IOWA STATE UNIVERSITY

WISCONSIN UNIVERSITY OF WISCONSIN–MADISON

MICHIGAN STATE UNIVERSITY

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

Bora Cetin, PI

Tuncer Edil, Co-PI

Halil Ceylan, PI

William Likos, Co-PI

Ashley Buss, Co-PI

Junxing Zheng, Co-PI

Haluk Sinan Coban, Research Personnel

MnDOT Project TPF-5(341)

NRRA Monthly Geotechnical Team Meeting

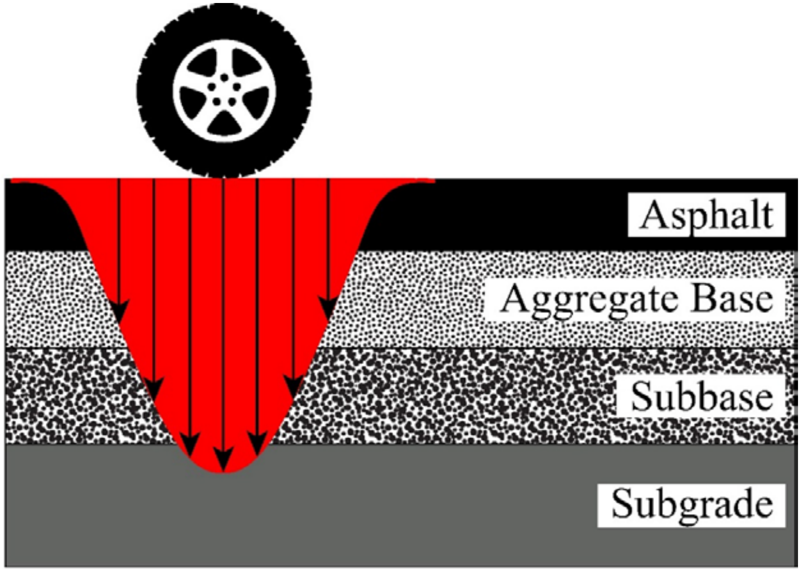
December 3, 2020

OUTLINE

- Introduction
- Research motivation
- Objectives
- Research plan
- Test cells and materials
- Tasks
- Conclusions & recommendations

