Iowa State University
Dept. of Civil, Construction & Envr. Engineering
WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON
Dept. of Civil & Envr. Engineering

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

Bora Cetin, PI
William Likos, Co-PI
Tuncer Edil, Co-PI
Ashley Buss, Co-PI
Halil Ceylan, Co-PI
Junxing Zheng, Co-PI
Askin Ozocak, Visiting Scholar
Haluk Sinan Coban, PhD Student

MnDOT Project TPF-5(341)
Monthly Meeting
October 11th, 2018

RESEARCH TEAM

Iowa State University

- Principal Investigator – Bora Cetin
  Assistant Professor – Department of Civil, Construction & Environmental Engineering
- Co-Principal Investigator – Ashley Buss
  Assistant Professor – Department of Civil, Construction & Environmental Engineering
- Co-Principal Investigator – Halil Ceylan
  Professor – Department of Civil, Construction & Environmental Engineering
- Co-Principal Investigator – Junxing Zheng
  Assistant Professor – Department of Civil, Construction & Environmental Engineering
- Research Personnel – Haluk Sinan Coban
  PhD Student – Department of Civil, Construction & Environmental Engineering

University of Wisconsin-Madison

- Co-Principal Investigator – William Likos
  Professor – Department of Civil and Environmental Engineering
- Co-Principal Investigator – Tuncer B. Edil
  Professor Emeritus – Department of Civil and Environmental Engineering
- Visiting Scholar – Askin Ozocak
  Associate Professor – Sakarya University

NRRA Members (Agency Partners)

- MnDOT
- Caltrans
- MDOT
- Illinois DOT
- LRRB
- MoDOT
- WisDOT

NRRA Members (Industry Partners)

- Aggregate & Ready Mix of MN
- Asphalt Pavement Alliance (APA)
- Braun Intertec
- Concrete Paving Association of MN (CPAM)
- 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
- 3M
- Asphalt Materials & Pavements Program
- Husky Energy
- Hardrives, Inc.
- Testquip LLC
- The Transtec Group
- The Dow Chemical Company
- Pavia Systems, Inc.
- 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
- Collaborative Aggregates LLC
- American Engineering Testing, Inc.
- Center for Transportation Infrastructure Systems (CTIS)
- Asphalt Recycling & Reclaiming Association (ARRA)
- First State Tire Recycling
- BASF Corporation
- Upper Great Plains Transportation Institute at North Dakota State University
- All States Materials Group
- Caterpillar
- University of California Pavement Research Centre
- Payne & Dolan, Inc.

OUTLINE

- Task 3 – Construction Monitoring and Reporting
  - Report
  - Effects of Geosynthetics
- Task 4 – Laboratory Testing
  - ISU Preliminary Laboratory Testing Plan

FOLLOW-UP

- **Task 1** – Literature Review and Recommendations
- **Task 2** – Tech Transfer "State of Practice"

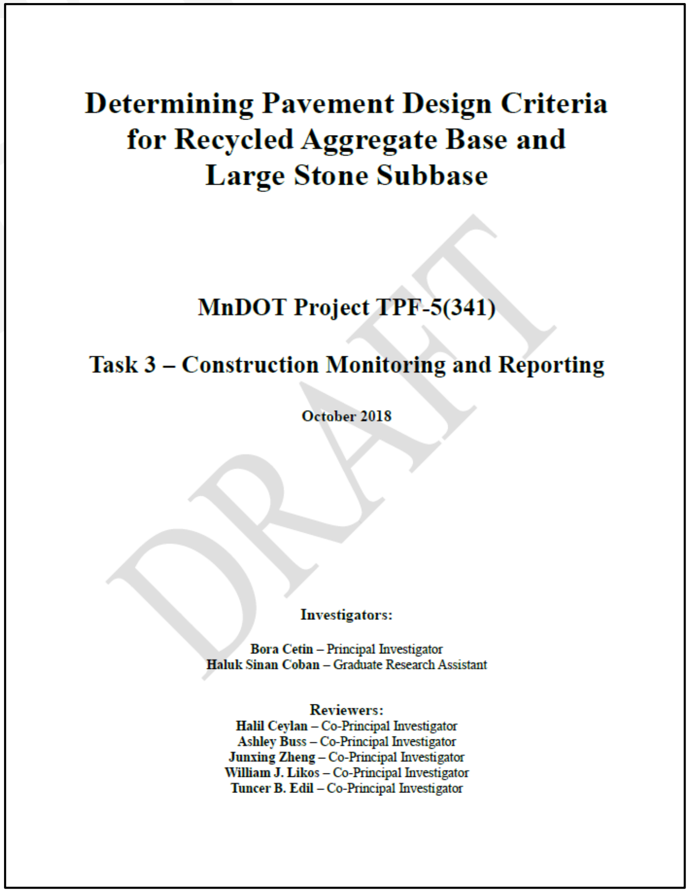
- **Task 3** – Construction Monitoring and Reporting
- **Task 4** – Laboratory Testing

- **Task 5** – Performance Monitoring and Reporting
- **Task 6** – Instrumentation
- **Task 7** – Pavement Design Criteria
- **Task 8 & 9** – Draft/Final Report

TASK 3

Report

- Test Cells and Construction
- Performance Monitoring
- Data Collected During and Shortly After Construction
  - Meteorological Data
  - Nuclear Density Gauge Measurements
  - Dynamic Cone Penetrometer (DCP) Data
  - Lightweight Deflectometer (LWD) Data
  - Gas Permeameter Test (GPT) Data
  - Intelligent Compaction (IC) Data
  - Falling Weight Deflectometer (FWD) Data



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

MnDOT Project TPF-5(341)

Task 3 – Construction Monitoring and Reporting

October 2018

Investigators:

Bora Cetin – Principal Investigator
Haluk Sinan Coban – Graduate Research Assistant

Reviewers:
Halil Ceylan – Co-Principal Investigator
Ashley Buss – Co-Principal Investigator
Junxing Zheng – Co-Principal Investigator
William J. Likos – Co-Principal Investigator
Tuncer B. Edil – Co-Principal Investigator

TASK 3

General Overview of Test Cells

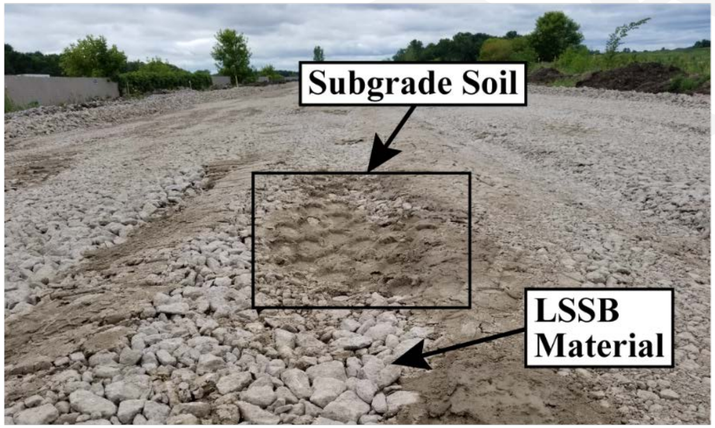
	Recycled Aggregate Base				Large Stone Subbase		Large Stone Subbase with Geosynthetics				
Cell	185	186	188	189	127	227	328	428	528	628	728
Surface	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave
Base	12 in Coarse RCA (Class 5Q)	12 in Fine RCA (Class 5)	12 in Limestone (Class 6)	12 in RCA+RAP (Class 6)	6 in Aggregate (Class 6)	6 in Aggregate (Class 6)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)
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

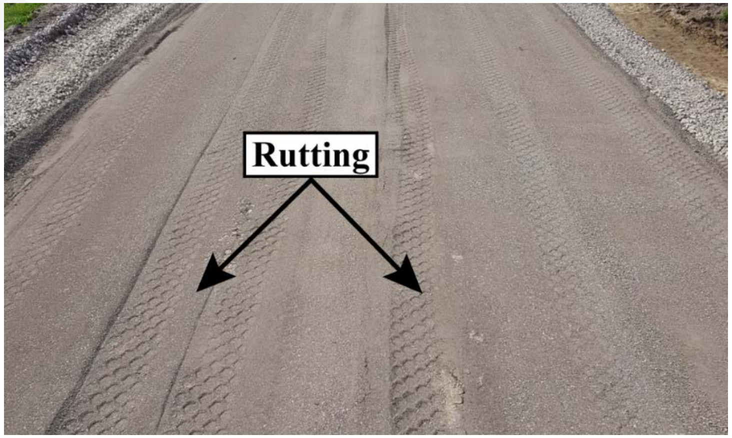
NOTE:
TX = Triaxial Geogrid
BX = Biaxial Geogrid
GT = Non-woven Geotextile

TASK 3

Designs of 9-in thick LSSB layers

- Original design
  - Only two cells – cells 128 and 228
  - 9-in thick LSSB layers with no geosynthetics
- Problems
  - Subgrade soil pumping into LSSB layers
  - Rutting of base and surface layers



