Evaluation of Subbase Compaction using the Superpave Gyratory Compactor

Craig Kumpel
Wing Ma
Stephen Rossi
Colin Yurick

Dr. Beena Sukumaran

FAA Working Group Meeting, April 16, 2013

Rowan University

Outline

- Background and Objectives
- P-154 Test Results
- P-209 Test Results
- Correlation of lab results with field data
- Conclusions

Background

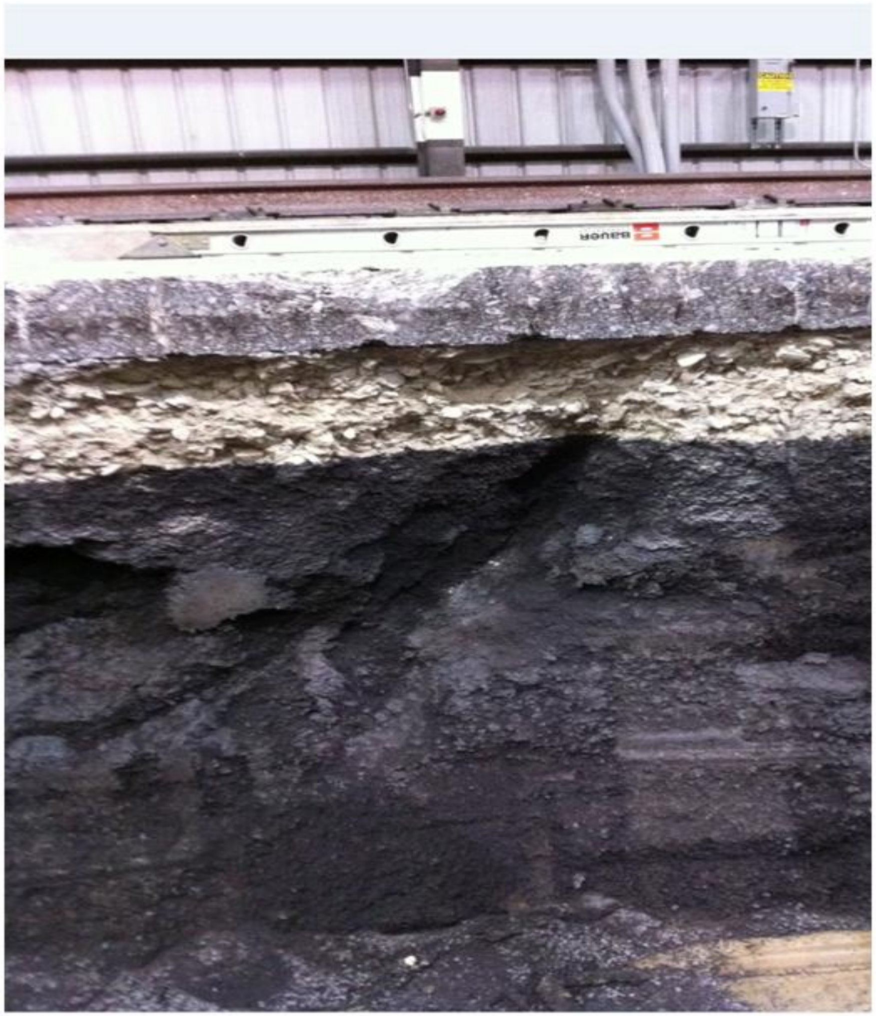
- Continuous loading from airplane landing gear creates ruts in pavement
- Bigger and heavier planes make rut prevention more difficult
- FAA believes rutting is caused by densification of subbase

NAPTF – Rutting Behavior

North wheel track of CC3 flexible pavements at 19,500 passes

Garg and Hayhoe (2006)

CC5 Trench Cross Section



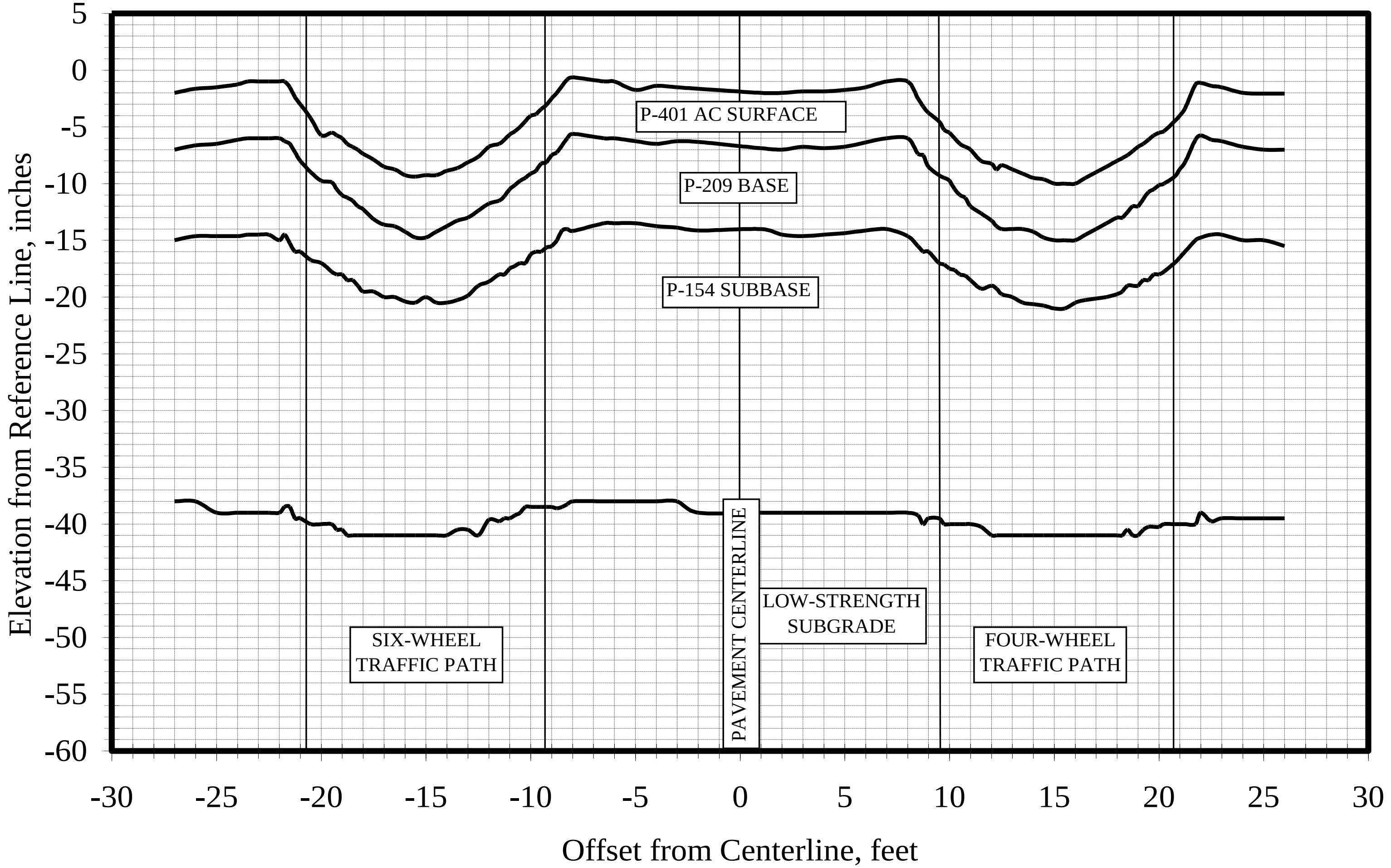
5” Asphalt

8” P-209
Base

34-38”
P-154 or DGA
Subbase

Dupont Clay
Subgrade

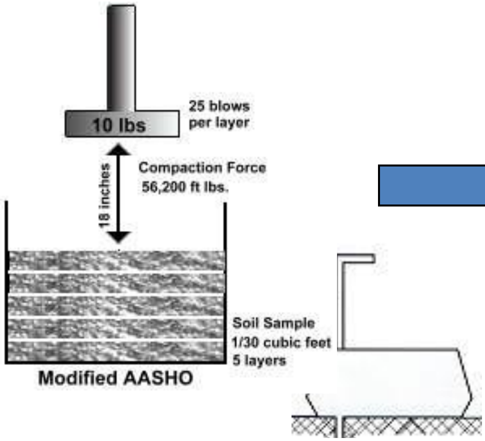
Field Compaction

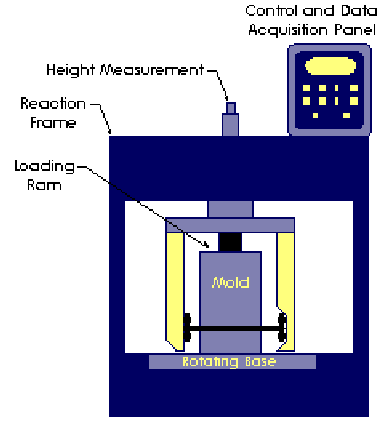


Interface profile measurements in the LFC2 trafficked trench

Garg and Hayhoe (2006)