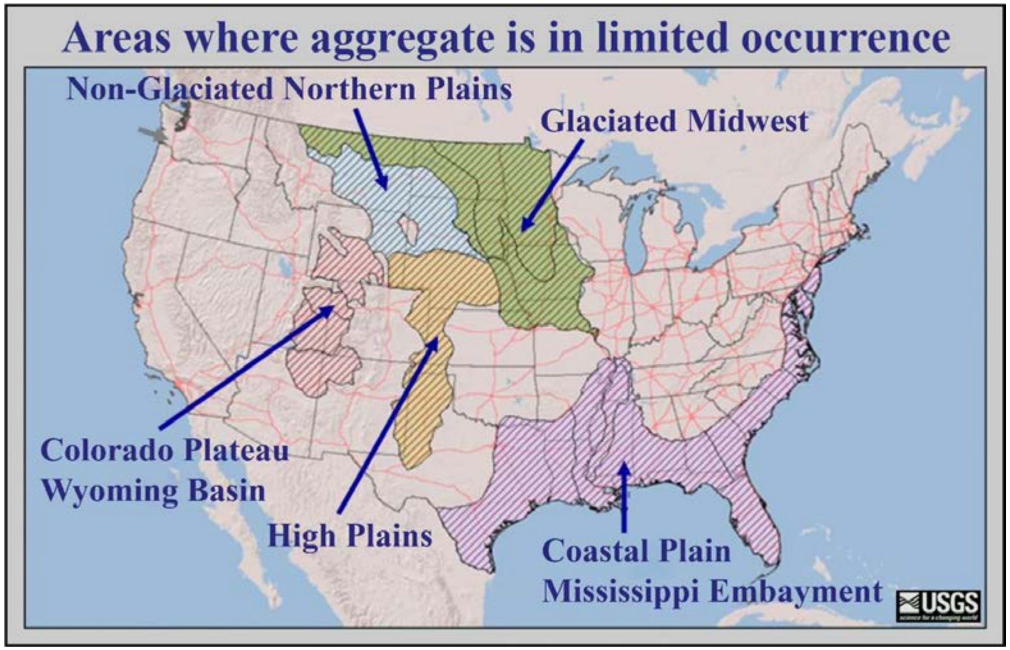
INTRODUCTION

- Flexible pavements
- Load distribution
- Long-term performance
- Aggregate base layer
  - Load-carrying sublayer
  - Adequately stiff & durable
  - Good-quality natural aggregates
- Subbase layer
  - Working platform
  - Filter/separation
  - Conventional-size natural aggregates
    - Majority of particles ≤ 25 mm



INTRODUCTION

- Cost of good-quality virgin aggregates (VAs) ↑
  - High demand
  - Loss of natural sources
  - Federal/local restrictions
- Pavement sustainability
  - Economical
  - Environmentally friendly
  - Long-lasting
- Alternative materials
  - Recycled aggregates
  - Large stones



https://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf

INTRODUCTION

- Recycled concrete aggregate (RCA)
  - Old & failed rigid pavements
  - Demolished structures
- Recycled asphalt pavement (RAP)
  - Old & failed asphalt pavement surfaces
- Large stones
  - Majority of particles > 25 mm

https://atlasconcrete.co.nz/benefits-of-recycling-concrete/

https://arthuge.com/dirt_sand_gravel_limestone_fill_sand_prices

https://greelysand.com/shop/decorative-stone-river-rock/granite-stone/

RESEARCH MOTIVATION

Variety of RCA

Rare use of mixtures of recycled aggregates

Limitations of laboratory facilities

Limited information about field performance

Limited information about RCA+RAP

Limited information about large stones

Lack of correlations between engineering properties & index properties
Inconsistent design methods & construction specifications

OBJECTIVES

1st Objective – Determine laboratory & field performance

- Index & engineering properties & abrasion
- Unsaturated & saturated characteristics
- Nuclear density, DCP, LWD, IC, FWD, rutting, IRI, distresses
- Environmental monitoring (temperature & moisture)

2nd Objective – Estimate laboratory & field test results

- Simple & multiple linear regression models
- Nonlinear models (power, exponential, logarithmic)
- Correlations

3rd Objective – Prepare a pavement design and construction specification

- Field and laboratory performance
- Material selection
- Design recommendations

RESEARCH PLAN

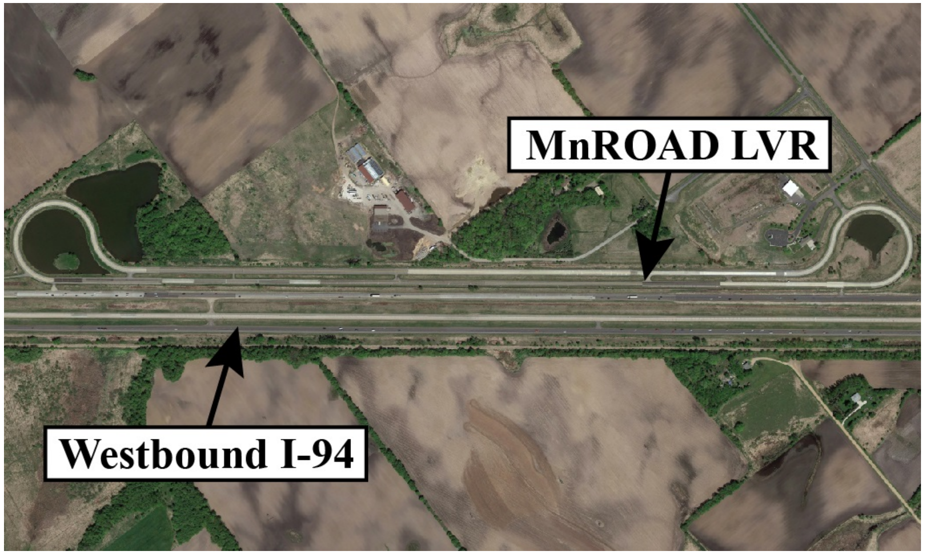
- **Task 1** – Literature review and recommendations
- **Task 2** – Tech transfer "state of practice"
- **Task 3** – Construction monitoring and reporting
- **Task 4** – Laboratory testing
- **Task 5** – Performance monitoring and reporting
- **Task 6** – Instrumentation
- **Task 7** – Pavement design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

