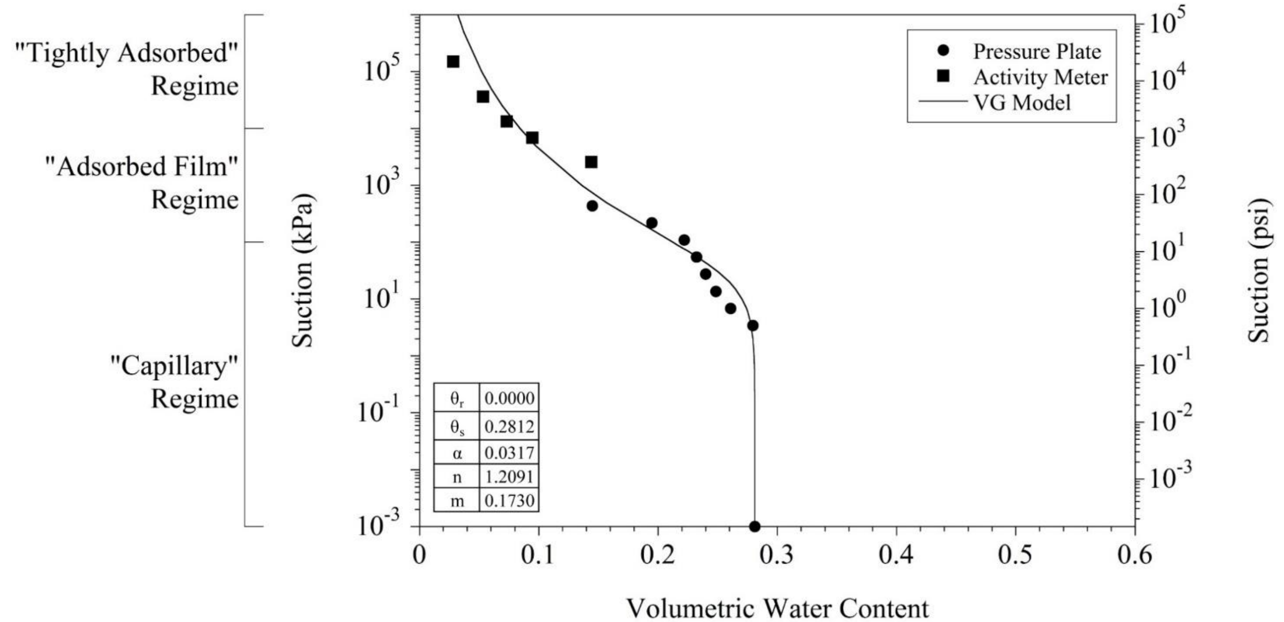
TASK 4

Pressure Plate and Activity Meter Test

- van Genuchten (1980) model

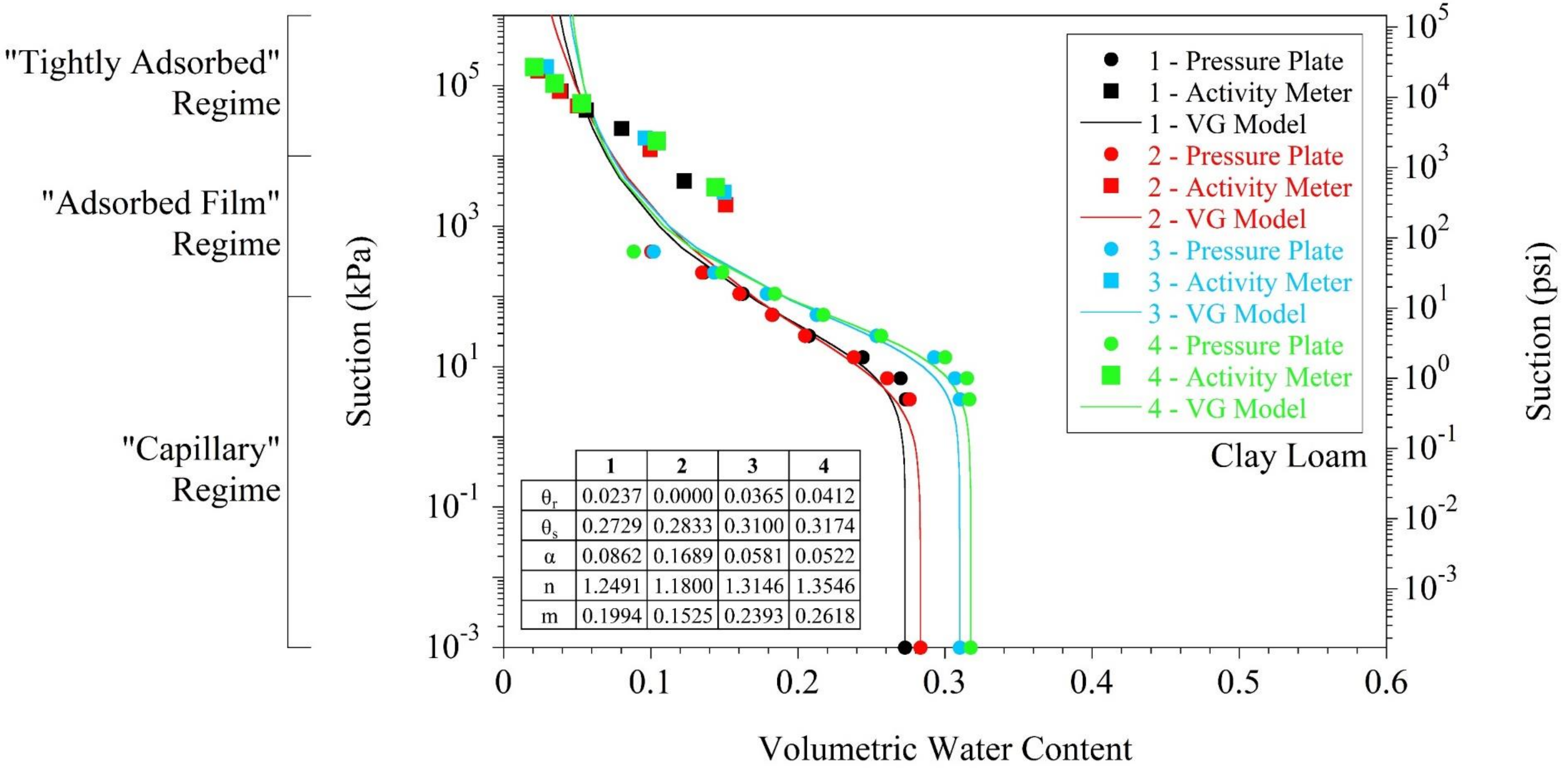
$$\Theta = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \left[\frac{1}{1 + (\alpha\psi)^n}\right]^m$$

Θ = Normalized volumetric water content
θ = Soil volumetric water content
θ_r = Residual volumetric water content
θ_s = Saturated volumetric water content
Ψ = Matric suction
α, n, and m = van Genuchten fitting parameters