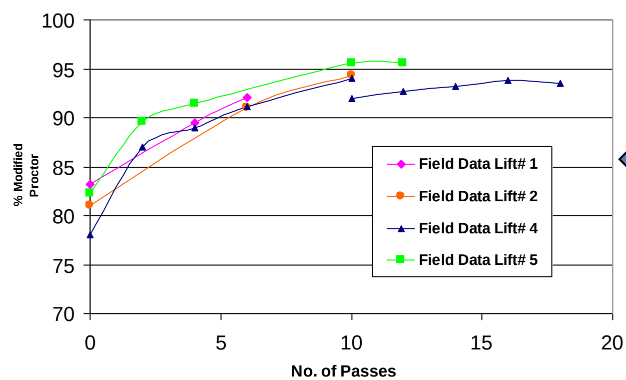
Research Approach



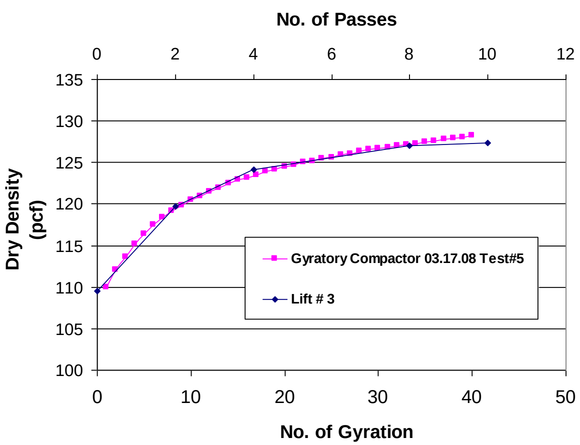


SGC

Nuclear Density Gauge



Field Compaction



Compare Compaction Curves

Rowan University

Objectives

- Determine change in performance metrics of aggregate when subjected to trafficking/gyrations in the SGC
- Determine the mechanism causing compaction of the aggregate during trafficking
- Find a correlation between event number in the SGC and event number during construction compaction

Gyratory Compactor

Variables

- Angle
- Pressure
- # of Gyrations

Rowan University

Gyratory Compactor and Soil Parameters

- Angle Used: 1.25°

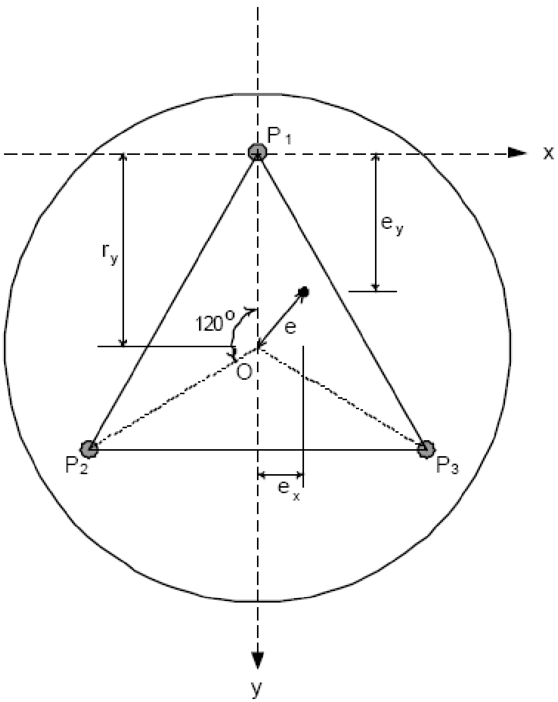
- Pressure Used: 600, 800 and 1000 kPa

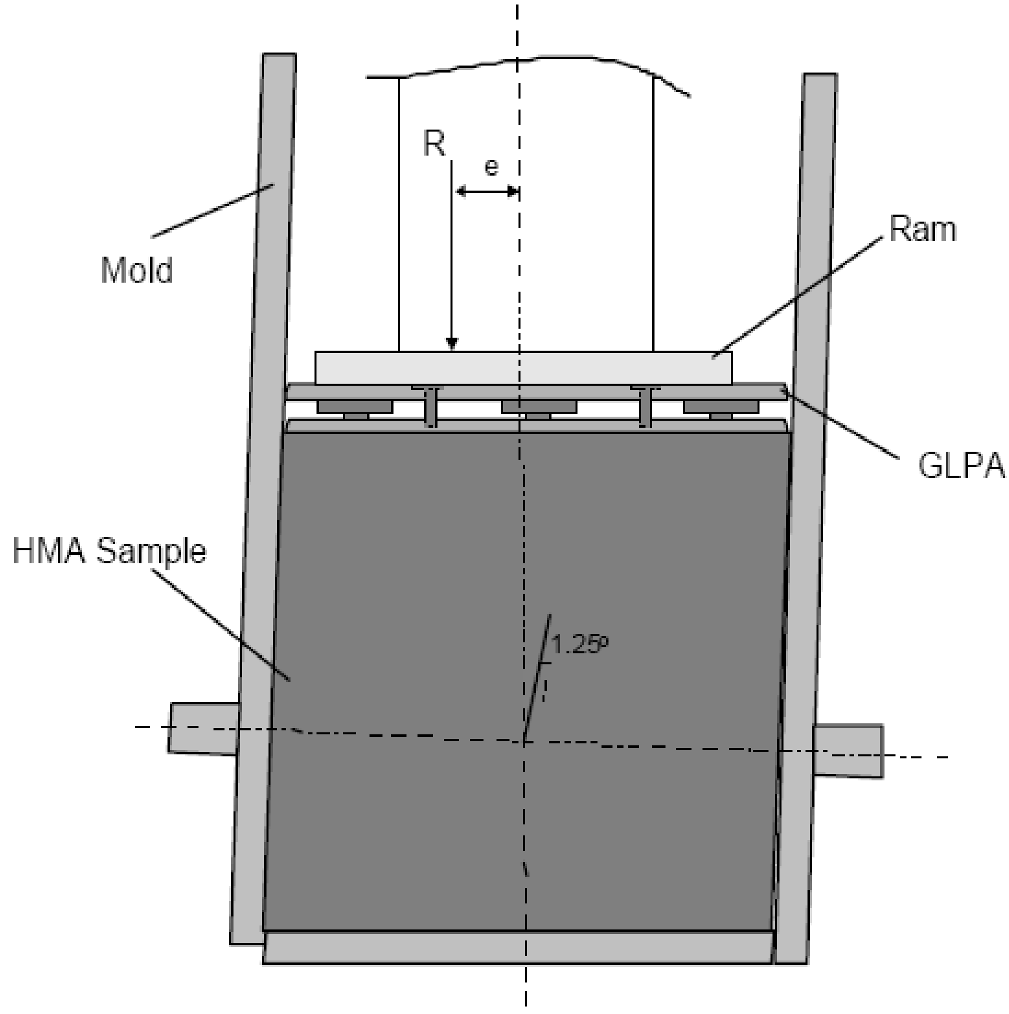
- # of Gyrations: 800

- Water Content Ranges: 1-1.5%, 1.5-2%, 2-2.5%, 2.5-3%, 3-3.5%, 3.5-4%, 4-5%, 5-6%

- Sample Size: 3000 and 5000 grams

Compaction Energy





Mahmoud (2004)

Rowan University

Vertical Work

$$w_v = PA\Delta h$$

w_v = vertical work (in-lb)

P = Pressure (600 kPa ~ 87 psi)

A = Cross Sectional Area (28.27 in^2)

Δh = change in height of sample (in)

Mahmoud (2004)

Shear Work

$$w = \frac{4Pe\theta}{Ah}$$

w = shear work (in-lb)
P = magnitude of the resultant force
A = Cross Sectional Area (28.27 in^2)
h = height of the specimen at any given gyration (in)
e = eccentricity of resultant force
θ = angle of tilt (1.25°)

Mahmoud (2004)

Performance Characteristics

- Several tests used to analyze engineering properties of aggregate:
  - Sieve Analysis
    - ASTM C117
  - Flat and Elongated
    - ASTM D4791
  - Modified Proctor
    - ASTM D1557
  - Shape and Image Analysis

Shape Analysis

- Shape Factor
  - Deviation from spherical shape
  - Sphere: 0%, Flat Plate: 100%
- Angularity Factor
  - Number and sharpness of corners
  - Sphere: 0%, Star: 100%