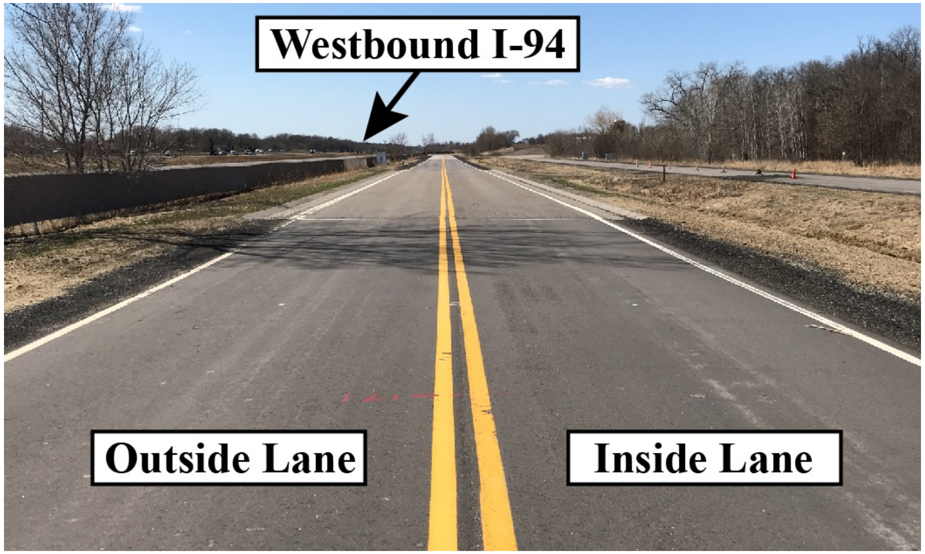
Green – Completed
Red – In Progress

TEST CELLS AND MATERIALS

Test Facility

- Minnesota Road Research Project (MnROAD) Low Volume Road (LVR)
  - Two-lane closed loop
  - Inside lane – traffic simulation
  - Outside lane – environmental monitoring