TASK 4

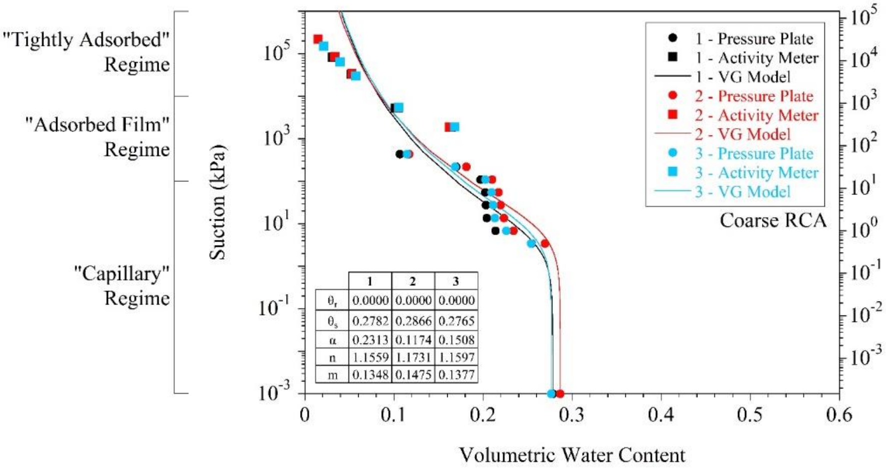
Pressure Plate and Activity Meter Test



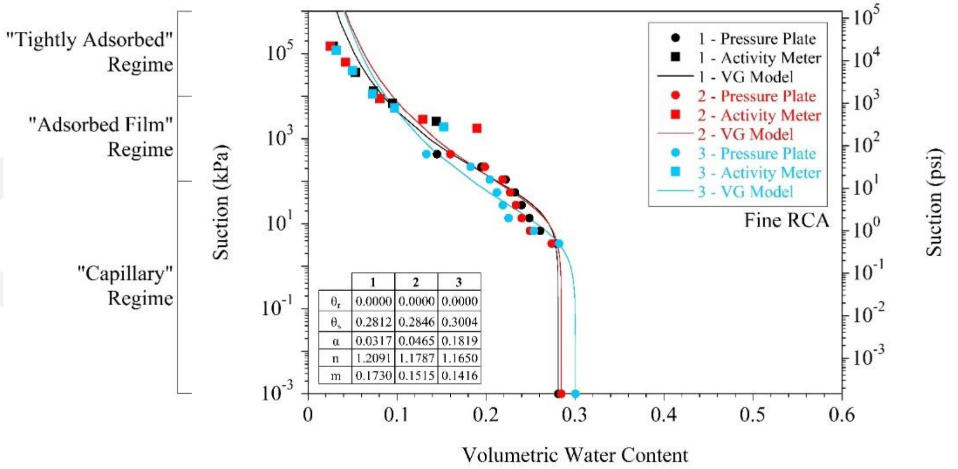
	1	2	3	4
θ_r	0.0237	0.0000	0.0365	0.0412
θ_s	0.2729	0.2833	0.3100	0.3174
α	0.0862	0.1689	0.0581	0.0522
n	1.2491	1.1800	1.3146	1.3546
m	0.1994	0.1525	0.2393	0.2618

TASK 4

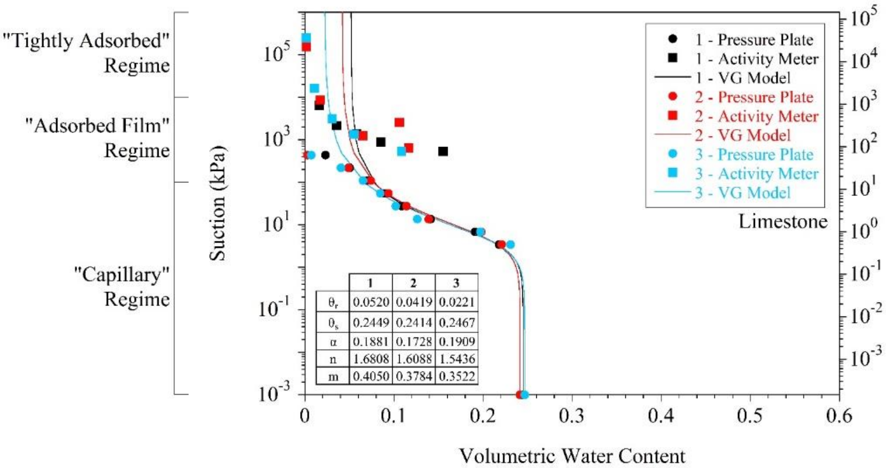
Pressure Plate and Activity Meter Test



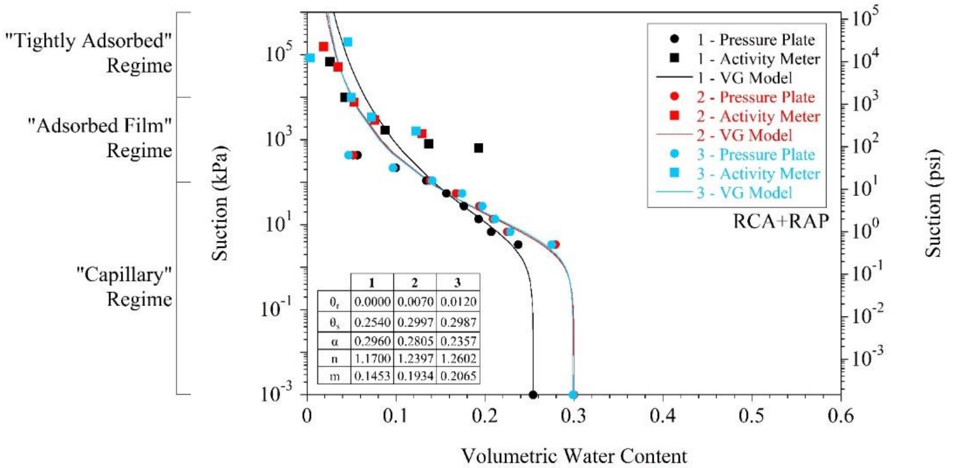
	1	2	3
θ_r	0.0000	0.0000	0.0000
θ_s	0.2782	0.2866	0.2765
α	0.2313	0.1174	0.1508
n	1.1559	1.1731	1.1597
m	0.1348	0.1475	0.1377