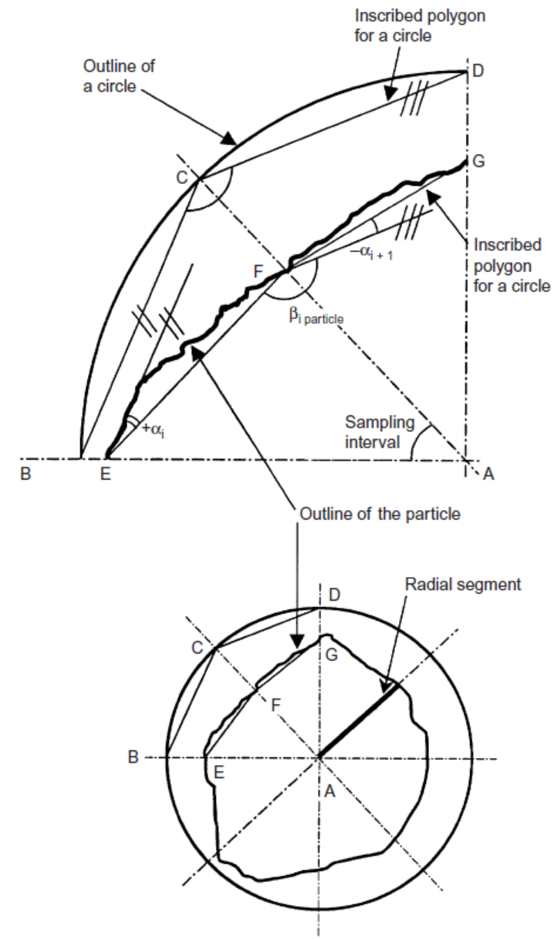


Fig. 2. Ideal geometric shapes used to verify shape and angularity factors

Shape Extreme Values

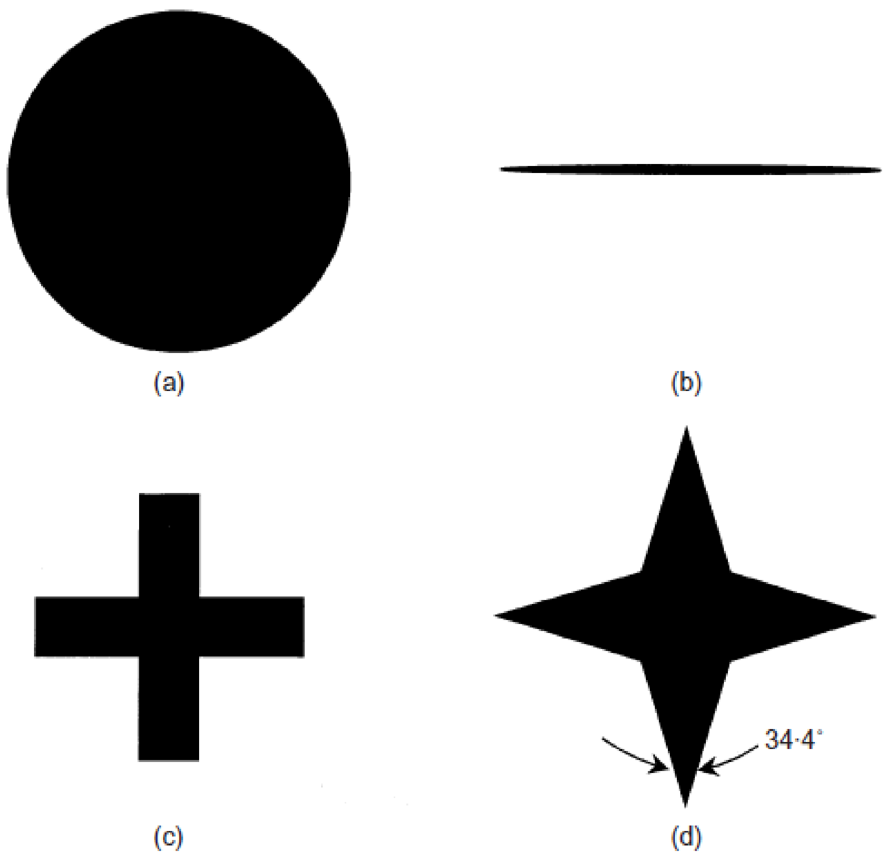
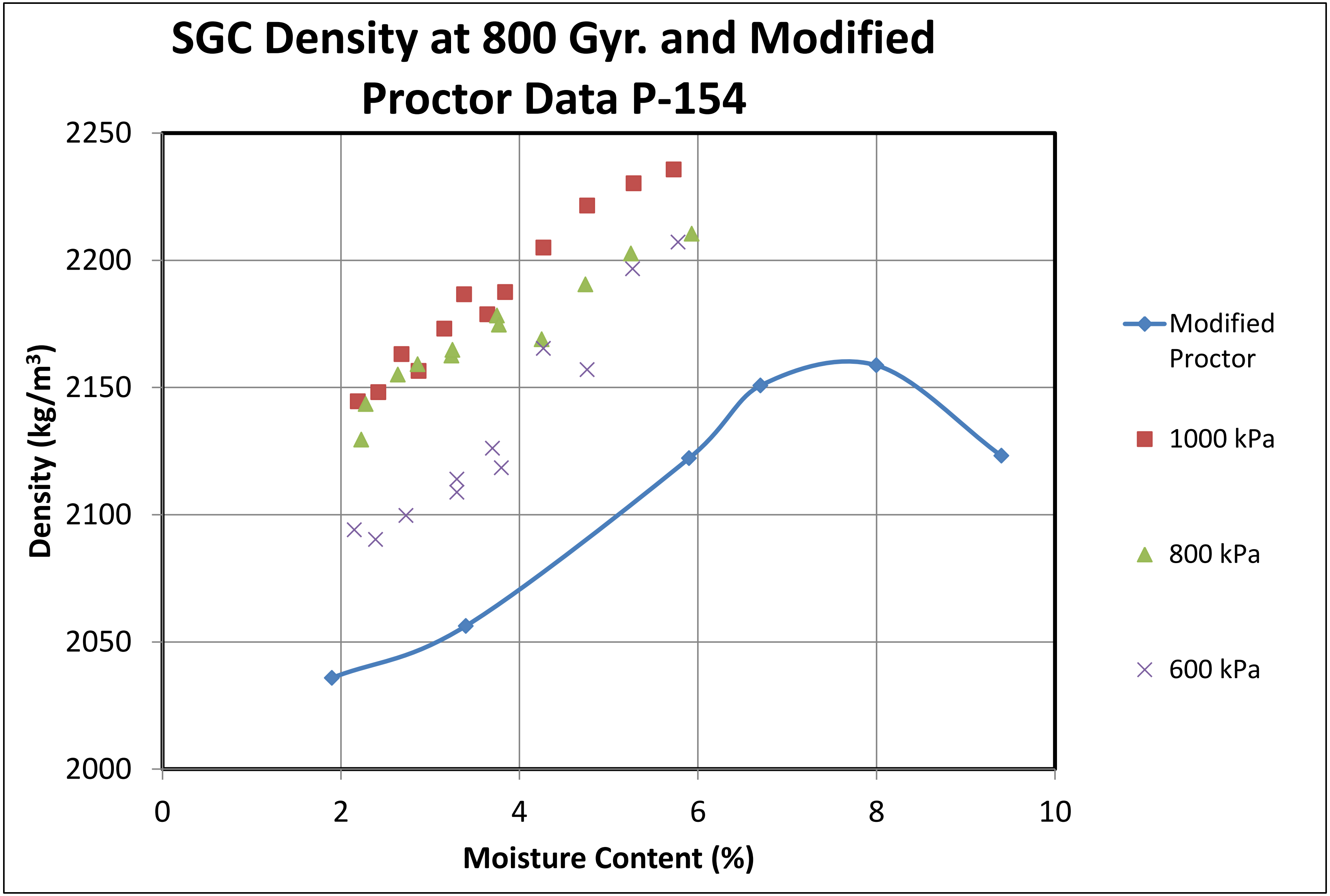


Fig. 4. Reference shapes: (a) circle, SF = AF = 0; (b) flat particle, SF = 100%; (c) cross, AF = 100%; (d) four-pointed star, AF = 100%