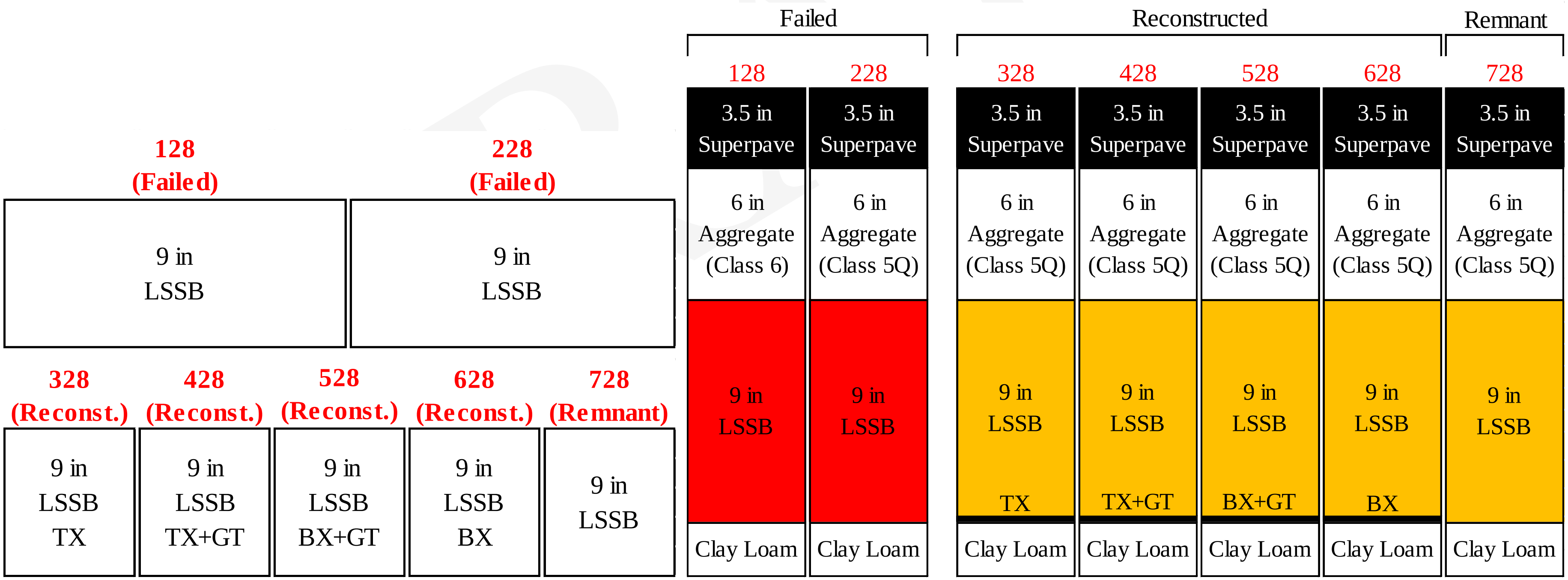


128	228
3.5 in Superpave	3.5 in Superpave
6 in Aggregate (Class 6)	6 in Aggregate (Class 5Q)
9 in LSSB	9 in LSSB
Clay Loam	Clay Loam

TASK 3

Designs of 9-in thick LSSB layers

- Solution
  - Removal of cells 128 and 228.
  - Reconstruction of cells 328, 428, 528, and 628 with geosynthetics.
  - Cell 728 ➔ Remnant from cell 228



TASK 3

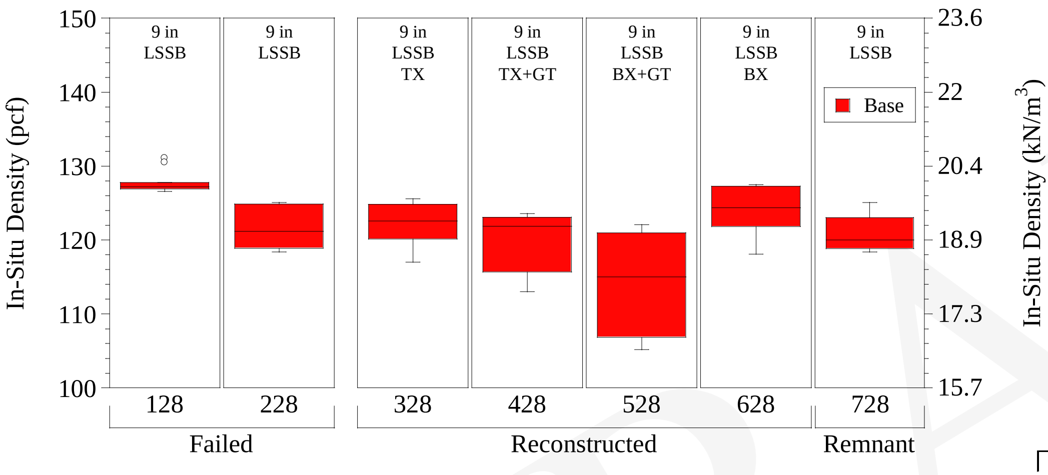
Designs of 9-in thick LSSB layers

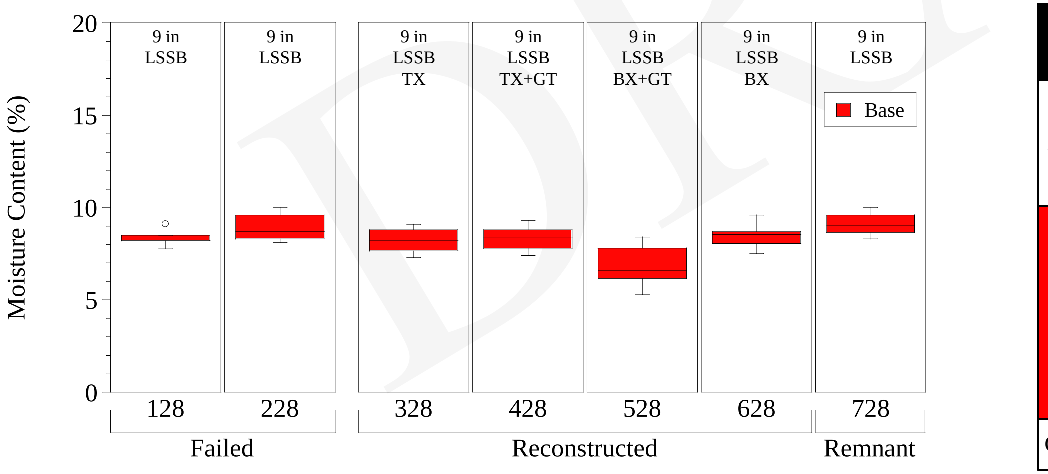
- Geosynthetics ➔ to prevent subgrade soil pumping
  - Cell 328 – Triaxial geogrid (TX)
  - Cell 428 – Triaxial geogrid (TX) + non-woven geotextile (GT)
  - Cell 528 – Biaxial geogrid (BX) + non-woven geotextile (GT)
  - Cell 628 – Biaxial geogrid (BX)
  - Cell 728 – No geosynthetic (remnant)

Reconstructed				Remnant
328	428	528	628	728
3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave
6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)	6 in Aggregate (Class 5Q)
9 in LSSB	9 in LSSB	9 in LSSB	9 in LSSB	9 in LSSB
TX	TX+GT	BX+GT	BX	
Clay Loam	Clay Loam	Clay Loam	Clay Loam	Clay Loam

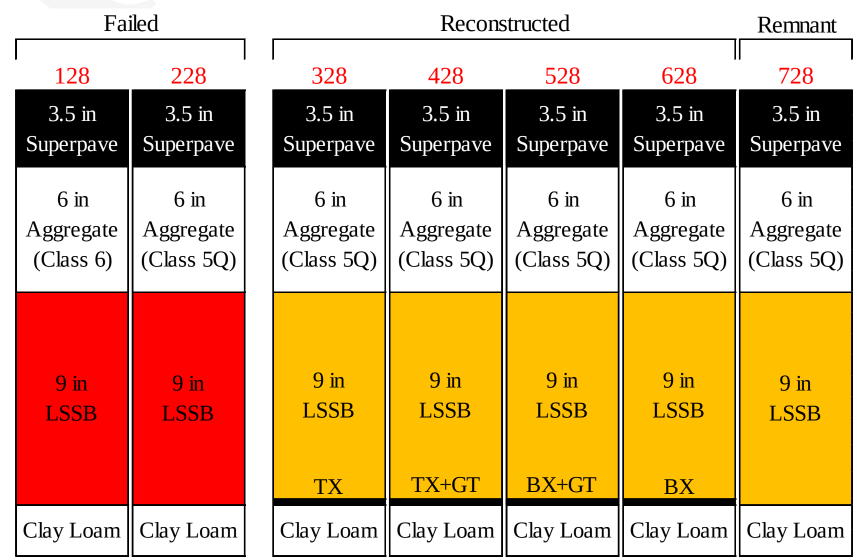
TASK 3

Nuclear Density Gauge (NDG)