TEST CELLS AND MATERIALS

Test Cells

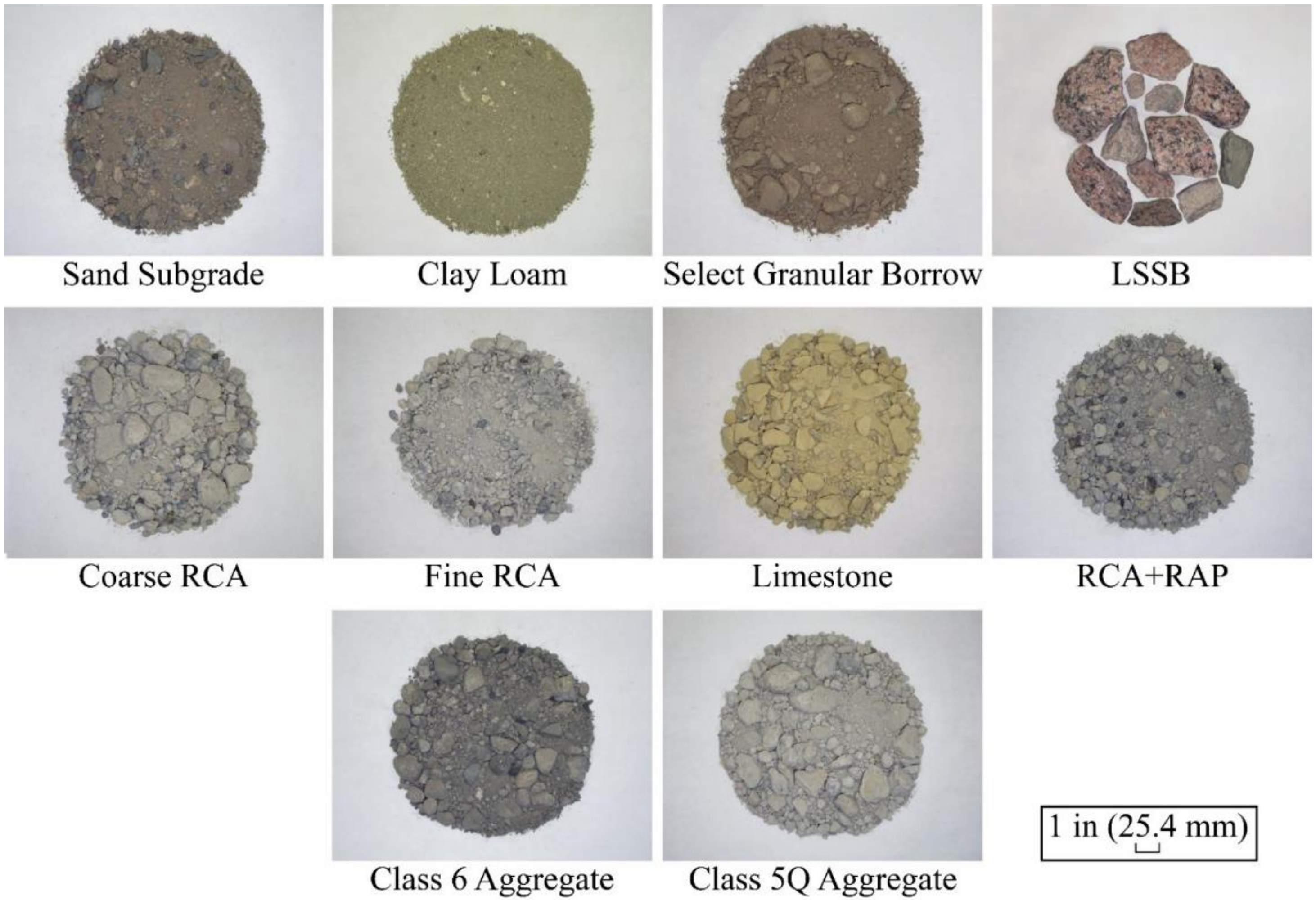
Recycled Aggregate Base				Large Stone Subbase		Large Stone Subbase with Geosynthetics				
185	186	188	189	127	227	328	428	528	628	728
3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave
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
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
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

TEST CELLS AND MATERIALS

Soils and Aggregates



TASK 1

Literature Review and Recommendations

- Index properties
  - Grain and gradation characteristics
  - Compaction characteristics
- Engineering properties
  - Hydraulic properties
  - Bearing capacity properties
  - Shear strength properties
  - Stiffness properties
  - Permanent deformation properties
  - Creep properties
  - Freeze-thaw (F-T) and wet-dry (W-D) durability
- Environmental properties
  - Properties of RAP
    - pH characteristics
    - Heavy metal leaching characteristics
    - Poly-aromatic hydrocarbons (PAHs) leaching characteristics
  - Properties of RCA
    - pH characteristics
    - Heavy metal leaching characteristics
- Geosynthetic applications
  - Functions of geosynthetics
  - Effects of using geosynthetics
- Design methods
  - AASHTO 1993 design method
  - Mechanistic-empirical (ME) pavement design method
- Selected practices of state DOTs
  - Caltrans, IDOT, MnDOT, MoDOT, WisDOT, and MDOT

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

MnDOT Project TPF-5(341)

Task 1 – Literature Review

April 2018

DRAFT

Investigators:

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

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 2

Tech Transfer "State of Practice"

- Determining pavement design criteria for recycled aggregate base materials
- Determining pavement design criteria for large stone subbase materials

NRRA National Road Research Alliance

June 2018

TECH TRANSFER "STATE OF PRACTICE" REVISED DRAFT REPORT

Determining Pavement Design Criteria for Recycled Aggregate Base Materials – REVISED DRAFT

Introduction

Figure 1. Recycled asphalt pavement (RAP) (Copeland 2011)

Figure 2. Recycled concrete aggregate (RCA) (Gonzalez and Moo-Young 2004)

Recycled Aggregate Base Materials

Index Properties of RAP and RCA

Develop Collaborate Research Implement 1

NRRA National Road Research Alliance

June 2018

TECH TRANSFER "STATE OF PRACTICE" REVISED DRAFT REPORT

Determining Pavement Design Criteria for Large Stone Subbase Materials – REVISED DRAFT

Introduction

Figure 1. General structure of rigid and flexible pavements

Large Stone Subbase Materials

Figure 2. Fine- to coarse-grained aggregates (left to right) (http://engineeringfeed.com/8-factors-affect-workability-fresh-concrete)

Index and Engineering Properties of LSSB Materials

Grain and Gradation Characteristics

Develop Collaborate Research Implement 1

TASK 3

Construction Monitoring and Reporting

- Construction monitoring
- In-situ density and moisture content measurements
- DCP tests
- LWD tests
- IC
- FWD


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

DRAFT

MnDOT Project TPF-5(341)

Task 3 – Construction Monitoring and Reporting

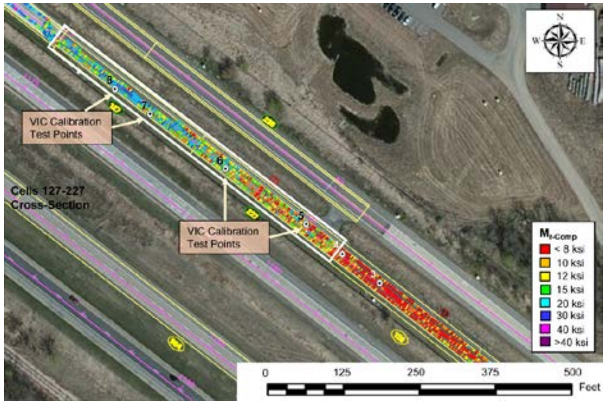
November 2018

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


(White and Vennapusa 2017)

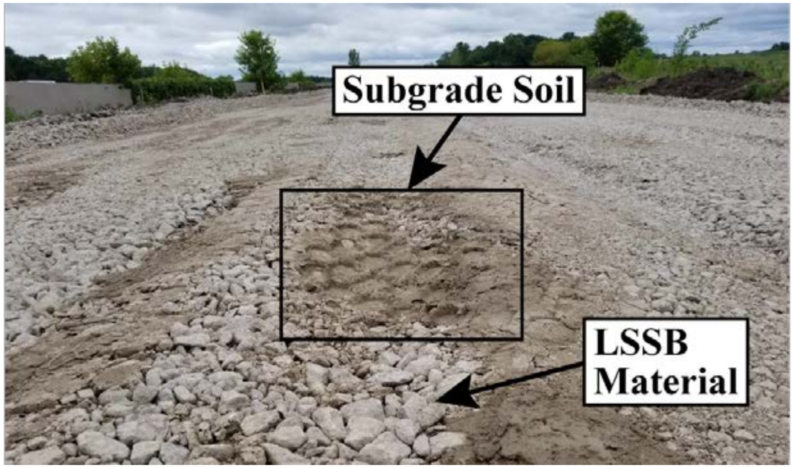


(White and Vennapusa 2017)

TASK 3

Construction Monitoring and Reporting - Summary

- Challenging construction for thinner LSSB
- Subgrade soil pumping & rutting
- Geosynthetics between LSSB/subgrade
- Staged construction for thicker LSSB → not practical
- Coarse RCA and Fine RCA base → good performance
- Thicker LSSB > thinner LSSB