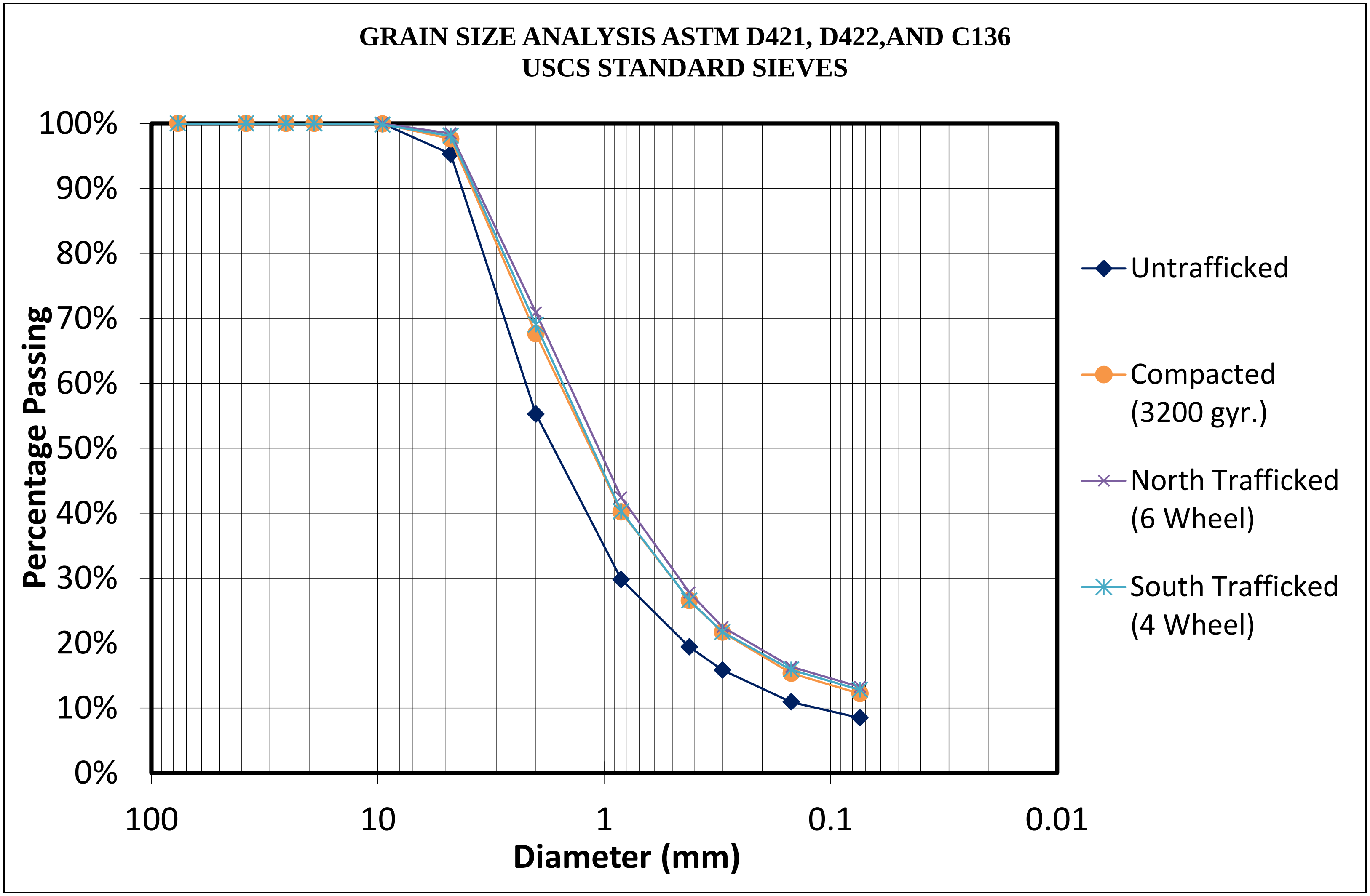
SGC vs. Proctor Tests

- Energy input from Proctor tests come from impact hammer (all vertical work)
- SGC can achieve higher densities than the impact hammer alone
- Energy input from the SGC comes from:
  - Vertical load applied
  - Shearing caused by the gyratory movement
  - Energy input more efficient at achieving similar densities

P-154


SGC Density at 800 Gyr. and Modified Proctor Data P-154
Density (kg/m³)
2250
2200
2150
2100
2050
2000
0
2
4
6
8
10
Moisture Content (%)
Modified Proctor
1000 kPa
800 kPa
600 kPa

P-154 Grain Size Distribution Analysis



Rowan University

P-154 Imaging Results

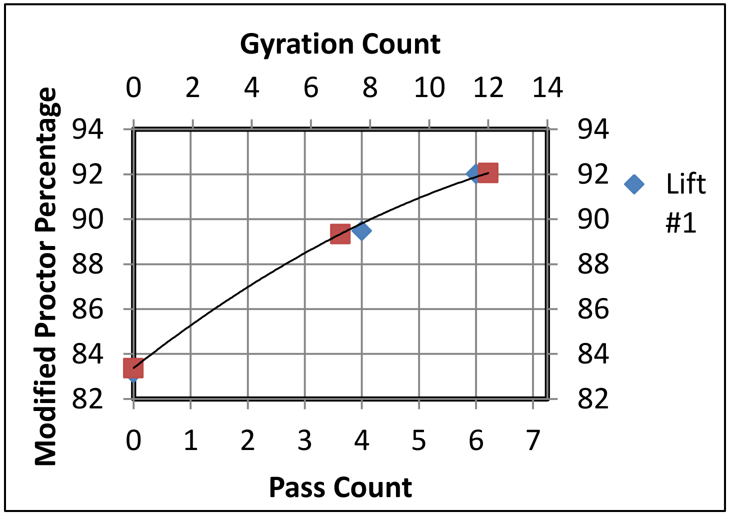
Shape Factor

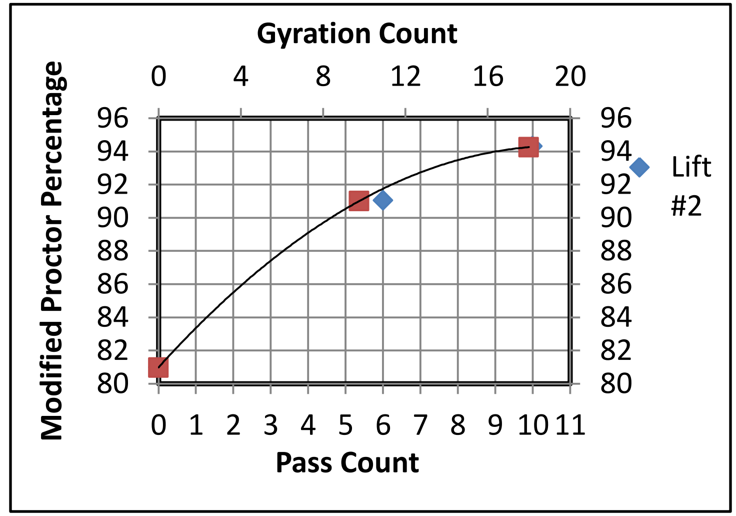
	Untrafficked	Compacted	North Trafficked	South Trafficked
Average Shape Factor	76.93	74.68	68.99	67.34
Standard Deviation	19.38	23.77	19.61	15.84

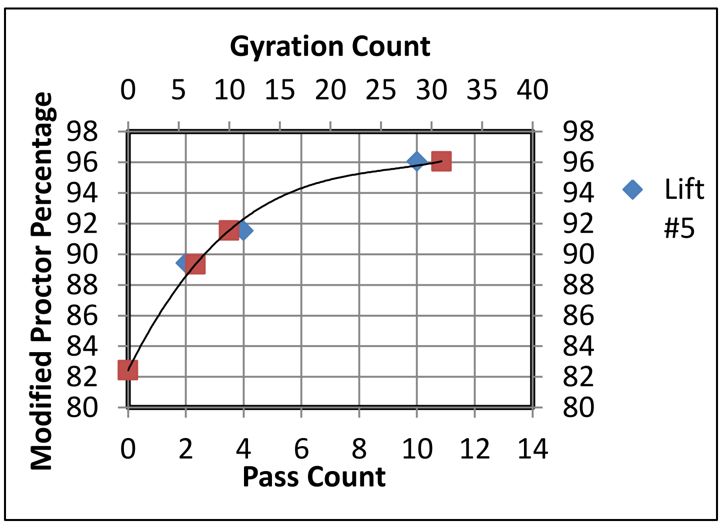
Angularity Factor

	Untrafficked	Compacted	North Trafficked	South Trafficked
Average Angularity Factor	13.97	11.34	10.32	11.64
Standard Deviation	4.75	4.37	3.84	5.03