	1	2	3
θ_r	0.0000	0.0000	0.0000
θ_s	0.2812	0.2846	0.3004
α	0.0317	0.0465	0.1819
n	1.2091	1.1787	1.1650
m	0.1730	0.1515	0.1416



	1	2	3
θ_r	0.0520	0.0419	0.0221
θ_s	0.2449	0.2414	0.2467
α	0.1881	0.1728	0.1909
n	1.6808	1.6088	1.5436
m	0.4050	0.3784	0.3522

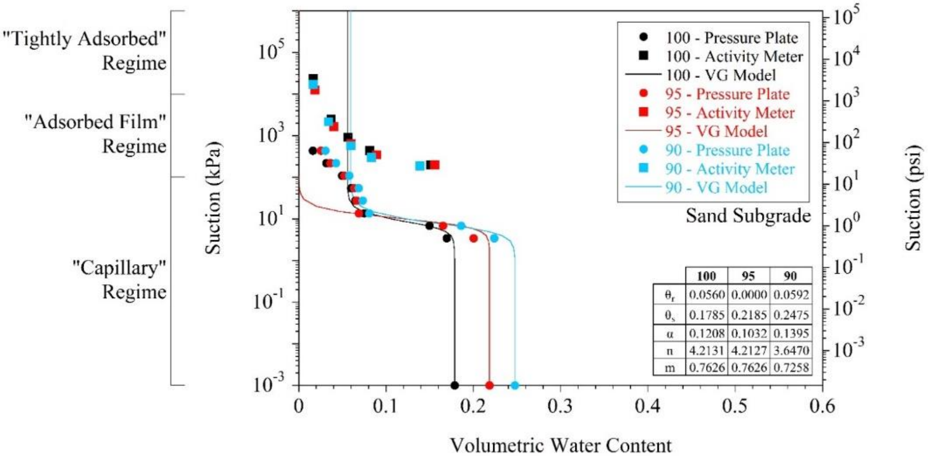


	1	2	3
θ_r	0.0000	0.0070	0.0120
θ_s	0.2540	0.2997	0.2987
α	0.2960	0.2805	0.2357
n	1.1700	1.2397	1.2602
m	0.1453	0.1934	0.2065