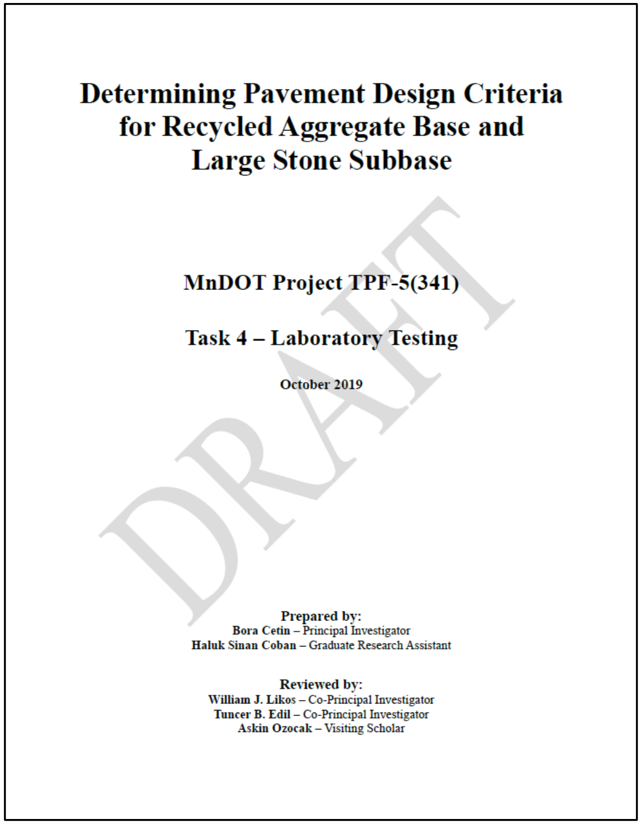
(White and Vennapusa 2017)

(White and Vennapusa 2017)

TASK 4

Laboratory Testing

- Index properties
  - Classification
  - G_s and absorption
  - Proctor compaction
  - Asphalt binder content
  - Residual mortar content
  - Water repellency
- Saturated & unsaturated properties
  - Permeability (K_{sat}) tests
  - Soil-water characteristic curve (SWCC)
- Stereophotography
  - Particle size & shape analyses
- Gyratory compaction and abrasion
  - Abrasion on particle size & shape



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

MnDOT Project TPF-5(341)

Task 4 – Laboratory Testing

October 2019

DRAFT

Prepared by:
Bora Cetin – Principal Investigator
Haluk Sinan Coban – Graduate Research Assistant

Reviewed by:
William J. Likos – Co-Principal Investigator
Tuncer B. Edil – Co-Principal Investigator
Askin Ozocak – Visiting Scholar