P-154 Correlation Between SGC at 800 kPa and Construction Event Number



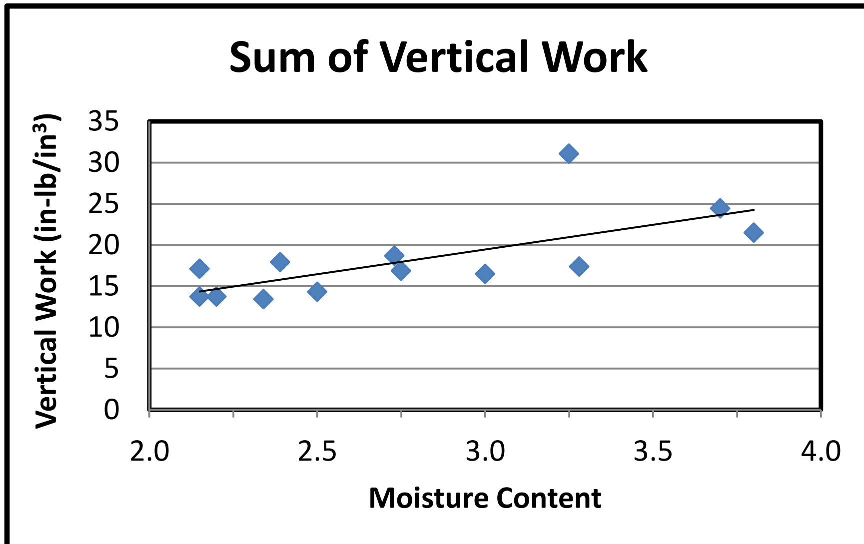


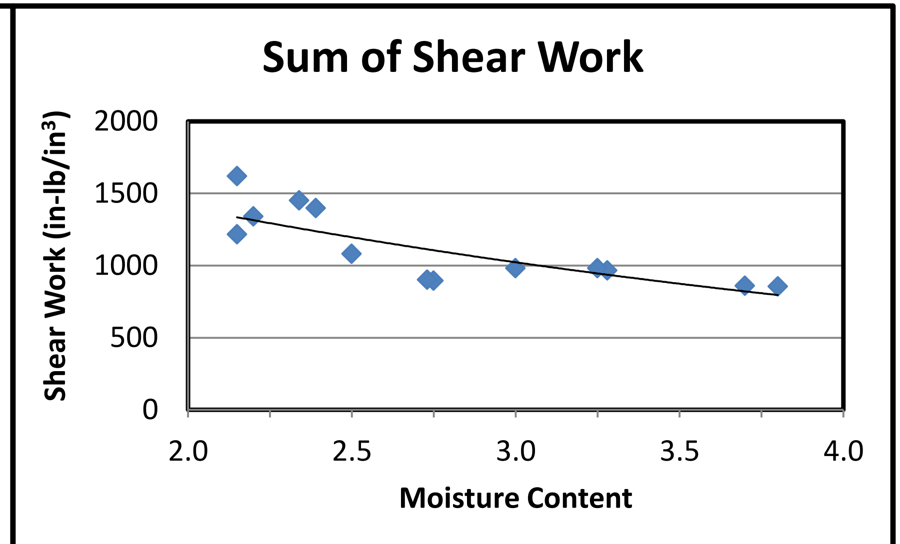


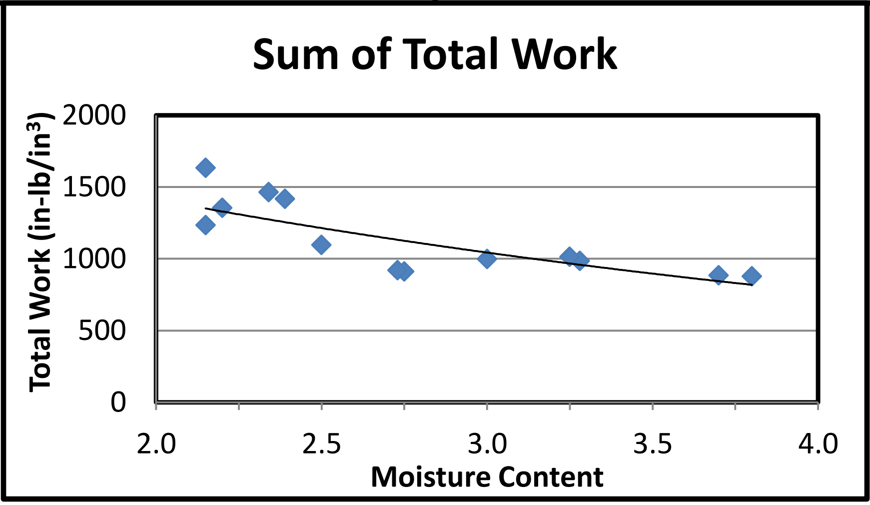
Lift #1	Mix of Static and Low Vibration Drum Roller
Lift #2	Mix of Static and Low/High Vibration Drum Roller
Lift #5	Low & High Vibration Drum + Rubber tire with weight

Rowan University

P-154 Energy Results







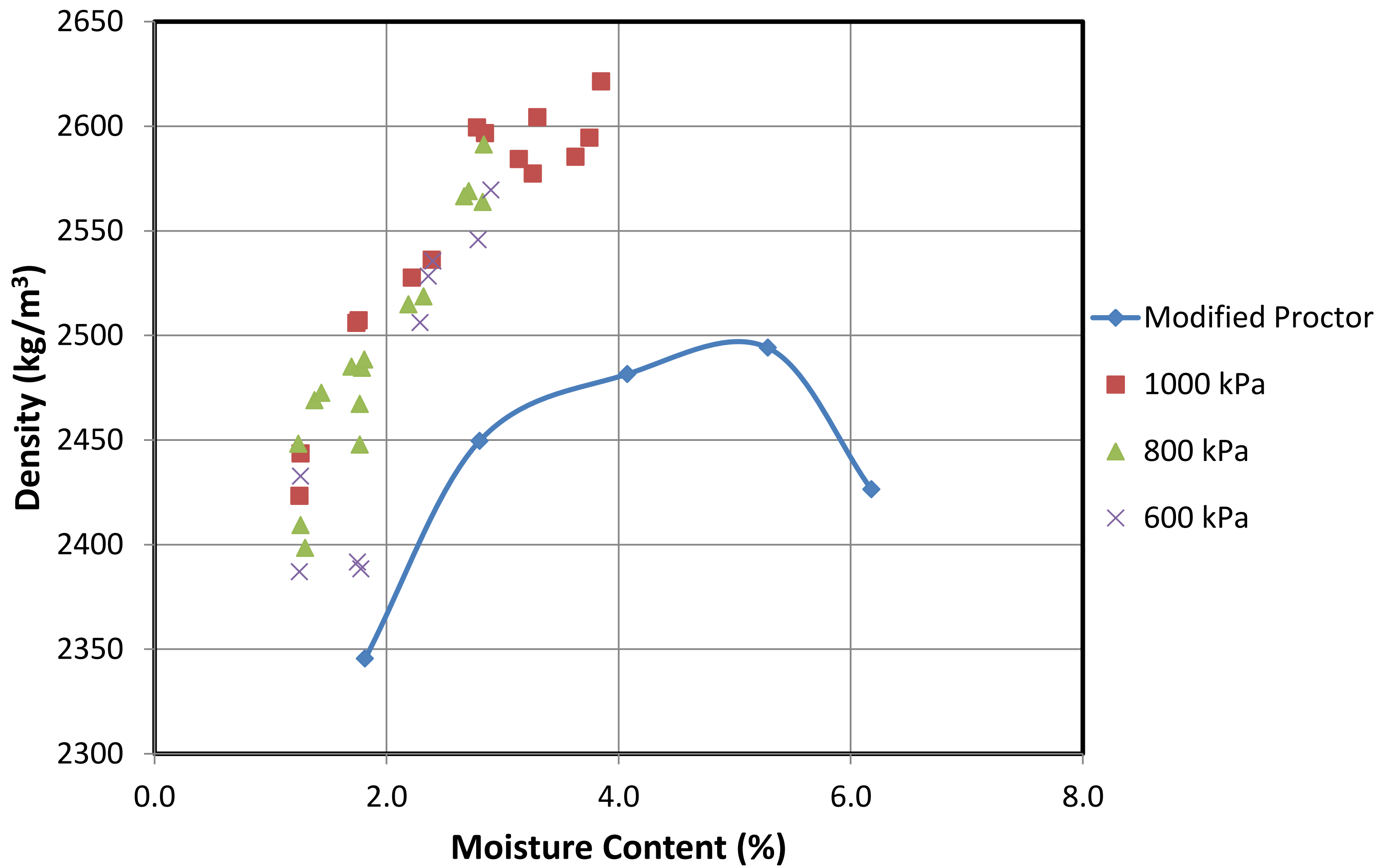
Comparison of Modified Proctor to SGC Results

	P-154											
Pressure (kPa)	1000	800	600	1000	800	600	1000	800	600	1000	800	600
Average Moisture (%)	2-2.5	2-2.5	2-2.5	2.5-3	2.5-3	2.5-3	3-3.5	3-3.5	3-3.5	3.5-4	3.5-4	3.5-4
No. of Tests	2	2	2	2	2	2	2	2	2	2	2	2
% Max Mod. Proctor	**Average Number of Gyrations**											
80 - 85%	2	2	4	2	3	4	2	4	6	3	4	6
85 - 90%	8	7	17	8	11	19	8	11	19	9	10	18
90 - 95%	39	43	131	32	44	123	30	42	107	33	37	93
95 - 100%	433	438	517	397	436	508	249	396	493	242	283	480