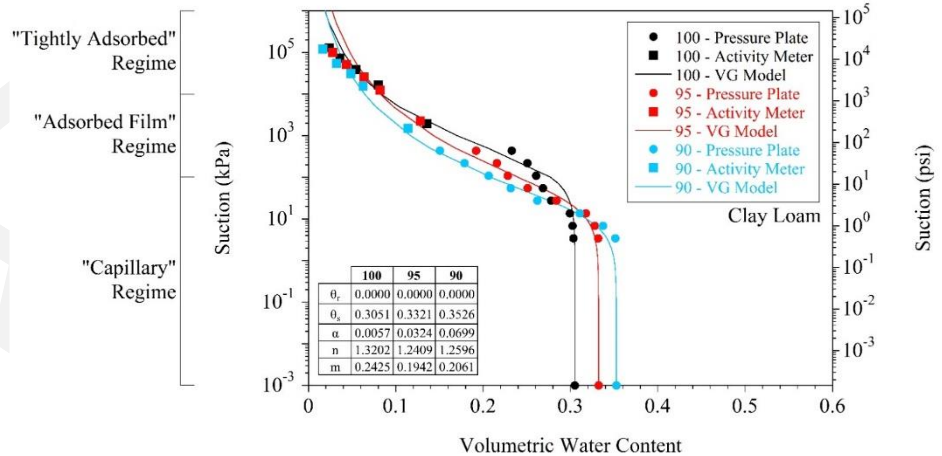
TASK 4

Pressure Plate and Activity Meter Test

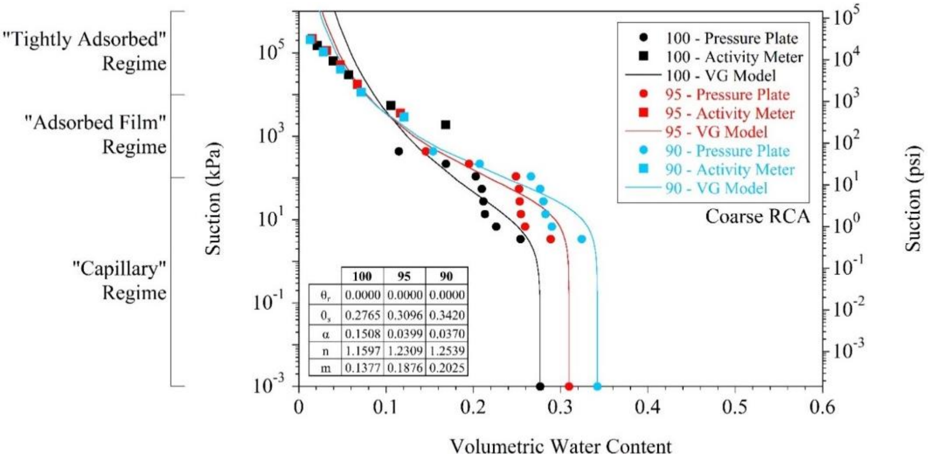
- Degree of compaction



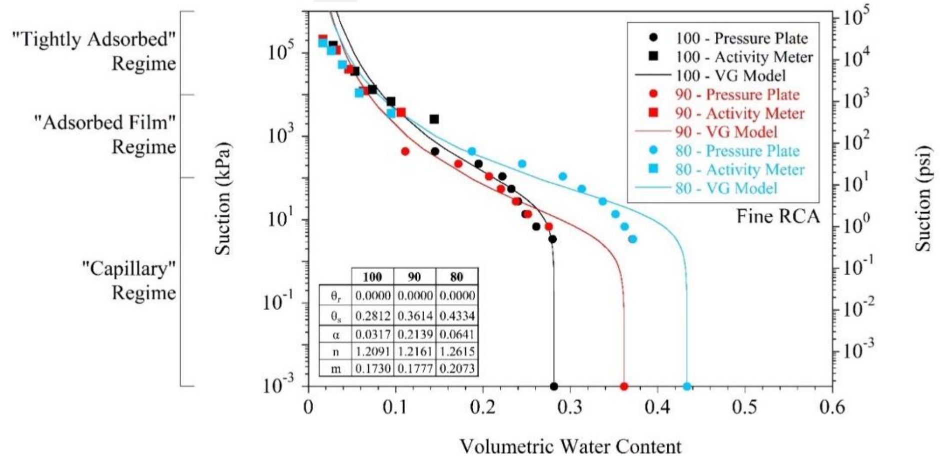
	100	95	90
θ_r	0.0560	0.0000	0.0592
θ_s	0.1785	0.2185	0.2475
α	0.1208	0.1032	0.1395
n	4.2131	4.2127	3.6470
m	0.7626	0.7626	0.7258



	100	95	90
θ_r	0.0000	0.0000	0.0000
θ_s	0.3051	0.3321	0.3526
α	0.0057	0.0324	0.0699
n	1.3202	1.2409	1.2596
m	0.2425	0.1942	0.2061



	100	95	90
θ_r	0.0000	0.0000	0.0000
θ_s	0.2765	0.3096	0.3420
α	0.1508	0.0399	0.0370
n	1.1597	1.2309	1.2539
m	0.1377	0.1876	0.2025