TASK 4

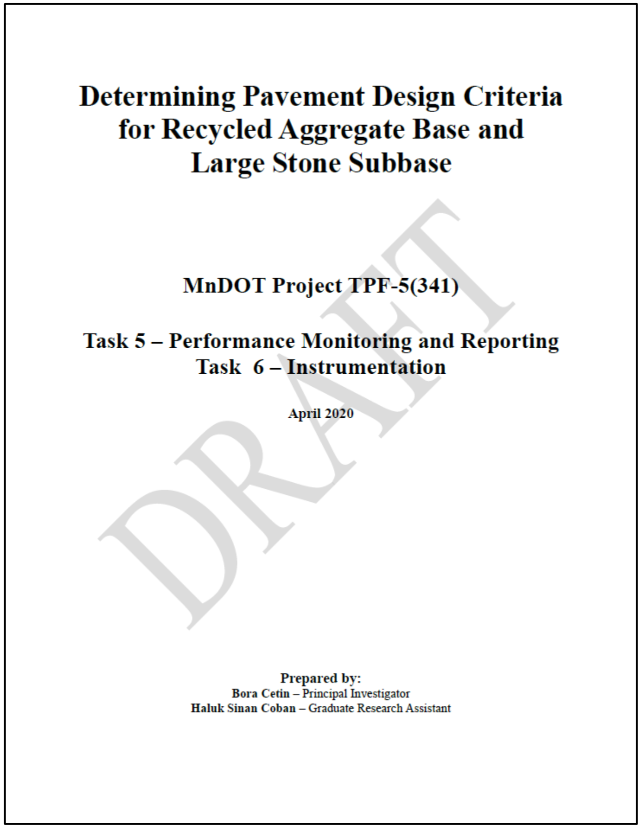
Laboratory Testing - Summary

- Class 6 & Class 5Q Aggregates → recycled
  - Class 6 Aggregate → similar to RCA+RAP
  - Class 5Q Aggregate → similar to Coarse RCA
- K_{sat}
  - Fine RCA > Class 5Q Aggregate > Coarse RCA > RCA+RAP > Class 6 Aggregate > Limestone
  - Porosity ↑ K_{sat} ↑
- Abrasion
  - Class 5Q Aggregate > Coarse RCA > Fine RCA > Class 6 Aggregate > RCA+RAP > Limestone
  - Higher abrasion for recycled aggregates

TASKS 5 & 6

Performance Monitoring and Reporting & Instrumentation

- Meteorological data
- Soil temperature and moisture monitoring
  - Temperature profiles
  - VWC profiles
  - Annual frost penetration depths
  - F-T periods
- FWD tests
- Frost heave & thaw settlement
- Rutting
- IRI
- Pavement distresses


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

MnDOT Project TPF-5(341)

Task 5 – Performance Monitoring and Reporting
Task 6 – Instrumentation

April 2020

DRAFT

Prepared by:
Bora Cetin – Principal Investigator
Haluk Sinan Coban – Graduate Research Assistant

TASKS 5 & 6

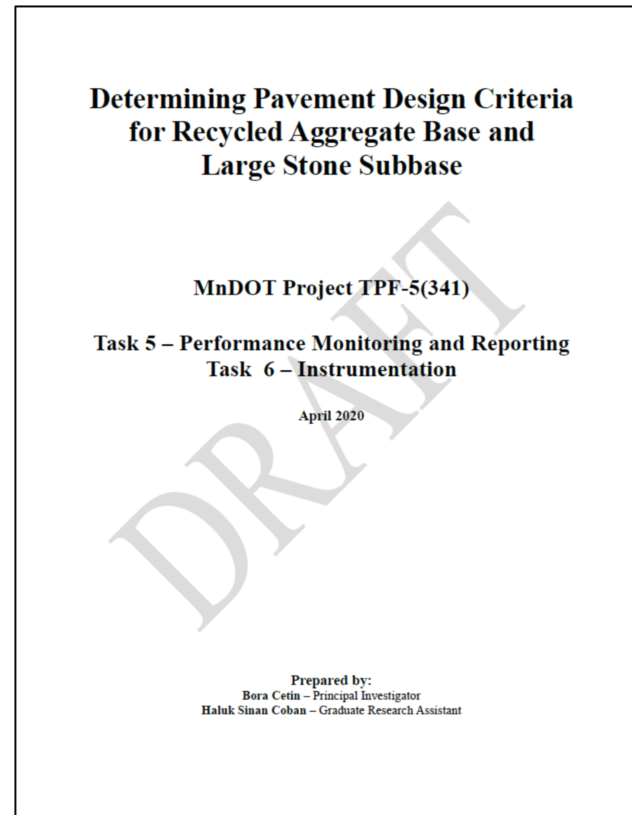
Performance Monitoring and Reporting & Instrumentation - Summary

- Successful detection of frost penetration depths & F-T periods
  - Consistency between thermocouple & moisture probe readings
- Field performance
  - Fine RCA > Coarse RCA > RCA+RAP > Limestone
  - Thicker LSSB > thinner LSSB