Rowan University

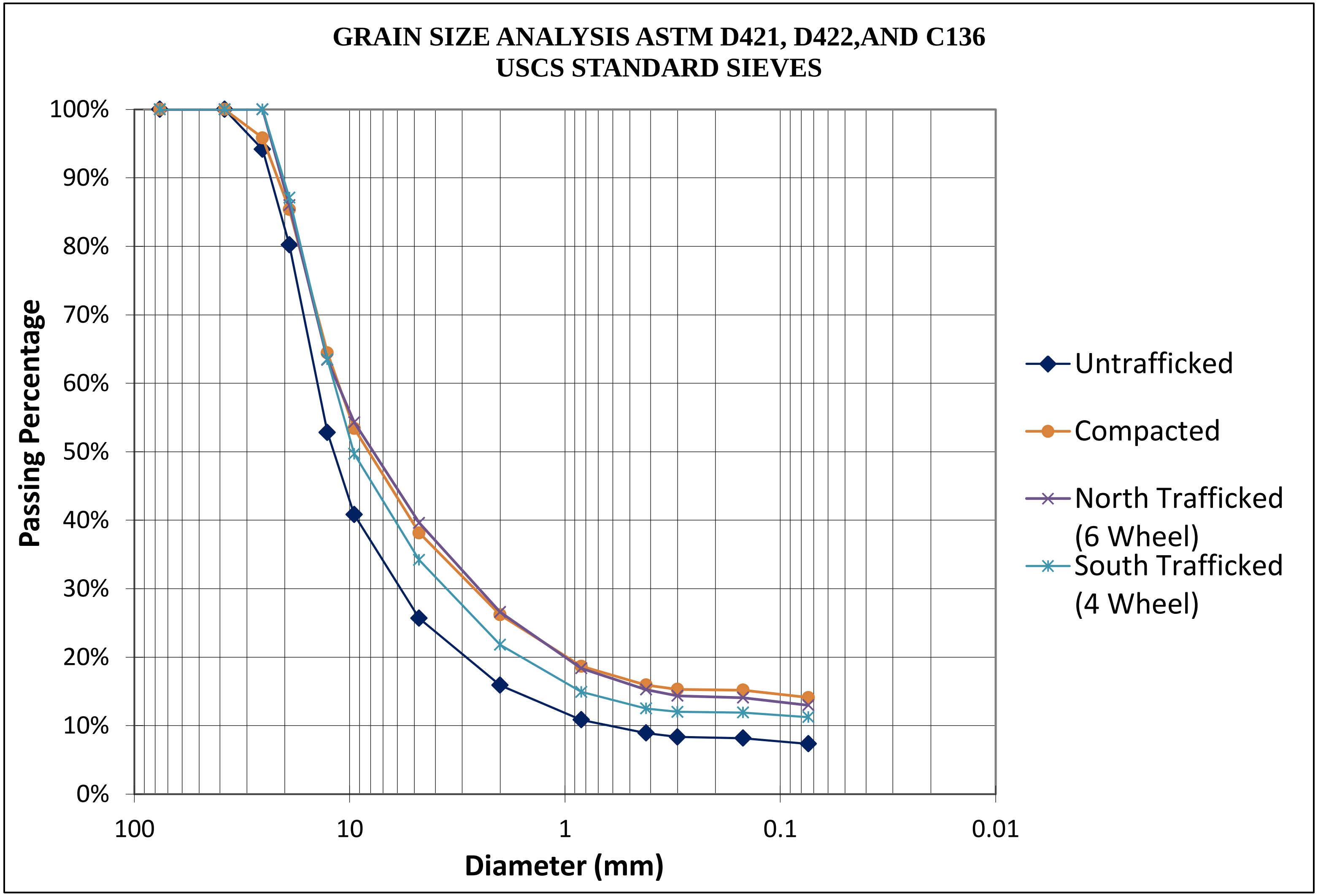
P-209

SGC Density at 800 gyr. and Modified Proctor Data P-209



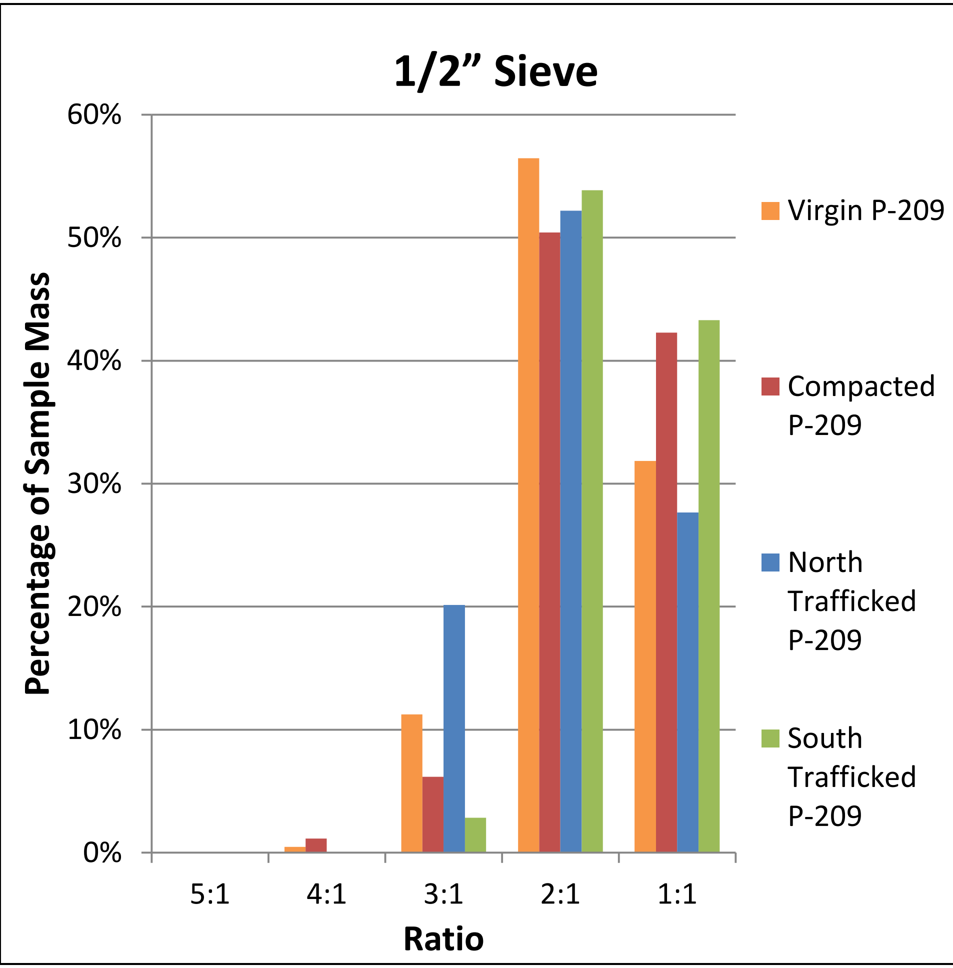
Rowan University

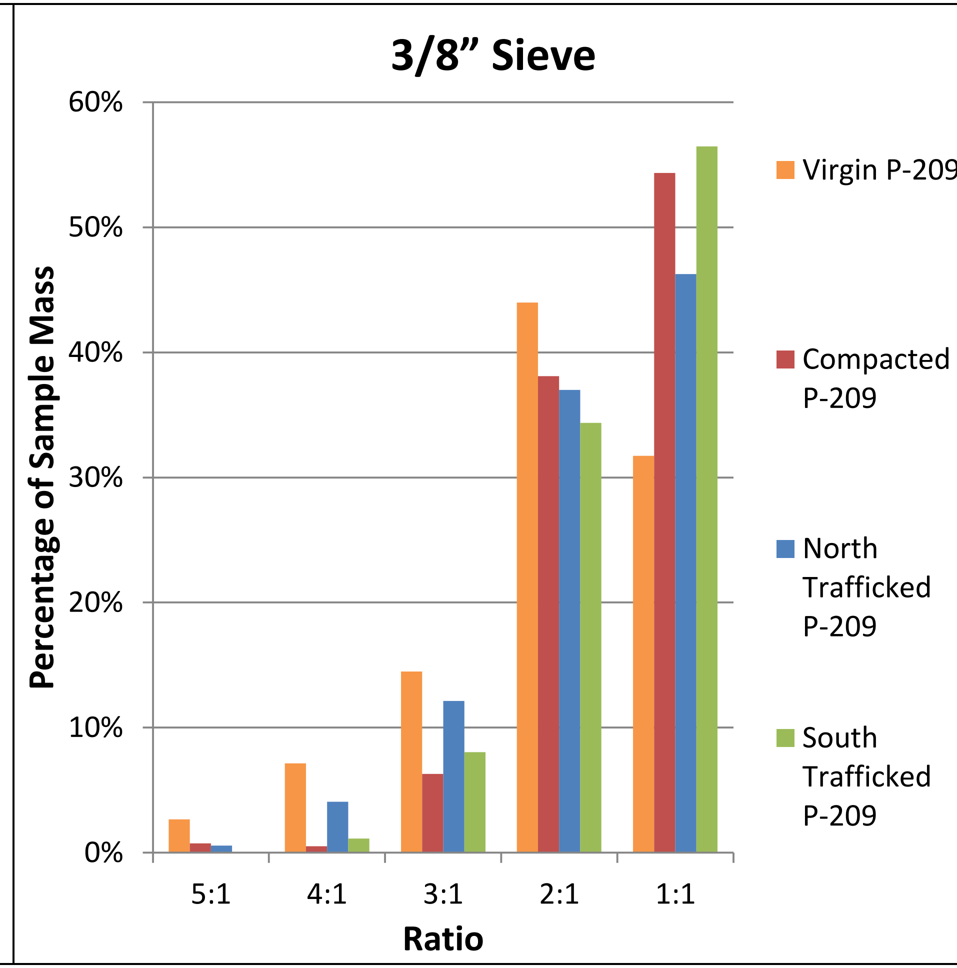
P-209 Grain Size Distribution Analysis



Rowan University

P-209 Flat and Elongated Test Results





Rowan University

P-209 Imaging Results

Shape Factor

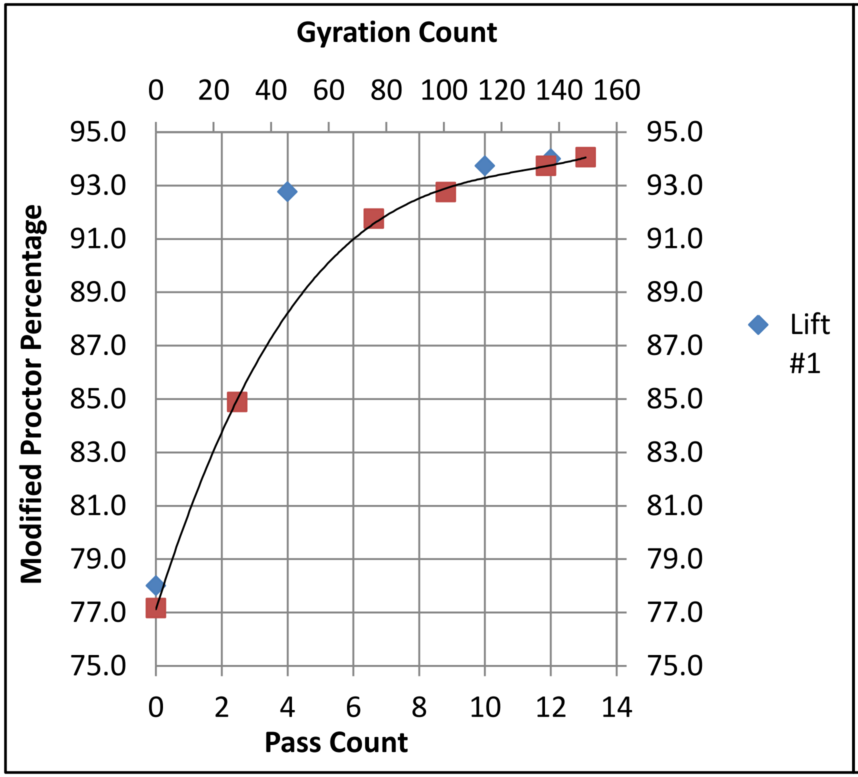
	Untrafficked	Compacted	North Trafficked	South Trafficked
Average Shape Factor	76.77	85.86	76.25	82.68
Standard Deviation	18.32	26.05	23.05	21.50