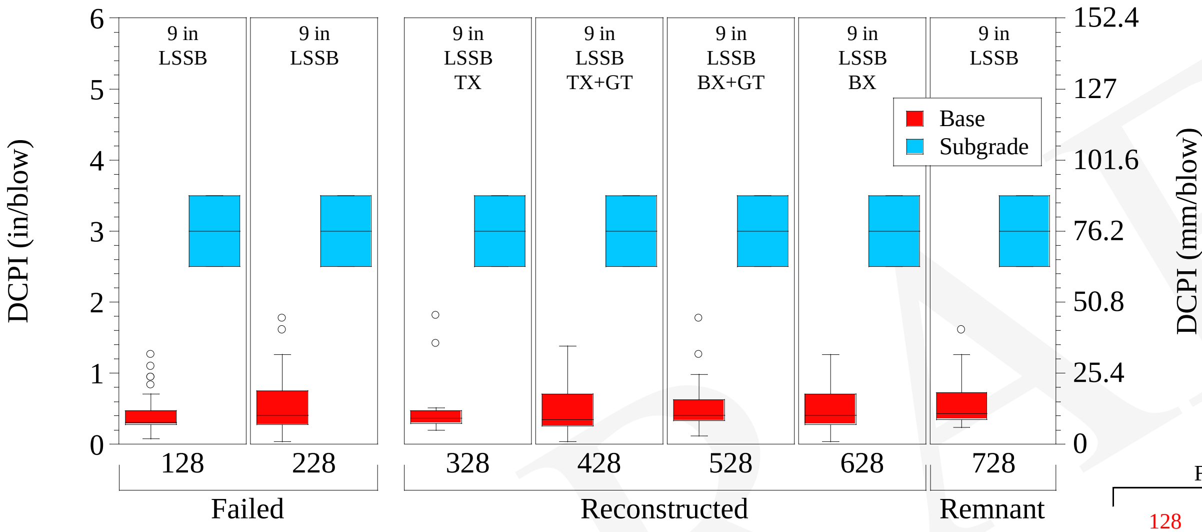


- Cell 128 – Class 6 agg. base
- Other cells – Class 5Q agg. base

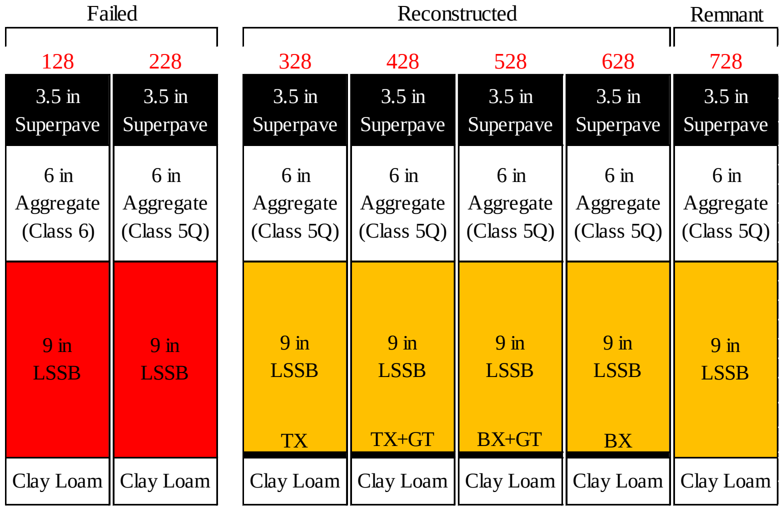


TASK 3

Dynamic Cone Penetrometer (DCP)

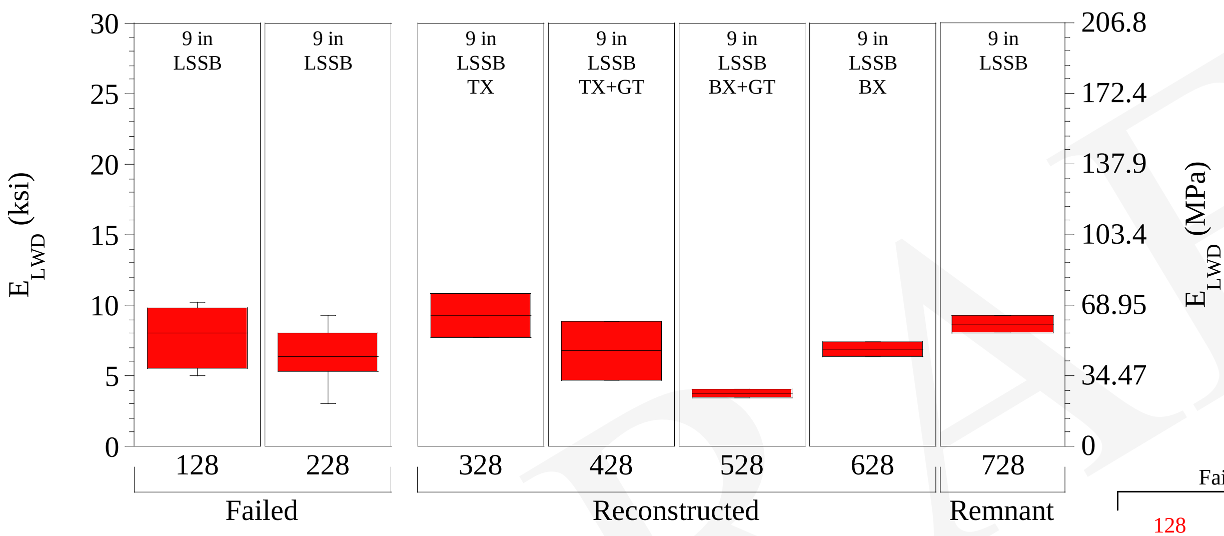


- Special subgrade preparation
  - DCPI: 2.5 to 3.5 in/blow
- No significant difference

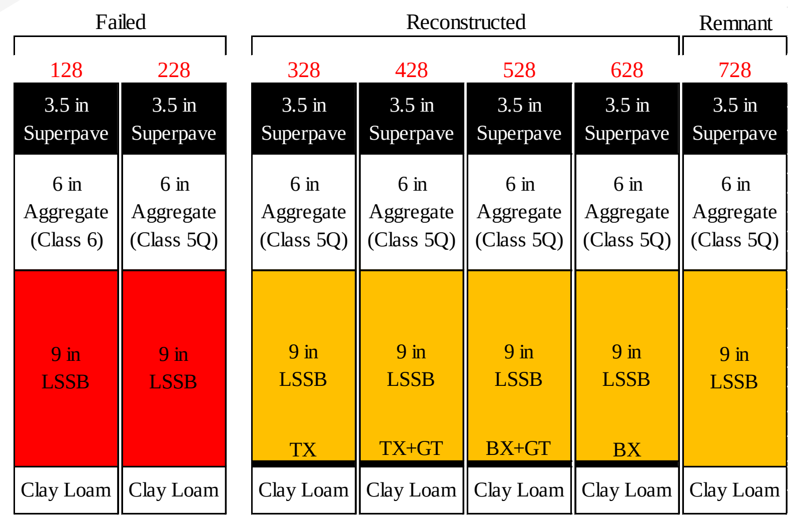


TASK 3

Lightweight Deflectometer (LWD)

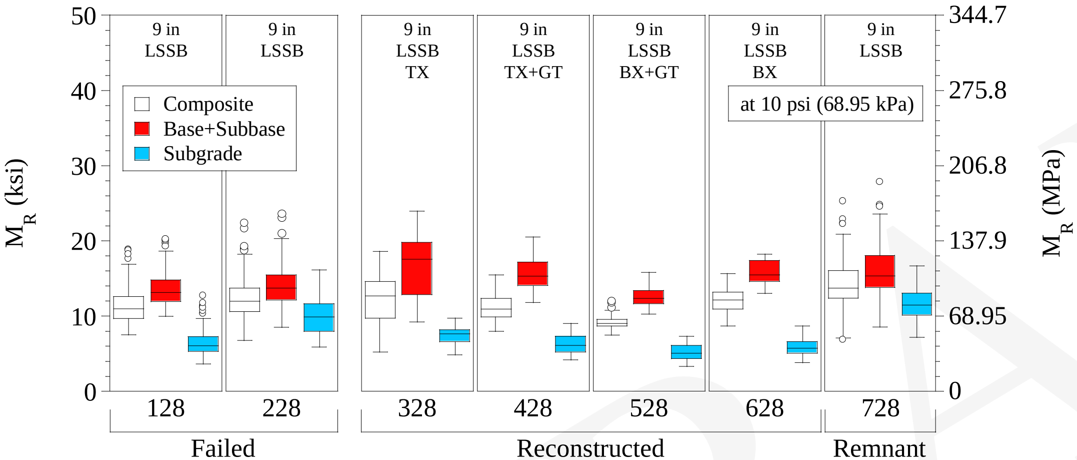


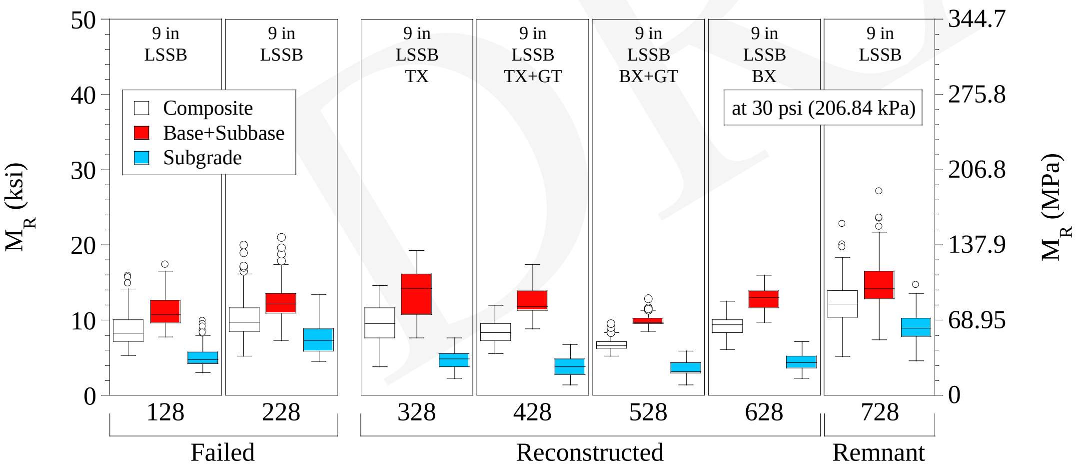
- Cells 328, 428, 628, and 728
  - ≥ Cells 128 and 228
- Cell 528 ➔ Lowest
- No considerable effects of geosynthetics