TASK 7

Pavement Design Criteria

- Estimation of laboratory test results
  - Proctor compaction (MDD & OMC)
  - K_{sat}
  - SWCC (θ_r, θ_S, and air-entry pressure)
  - M_R (SM_R, k_1, k_2, k_3)
  - Abrasion
- Estimation of field test results during construction
  - DCP (DCPI and CBR)
  - LWD (E_{LWD})
  - FWD (E_{FWD})
  - IC (M_R)
- Pavement ME performance models
  - Equivalent (or similar) structural capacity



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

DRAFT

MnDOT Project TPF-5(341)

Task 5 – Performance Monitoring and Reporting
Task 6 – Instrumentation

April 2020

Prepared by:
Bora Cetin – Principal Investigator
Haluk Sinan Coban – Graduate Research Assistant

TASK 7

Pavement Design Criteria - Summary

- Correlation equations
- Common parameters → estimation of more advanced parameters
- Relative breakage
  - Residual mortar content ↑ coarse OD Gs ↓ breakage ↑
  - Roundness ↑ breakage ↓
- Thinner RAB layers (as thin as 4 in)
- More info needed for LSSB layers

TASK 8

Draft Report

- 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

CONCLUSIONS & RECOMMENDATIONS

Material Selection for RAB Layers

- Material classification
  - Assessing G_s, absorption, and residual mortar contents
- Water absorption
  - Fine RCA > Coarse RCA > Class 5Q Aggregate > RCA+RAP > Class 6 Aggregate > Limestone
  - RCA → higher absorption
  - Absorption ↑ F-T durability ↓
  - Mixing RCA & RAP → absorption ↓ (mix until 4.3% absorption)
  - Absorption of coarser RCA < finer RCA (no more than 7% absorption)
- Hydrophobicity
  - Asphalt binder → 3% (ignition) or 1.5% (extraction)
  - F-T durability ↑
  - Drainage

CONCLUSIONS & RECOMMENDATIONS

Material Selection for RAB Layers - cont'd

- Abrasion
  - Class 5Q Aggregate > Coarse RCA > Fine RCA > Class 6 Aggregate > RCA+RAP > Limestone
  - High breakage of RCA → fines ↑ drainage ↓ durability ↓
  - Coarser RCA → lower DOC
  - Gradation after compaction
- Permeability
  - Fine RCA > Class 5Q Aggregate > Coarse RCA > RCA+RAP > Class 6 Aggregate > Limestone
  - Porosity ↑ K_{sat} ↑
  - Finer RCA → Porosity ↑
- Field performance
  - Fine RCA > Coarse RCA > RCA+RAP > Limestone

CONCLUSIONS & RECOMMENDATIONS

Material Selection for LSSB Layers

- Large stone → poorly graded
- Large voids → particle reorientation
- Subgrade soil pumping & rutting
- Well graded → less pumping & rutting

CONCLUSIONS & RECOMMENDATIONS

RAB Layer Design

- Thickness optimization
  - IRI & rutting
  - Alligator & longitudinal cracking
- RAB layer thickness < Limestone base layer thickness
- As thin as 4 in (instead of 12 in Limestone base)
- Minimize water-related issues
  - High absorption of RCA
  - Highly permeable subbase
  - Geosynthetics
    - Between base/subbase
    - Middle of base
- Gradation after compaction
- G_s and absorption → estimate other design input parameters

CONCLUSIONS & RECOMMENDATIONS

LSSB Layer Design

- LSSB → good drainage
  - Intermingling of subgrade/LSSB
  - Drainage ↓
- LSSB thickness → must be adequate
- Geogrid aperture size
  - Interlocking
  - Few geogrids
- Geosynthetic in the middle of LSSB
  - To improve lateral drainage
  - Not practical → problem with staged construction
- Geosynthetic on top of LSSB
  - To improve load distribution & stability of LSSB

Thank You!

QUESTIONS??

AGENCY MEMBERS

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

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
- University of California Pavement Research Center
- 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
- 3M
- Pavia Systems, Inc.
- All States Materials Group
- Payne & Dolan, Inc.
- 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