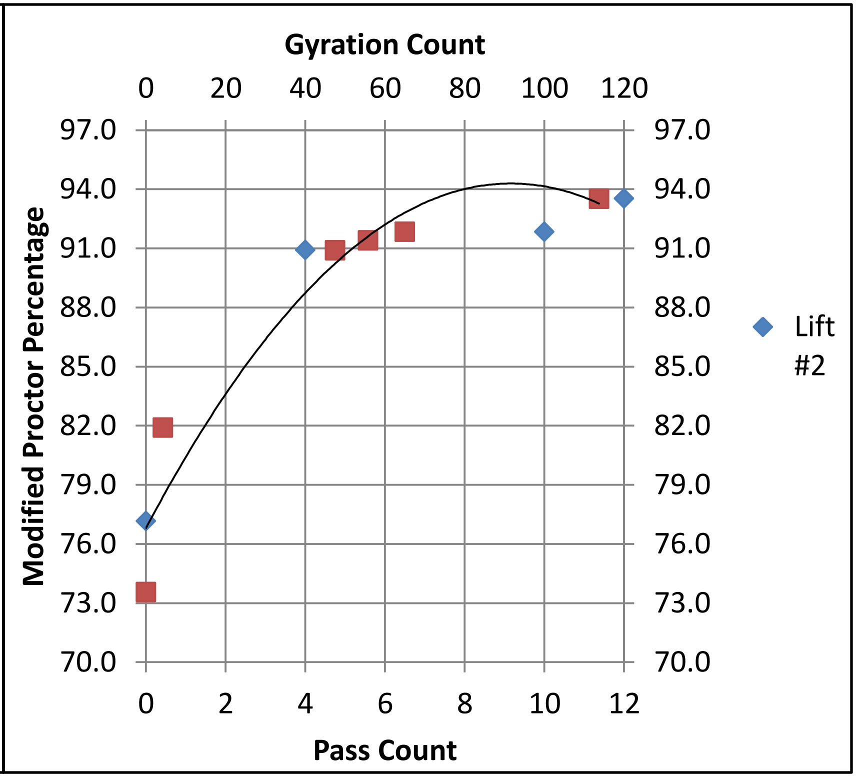
Angularity Factor

	Untrafficked	Compacted	North Trafficked	South Trafficked
Average Angularity Factor	17.29	15.17	15.78	15.37
Standard Deviation	5.61	7.09	5.73	3.80

Rowan University

P-209 SGC Density at 800 kPa and Construction Density Comparison

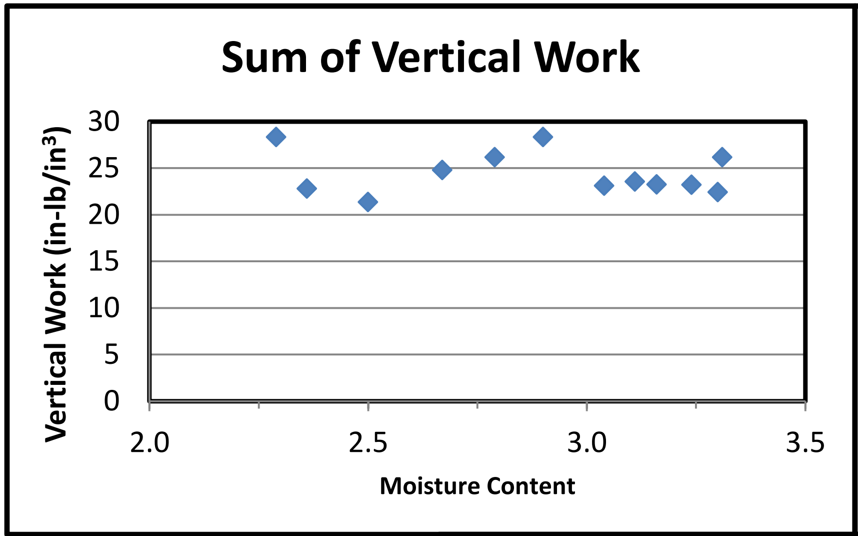


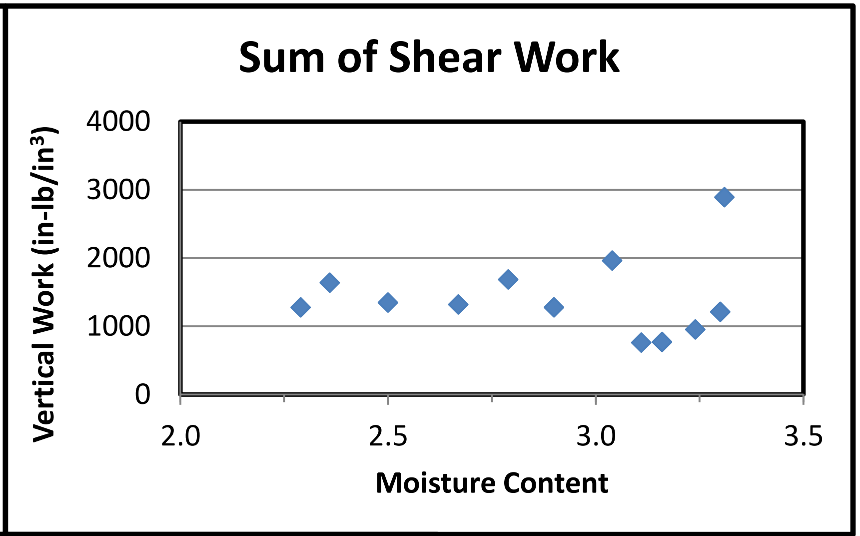


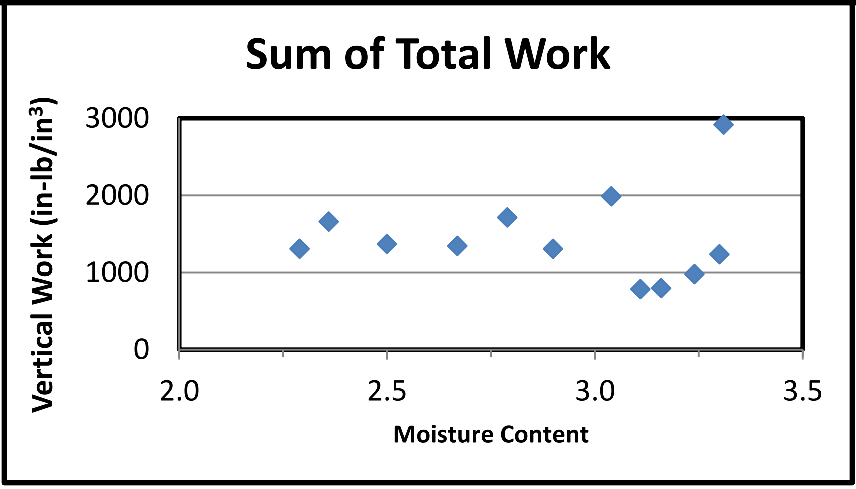
Lift #1 Combination of vibratory roller and rubber tire
Lift #2 Combination of vibratory roller and rubber tire