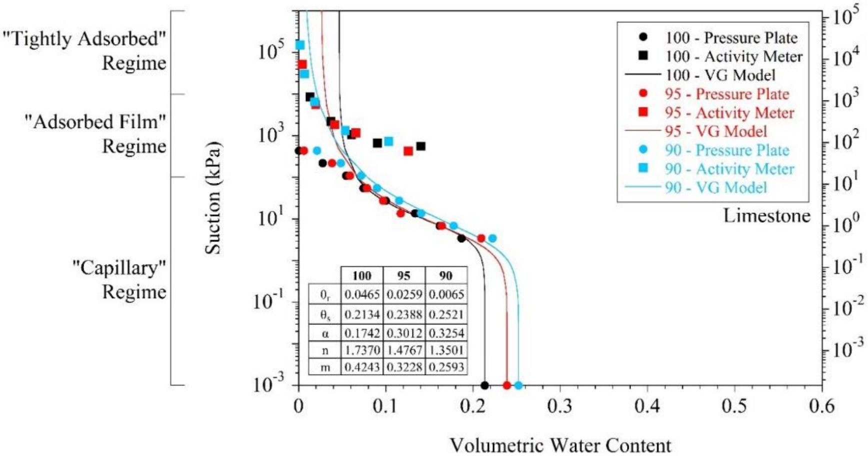


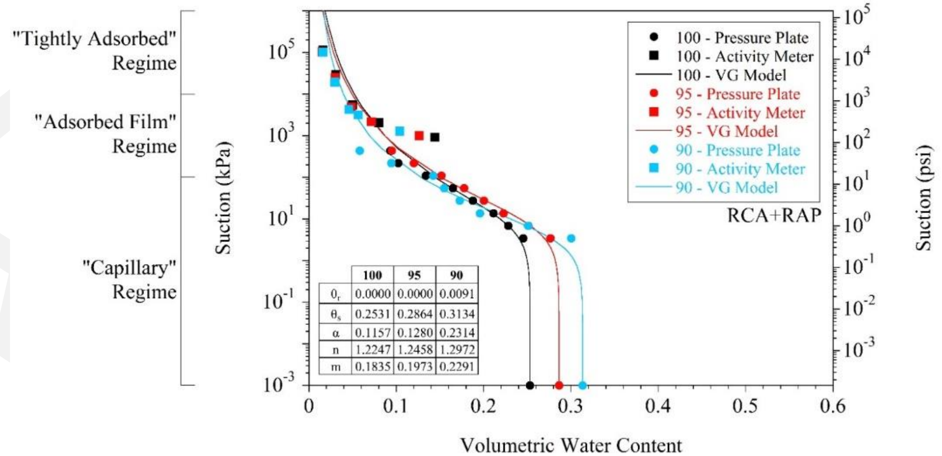
	100	90	80
θ_r	0.0000	0.0000	0.0000
θ_s	0.2812	0.3614	0.4334
α	0.0317	0.2139	0.0641
n	1.2091	1.2161	1.2615
m	0.1730	0.1777	0.2073