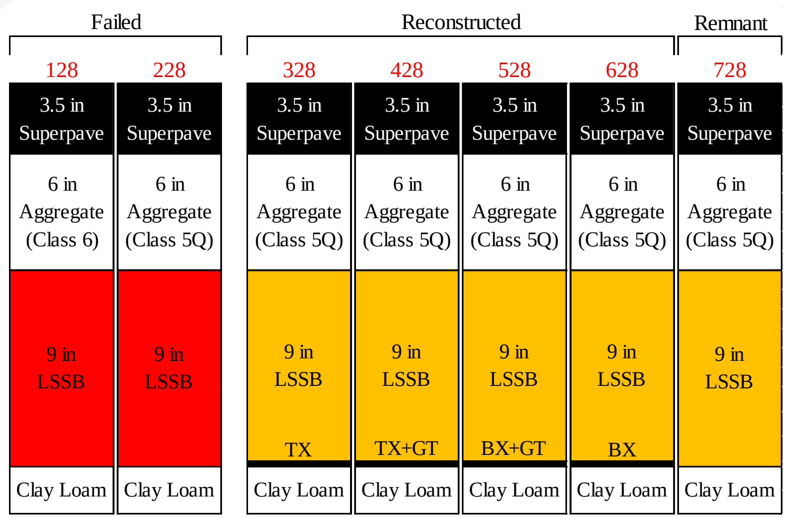
TASK 3

Intelligent Compaction (IC)



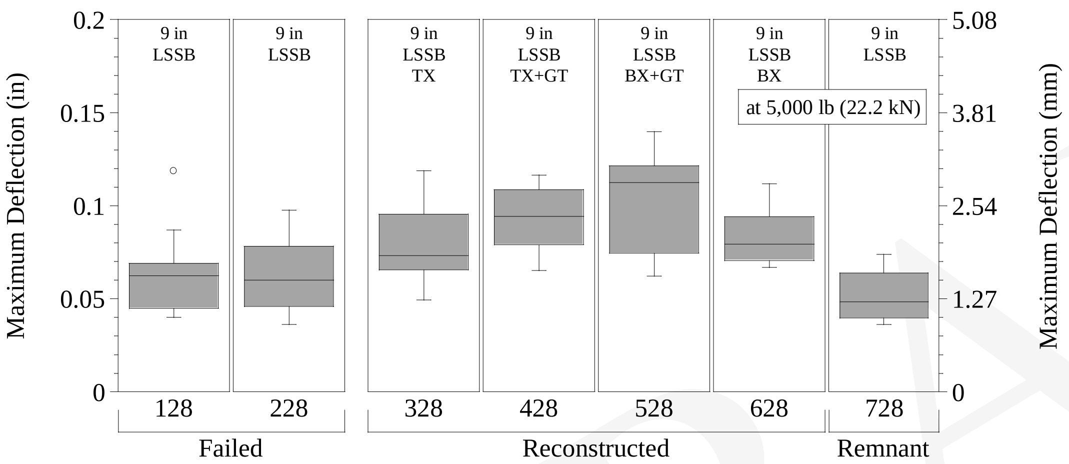


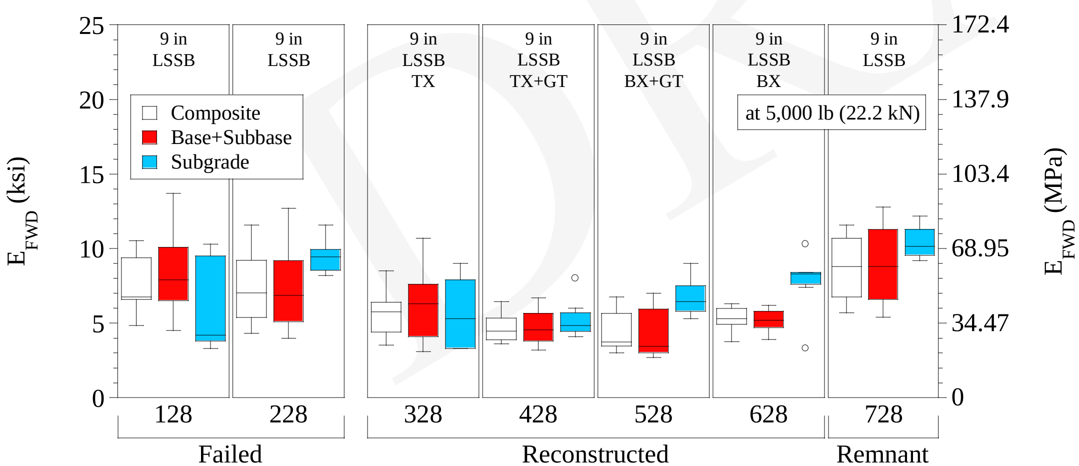
- Cells 528 ➔ Lowest
- Cells 728 > Cell 228
  - Stiffer part
- No considerable effects of geosynthetics



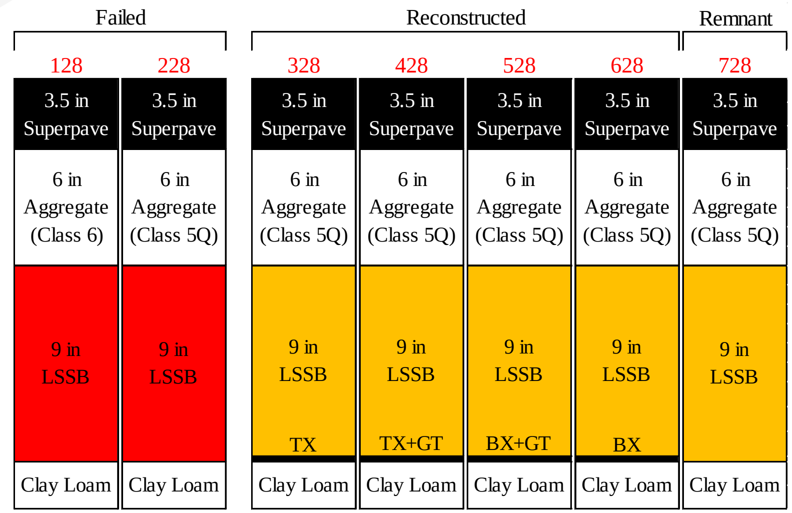
TASK 3

Falling Weight Deflectometer (FWD)





- Cells 128 and 228 ➔ Lower deflections and higher modulus
- Cells 728 ➔ Better than cell 228
  - Stiffer part
- No considerable effects of geosynthetics



TASK 3

Summary

- Effects of geosynthetics on overall engineering properties of reconstructed cells were investigated by LWD, IC, and FWD tests.
- During construction, using geosynthetics between LSSB layers and subgrade soils mitigated rutting and subgrade soil pumping.
- Benefits of geosynthetics could not be detected by LWD, IC, and FWD tests in terms of stiffness.
- Structures of test cells will be investigated by GPR.
- Drilling a test hole and investigating morphology of pavement layers by geo-endoscope method would be desired.
- More analyses will be performed as monitoring continues to observe the long-term performance of each cell.