Rowan University

P-209 Energy Results





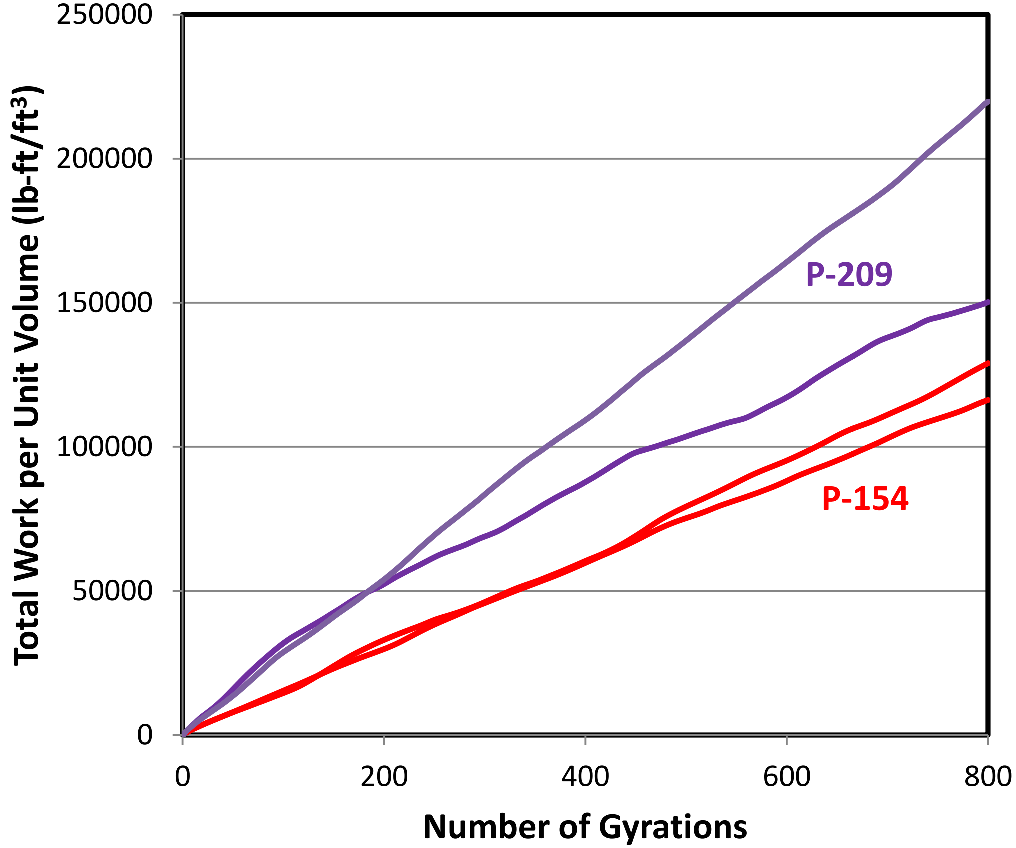


Rowan University

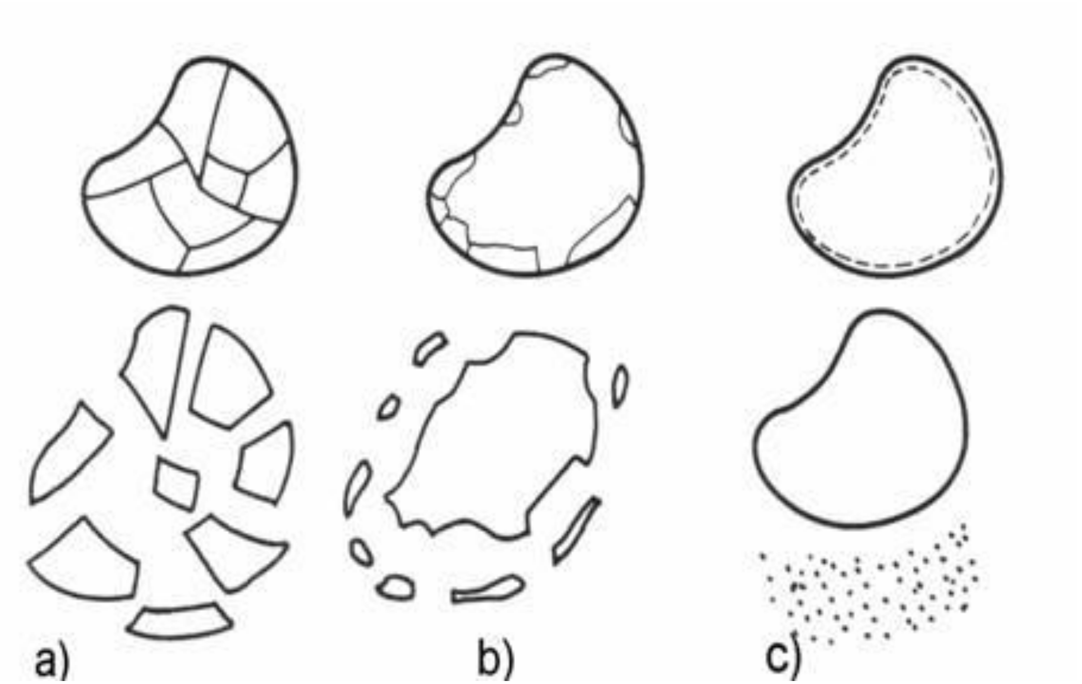
Modified Proctor to SGC Comparison

Percent Modified Proctor vs Gyration for P-209						
Pressure (kPa)	**1000**	**800**	**600**	**1000**	**800**	**600**
Moisture (%)	**2.0 - 2.5**	**2.0 - 2.5**	**2.0-2.5**	**2.5-3.0**	**2.5-3.0**	**2.5-3.0**
No. of Tests	2	3	3	2	3	3
% Mod. Proctor	Average Number of Gyrations					
80 - 85%	13	8	8	5	6	7
85 - 90%	35	24	24	13	18	20
90 - 95%	95	84	83	40	61	68
95 - 100%	300	326	343	137	216	259
100 - 105%	630	660	678	507	570	607

Material Energy Comparison



Mechanism of Crushing



Different modes of grain breakage: a) fracture, b) attrition and c) abrasion. (Ramamurthy et al., 1974)

Hypothesis of Mechanism of Compaction

- Aggregate is undergoing some fracture but more abrasion and attrition
  - Resulting in less angular aggregate as trafficking progresses
  - Reduces aggregate interlock enabling higher compaction density to be achieved

Conclusions

- SGC is capable of replicating field compaction results
  - Capable of achieving much higher densities than the Modified Proctor test
  - SGC density results follow the same trend as the Modified Proctor test
  - SGC reaches construction densities at relatively low gyration counts
- Compaction mechanism for trafficking is attrition and abrasion
  - Reduces angularity and interlock
  - SGC follows same mechanism of compaction as trafficking
  - SGC was able to produce a similar amount of aggregate crushing in comparison to trafficked material
    - Done by compacting to final maximum densities provided by the FAA

Conclusions Continued

- PDA is capable of producing reliable energy measurements
  - P-154
    - As moisture content increases vertical work increases
    - As moisture content increases shear work and total work decreases
    - Shear work which is the majority of work done on the sample
  - P-209
    - Results are inconclusive and show no clear trend
    - Shows energy input is material dependent

Future Work

- Continue investigation of energy measurements of all materials
  - Correlation between total work and moisture content
- Complete testing of DGA
- Eventual end goal is to establish an N_{design} chart similar to SUPERPAVE

Acknowledgments

- FAA Airport Technology Research and Development Branch AJP-6310
- Dr. Satish K. Agrawal
- The contents of the presentation reflect the views of the authors, who are responsible for the facts and accuracy of the data presented within. The contents do not necessarily reflect the official views and policies of the FAA. The presentation does not constitute a standard, specification, or regulation.

Questions ?

Rowan University