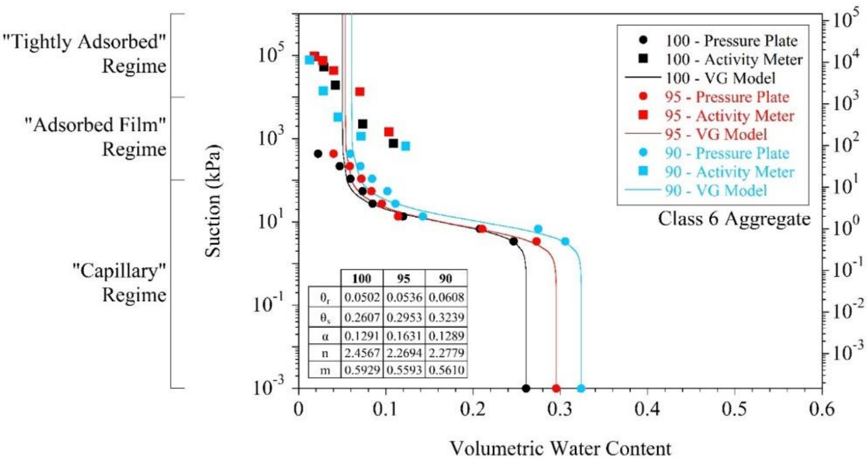
TASK 4

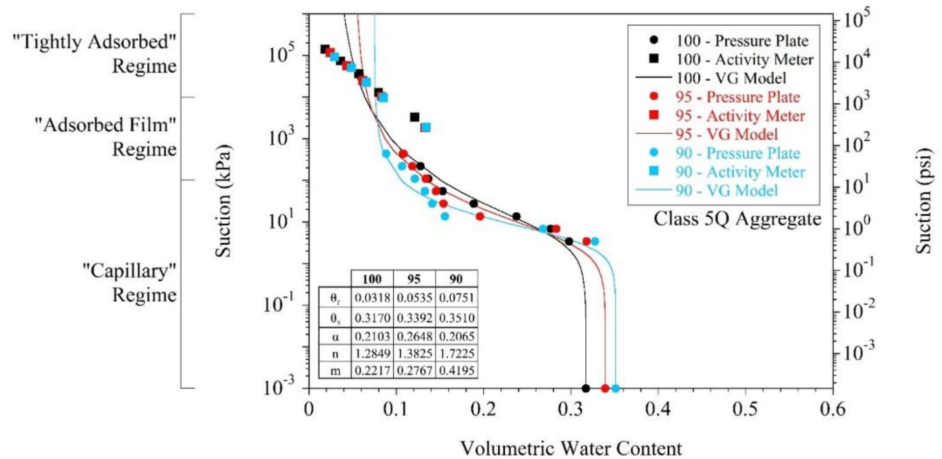
Pressure Plate and Activity Meter Test

- Degree of compaction









SUMMARY

- Particle morphology change due to compaction
  – Increase in sphericity
  – Increase in roundness
- Mortar content
  – Class 5Q aggregate > coarse RCA > fine RCA > class 6 aggregate > RCA+RAP > limestone
- Water repellency
  – Hydrophilic ➔ coarse RCA, fine RCA, limestone, class 5Q aggregate
  – Hydrophobic ➔ RCA+RAP & class 6 aggregate
- Constant head permeability
  – Insufficient compaction by light hammering in the membrane
  – Fine RCA > limestone, class 6 aggregate, & class 5Q aggregate > coarse RCA & RCA+RAP

SUMMARY

- Falling head permeability
  - Coarse RCA, fine RCA, & RCA+RAP > limestone
- Falling head permeability – different DOC
  - DOC ↓ permeability ↑
  - Fine RCA > coarse RCA
- Hanging column test (for SWCC)
  - Lower suctions
  - Not suitable for RCA - cementation
- Pressure plate and activity meter test (for SWCC)
  - Higher suctions
  - DOC ↓ initial VWC ↑