TASK 4

Task 4 – Laboratory Testing

- **Iowa State University**
  - Soil classification
  - Image analysis
  - Proctor & gyratory compaction
  - Asphalt & cement content determination
  - Contact angle measurement
- **University of Wisconsin-Madison**
  - Soil-water characteristic curve (Hanging Column Test)
  - Permeability (Constant Head Hydraulic Conductivity)

TASK 4

Soil Classification

- Gradation of aggregates highly affects (Saeed 2008):
  - Hydraulic conductivity
  - Shear strength
  - Elastic and resilient modulus
  - Frost-susceptibility

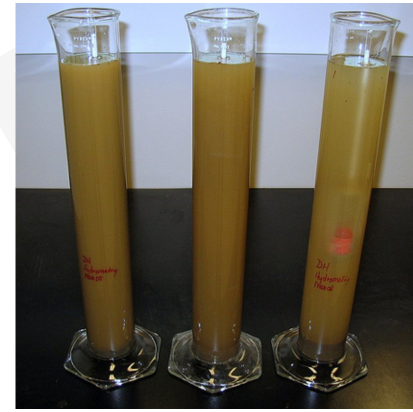
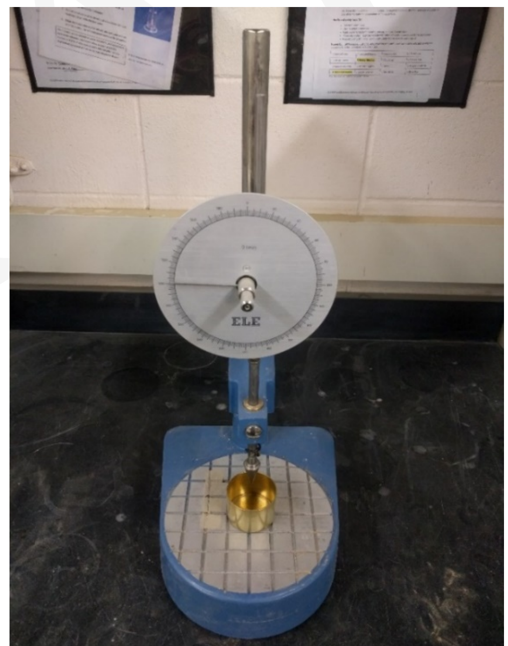
- Gradations of RCA and RAP are affected by (Cosentino and Kalajian 2001):
  - Original aggregate type
  - Milling operations
  - Crushing methods

- Importance of gradation for RCA
  - Fine RCA particles ➔ Higher unhydrated cement content (ACPA 2009)
  - Higher unhydrated cement content ➔ More cementation

TASK 4

Soil Classification

- Base materials:
  - Coarse RCA (Class 5Q)
  - Fine RCA (Class 5)
  - Limestone (Class 6)
  - RCA+RAP (Class 6)
  - Class 6 aggregates
  - Class 5Q aggregates
- Subbase materials:
  - Select granular borrow
  - LSSB material
- Subgrade materials:
  - Sandy soil
  - A-6 Clay Loam


TASK 4

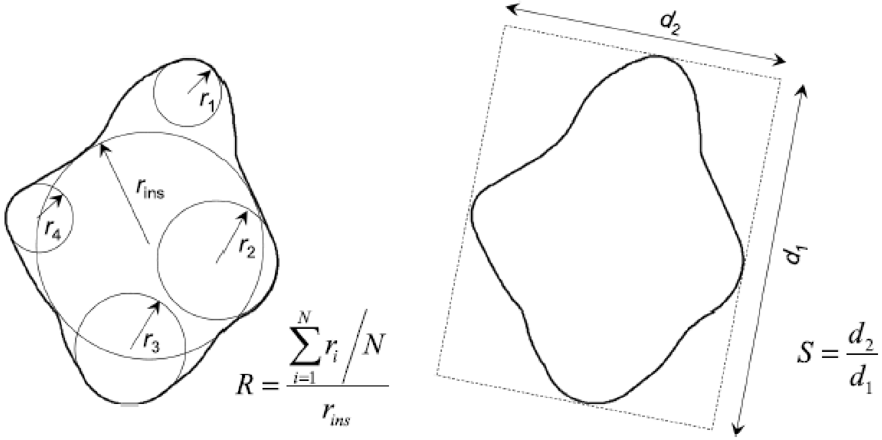
Image Analysis

- RCA particles – more angular than RAP particles (Cosentino et al. 2003).
- RCA particles – rougher texture than RAP particles (Cosentino et al. 2003).
- LSSB materials (Kazmee et al. 2016):
  - Large-size aggregates
  - Limitations of standard sieve sizes – not practical
  - Image analysis is more suitable for characterization.
- Large-size aggregates ➔ Less angular due to single crushing operation (Kazmee et al. 2016).

TASK 4

Image Analysis

- Particle roundness
  - Wadell (1932) ➔ The ratio of the average radius of curvature of the corners of a particle (r_i where i = corner number) to the radius of the maximum inscribed circle (r_{ins}).
- Particle sphericity
  - Krumbein and Sloss (1951) ➔ The ratio of particle width (d_2) to particle length (d_1).



(Hryciw et al. 2016)

TASK 4

Image Analysis

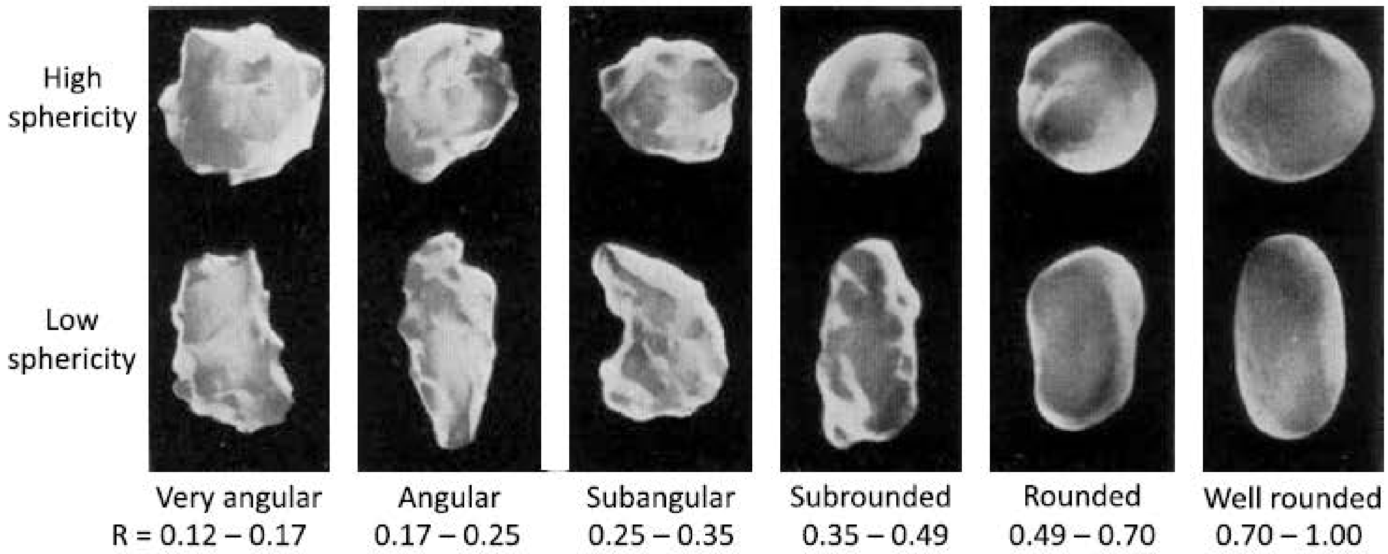


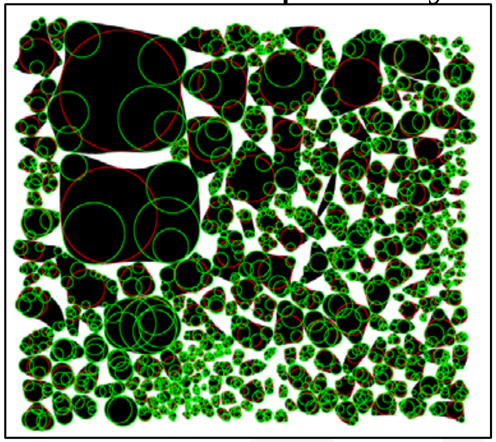
Fig. 4. Chart for qualitatively describing roundness (R^c) and sphericity (S^c) [reprinted from Powers 1953, with permission from SEPM (Society for Sedimentary Geology)]

(Hryciw et al. 2016)