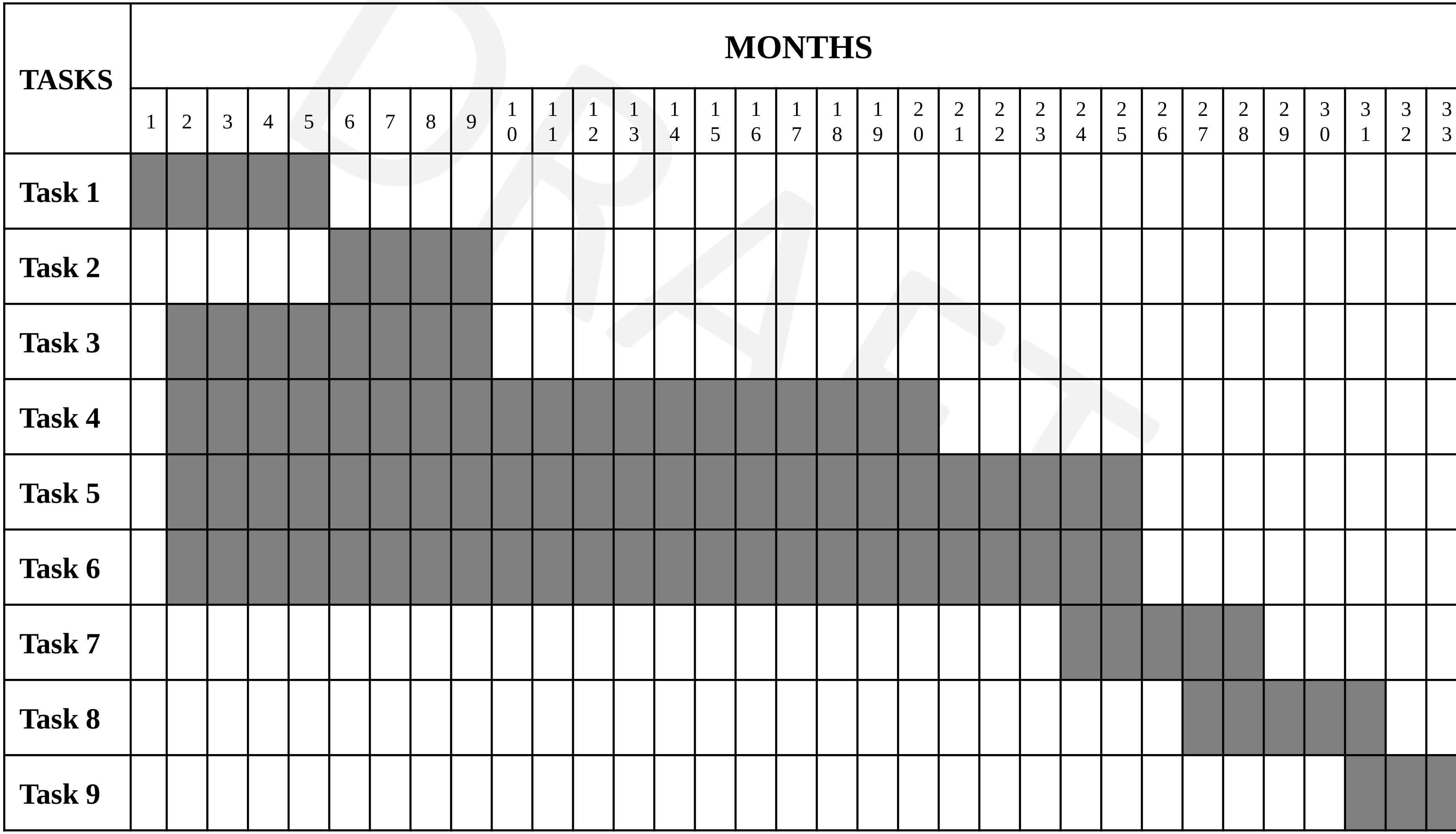
DISCUSSION

- Coarse RCA & class 5Q aggregate may performance problems
  - Higher breakage potential
  - Higher total breakage
  - Decrease in permeability
  - High potential for tufa formation
- RCA materials likely attract more water
  - Mortar content
  - Higher water absorption
  - Hydrophilicity
  - Decrease in F-T resistance

FUTURE STUDY

- Task 5 – Performance monitoring and reporting
- Task 6 – Instrumentation

SCHEDULE


TASKS
MONTHS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33
Task 1
Task 2
Task 3
Task 4
Task 5
Task 6
Task 7
Task 8
Task 9

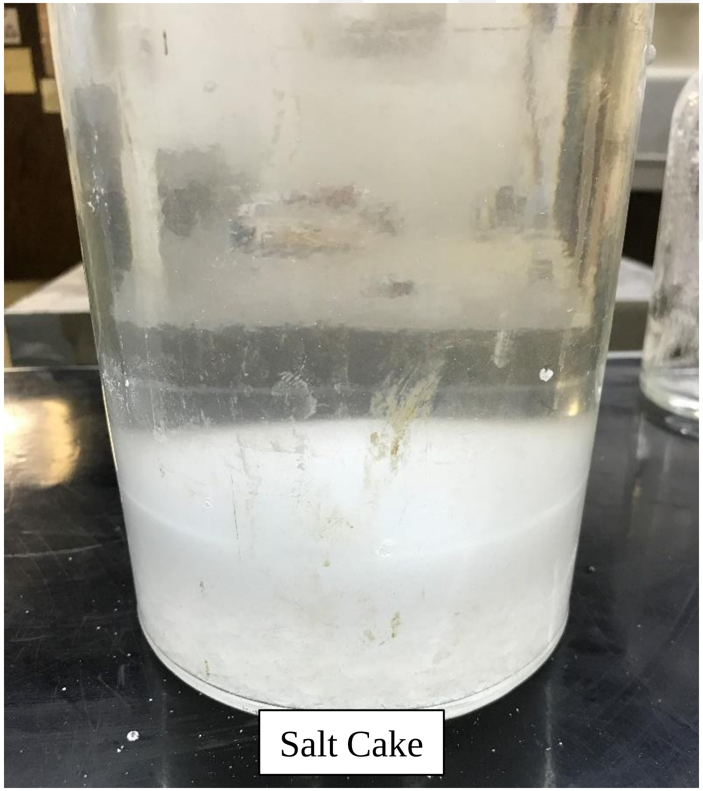
Thank You!

QUESTIONS??

TASK 4

Mortar Content

- 26 % (by weight) sodium sulphate solution
  - Saturated solution



Salt Cake

Salt Formation