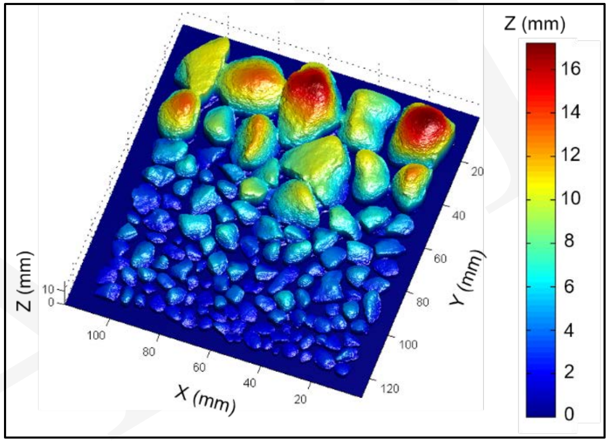
TASK 4

Image Analysis

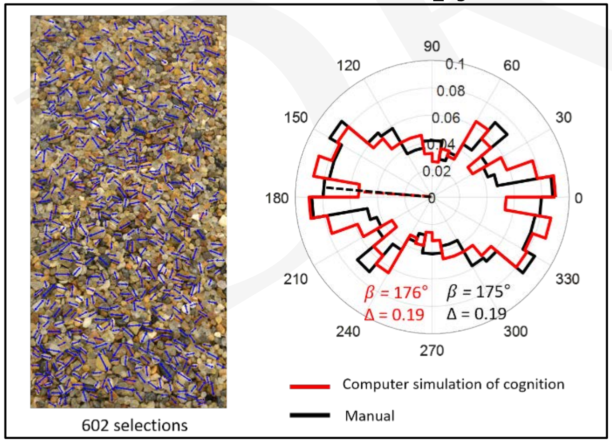
2D Particle Shape Analysis



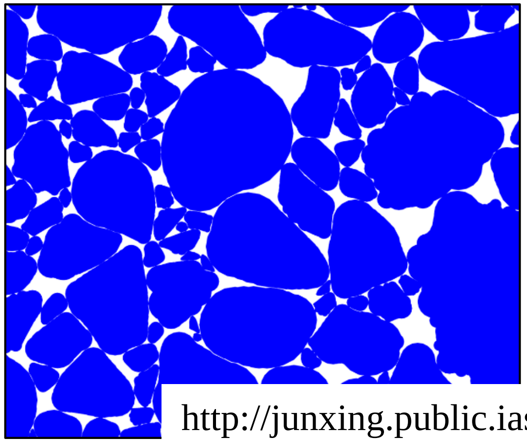
Stereophotography



Fabric Anisotropy



Intrinsic Property Based DEM Modeling

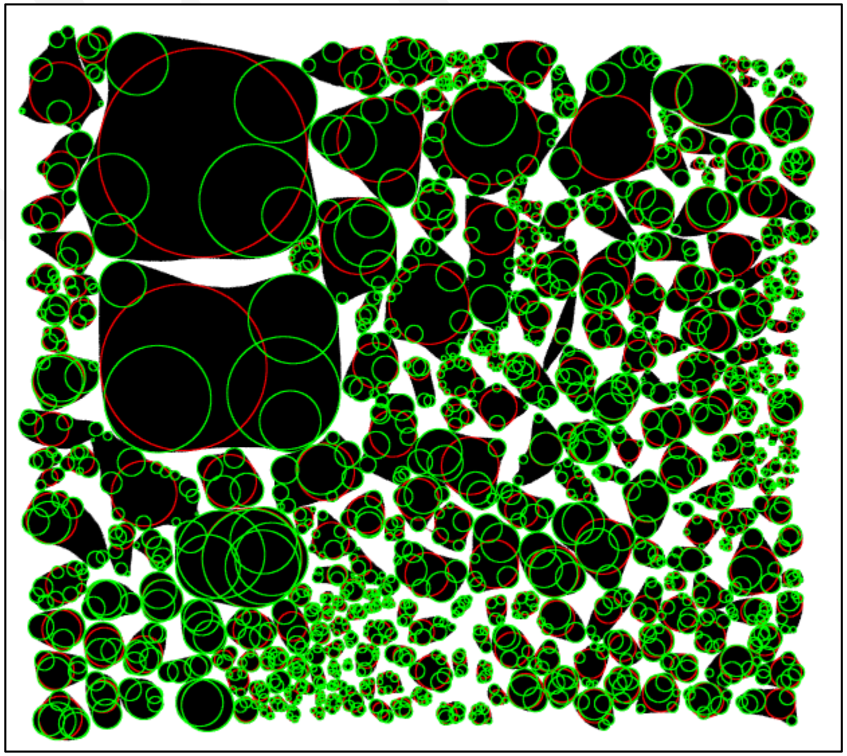


http://junxing.public.iastate.edu/research.html

TASK 4

Image Analysis

- 2D Particle Shape Analysis
  - Code based on Matlab to automatically compute
    - Sphericity
    - Roundness
    - Surface Roughness

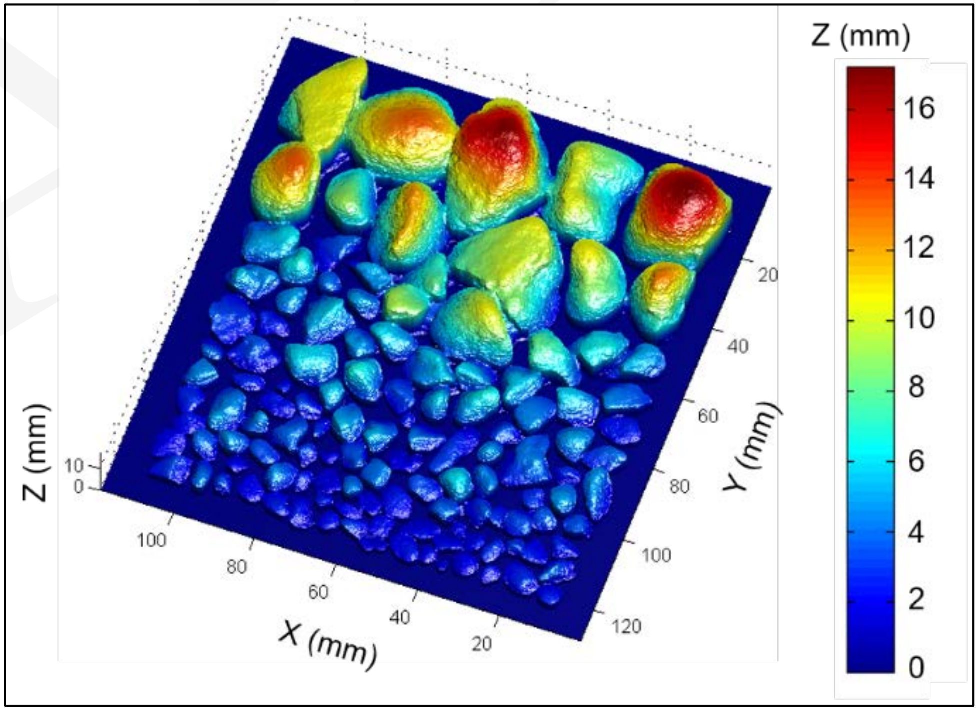


http://junxing.public.iastate.edu/research.html

TASK 4

Image Analysis

- Stereophotography
  - Traditional images ➔ 2D
  - Stereophotography ➔ 3D
  - Only 2 parallel images are required for 3D reconstruction.

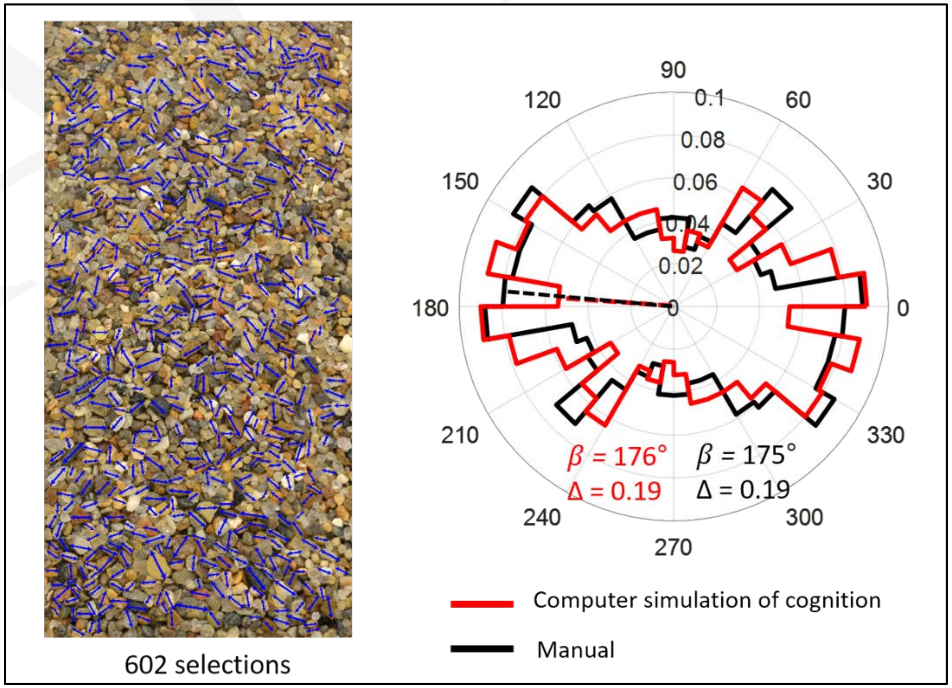


http://junxing.public.iastate.edu/research.html

TASK 4

Image Analysis

- Fabric Anisotropy
  - Rotational Haar Wavelet method
  - Estimation of orientations of particle long axes
  - Computation of fabric tensor.

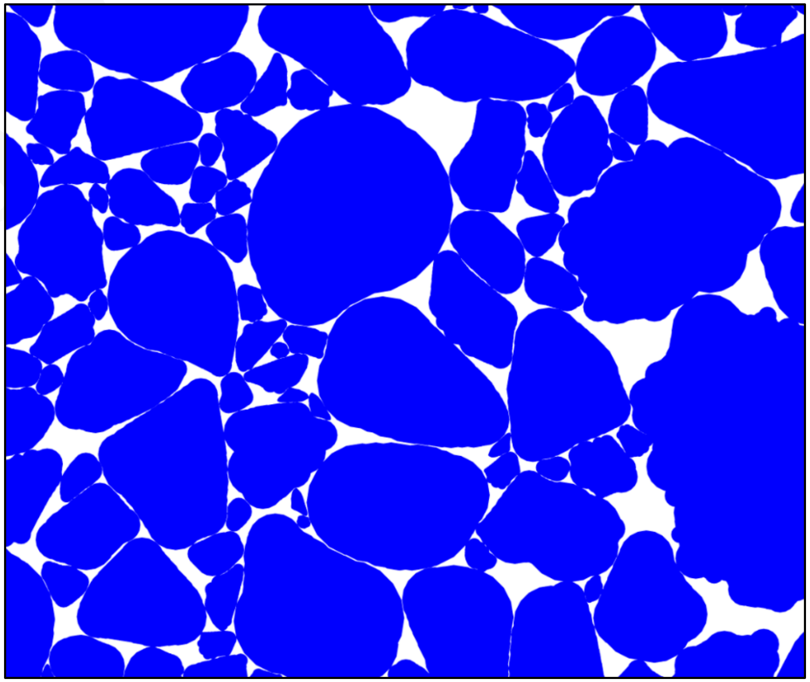


http://junxing.public.iastate.edu/research.html

TASK 4

Image Analysis

- Intrinsic Property Based DEM Modeling
  - 2D corner preserving algorithm
    - To generate realistic DEM geometries from particle images
  - DEM particle library
    - User defines particle size, sphericity, and roundness distributions.
    - DEM particle library builds a virtual soil specimen.

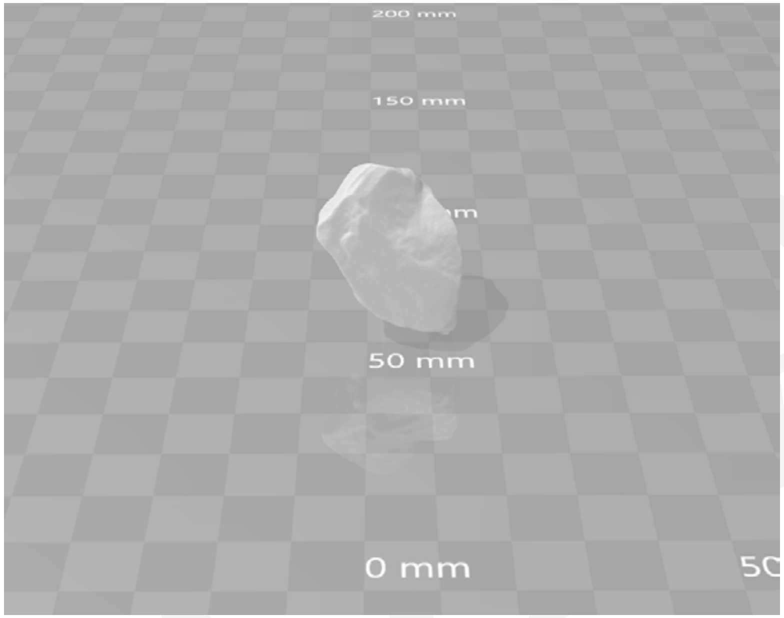


http://junxing.public.iastate.edu/research.html

TASK 4

Image Analysis

- Shining 3D – EinScan-SP



https://www.dream3d.co.uk/product/shining-3d-einscan-sp/

TASK 4

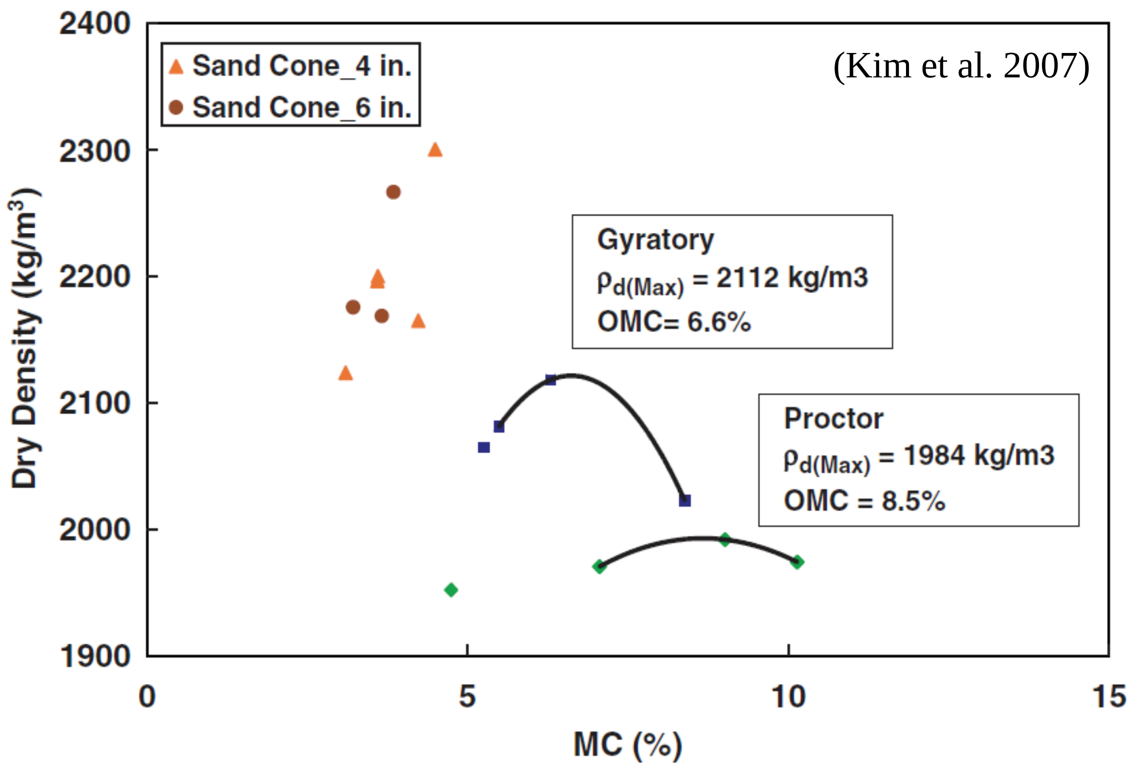
Proctor & Gyratory Compaction

- Proctor tests (Edil et al. 2012; Nokkaew et al. 2012; Sayed et al. 1993)
  - RAP and RCA have lower maximum dry unit weight than VA.
    - RAP ➔ Lower specific gravity than VA due to asphalt (Guthrie et al. 2007, Locander 2009).
    - RCA ➔ Resistance of particles against the compaction effort due to cementation (Hussain and Dash 2010).
  - RAP has lower optimum water content than VA ➔ hydrophobicity
  - RCA shows a higher optimum moisture content ➔ hydrophilicity

TASK 4

Proctor & Gyratory Compaction

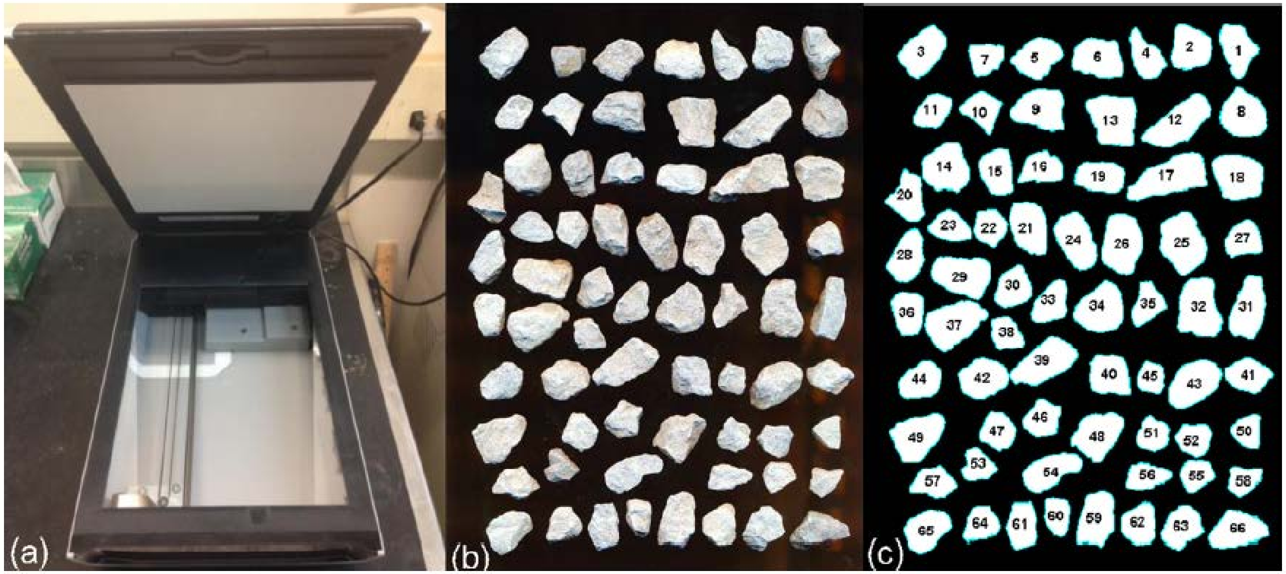
- Kim et al. (2007) → Gyratory compactor provided better results to simulate the in-situ conditions.



TASK 4

Proctor & Gyratory Compaction

- Gyratory Abrasion and Image Analysis (GAIA) test method (Li et al. 2017)
  - Percent crushing of aggregates after the test
- Canon 9000F Mark II high-speed optical scanner – 2D
  - Dust and scratch removal image processing feature



(Li et al. 2017)

TASK 4

Asphalt & Cement Content Determination

- Coarse RCA & Fine RCA – Cement content
- RCA+RAP – Material contents
  - Engineering properties of RCA and RAP
  - Temperature-sensitivity of RAP due to asphalt (Soleimanbeigi et al. 2015).
  - Repositioning of particles in the long-term due to the asphalt (Cosentino et al. 2012; Yin et al. 2016)
  - Cementation of unhydrated cement
  - Fine RCA particles ➔ Contain higher unhydrated cement (ACPA 2009)

TASK 4

Asphalt & Cement Content Determination

- Asphalt content determination ➔ Ignition method
  - *AASHTO T 308-16, Standard Method of Test for Determining the Asphalt Binder Content of Hot Mix Asphalt (HMA) by the Ignition Method*

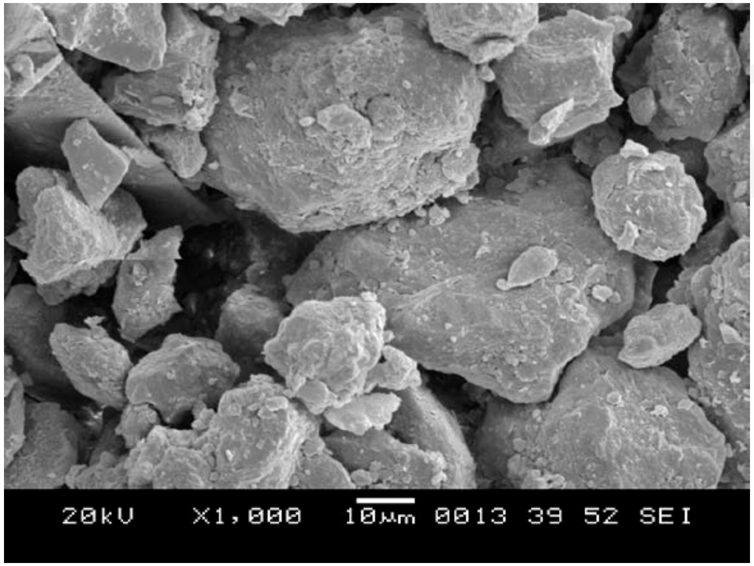
Before Ignition

After Ignition

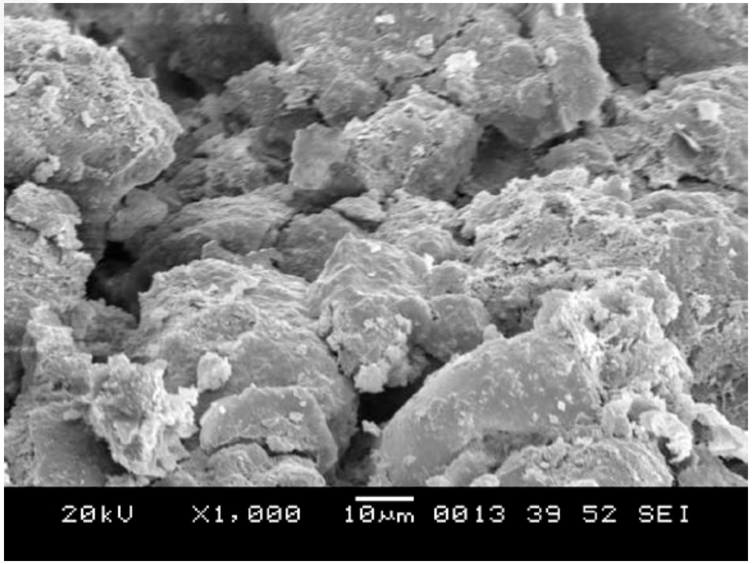
TASK 4

Asphalt & Cement Content Determination

- Cement content determination ➔ Acid treatment technique
- Cementation ➔ Heat of hydration
- Linking between particles due to cementation ➔ SEM images



Loess



Loess + 4 % PC

(Coban 2017)

TASK 4

Contact Angle Measurement

- Hydrophobicity of RAP ➔ due to asphalt
- Hydrophilicity of RCA ➔ due to unhydrated cement
- RAP tends to have higher K_{sat} than RCA ➔ hydrophobicity.

RAP

RCA

(Edil et al. 2012)

TASK 4

Contact Angle Measurement

- Water drop penetration time (WDPT) (Edil et al. 2012)
  - Time that takes for a water drop to completely infiltrate the material after the water drop is placed at the surface of soil.
- Effective contact angle (Edil et al. 2012)
  - Dynamic property depending on energy state of water
- Apparent contact angle (Edil et al. 2012)
  - Contact angle at zero energy state of water
  - The higher the contact angle the greater the water repellency
  - RAP > 90° and RCA ~ 0°

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																															■	■	■

REFERENCES

ACPA (2009). *Recycling Concrete Pavements*. Engineering Bulletin 043P. American Concrete Paving Association, Skokie, IL.

Coban, H. S. (2017). "The use of lime sludge for soil stabilization". *Graduate Theses and Dissertations*. 15502.

Cosentino, P. J., & Kalajian, E. H. (2001). Developing specifications for using recycled asphalt pavement as base, subbase or general fill materials (No. Final Report).

Cosentino, P. J., Kalajian, E. H., Bleakley, A. M., Diouf, B. S., Misilo, T. J., Petersen, A. J., Krajcik, R. E., & Sajjadi, A. M. (2012). *Improving the properties of reclaimed asphalt pavement for roadway base applications* (No. FL/DOT/BDK81 97702).

Cosentino, P. J., Kalajian, E. H., Shieh, C. S., Mathurin, W. J. K., Gomez, F. A., Cleary, E. D., & Treeratrakoon, A. (2003). *Developing specifications for using recycled asphalt pavement as base, subbase or general fill materials, phase II* (No. FL/DOT/RMC/06650-7754).

Edil, T. B., Tinjum, J. M., & Benson, C. H. (2012). Recycled Unbound Materials. Report No. 2012-35. Minnesota Department of Transportation. St. Paul, MN.

Guthrie, W., Cooley, D., & Eggett, D. (2007). Effects of reclaimed asphalt pavement on mechanical properties of base materials. *Transportation Research Record: Journal of the Transportation Research Board*, 44-52.

Hryciw, R.D., Zheng, J., and Shetler, K. (2016). "Comparison of Particle Roundness and Sphericity by Traditional Chart and Computer Methods", ASCE Journal of Geotechnical and Geoenvironmental Engineering, Vol. 142, No. 9, 1-15, DOI: 10.1061/(ASCE)GT.1943-5606.0001485.

Hussain, M., and Dash, S. K. (2010). "Influence of lime on plasticity behaviour of soils." *Proc., Indian Geotechnical Conference,* Guntur, India, 537–540.

Kazmee, H., Tutumluer, E., & Beshears, S. (2016). Pavement working platforms constructed with large-size unconventional aggregates. *Transportation Research Record: Journal of the Transportation Research Board*, (2578), 1-11.

Kim, W., Labuz, J., & Dai, S. (2007). Resilient modulus of base course containing recycled asphalt pavement. *Transportation Research Record: Journal of the Transportation Research Board*, (2005), 27-35.

Krumbein, W. C., and Sloss, L. L. (1951). Stratigraphy and sedimentation, W. H. Freeman and Company, San Francisco.

Li, C., Ashlock, J. C., White, D. J., Jahren, C. T., & Cetin, B. (2017). Gyratory abrasion with 2D image analysis test method for evaluation of mechanical degradation and changes in morphology and shear strength of compacted granular materials. *Construction and Building Materials*, *152*, 547-557.

Locander, R. (2009). Analysis of using Reclaimed Asphalt Pavement (RAP) as a Base Course Material. Colorado Department of Transportation DTD Applied Research and Innovation Branch (pp. 1-68). Report No. CDOT-2009-5.

Nokkaew, K., Tinjum, J. M., & Benson, C. H. (2012). Hydraulic properties of recycled asphalt pavement and recycled concrete aggregate. In *GeoCongress 2012: State of the Art and Practice in Geotechnical Engineering* (pp. 1476-1485).

Saeed, A. (2008). "Performance-Related Tests of Recycled Aggregates for Use in Unbound Pavement Layers." Transportation Research Board of the National Academies. Washington, D.C.

Sayed, S. M., Pulsifer, J. M., & Schmitt, R. C. (1993). Construction and performance of shoulders using UNRAP base. *Journal of materials in civil engineering*, *5*(3), 321-338.

Soleimanbeigi, A., Shedivy, R. F., Tinjum, J. M., & Edil, T. B. (2015). Climatic effect on resilient modulus of recycled unbound aggregates. *Road Materials and Pavement Design*, *16*(4), 836-853.

Wadell, H. (1932). "Volume, shape, and roundness of rock particles." J. Geol., 40(5), 443–451.

Yin, J., Soleimanbeigi, A., Likos, W. J., & Edil, T. B. (2016). Effects of Temperature on Creep Behavior of Compacted Recycled Asphalt Pavement. *Journal of Geotechnical and Geoenvironmental Engineering*, *143*(4), 06016028.

Thank You!

QUESTIONS??