

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

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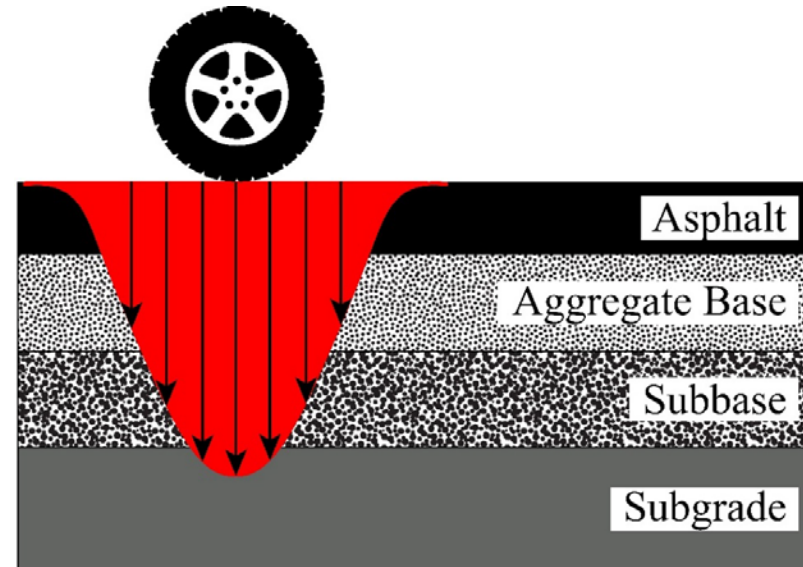
MnDOT Project TPF-5(341)
NRRA Monthly Geotechnical Team Meeting
December 3, 2020

OUTLINE

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

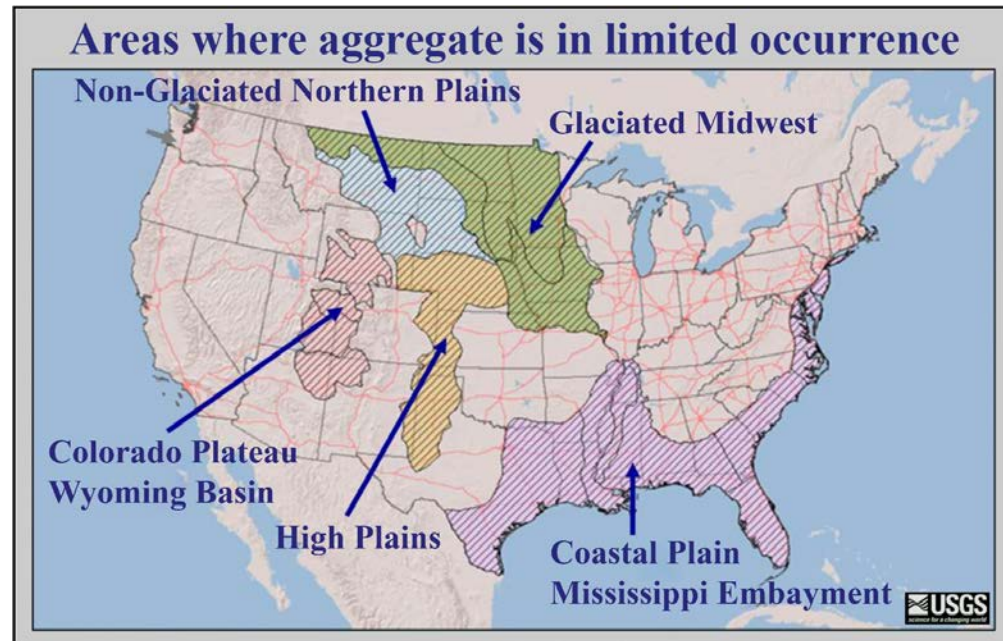
INTRODUCTION

- 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



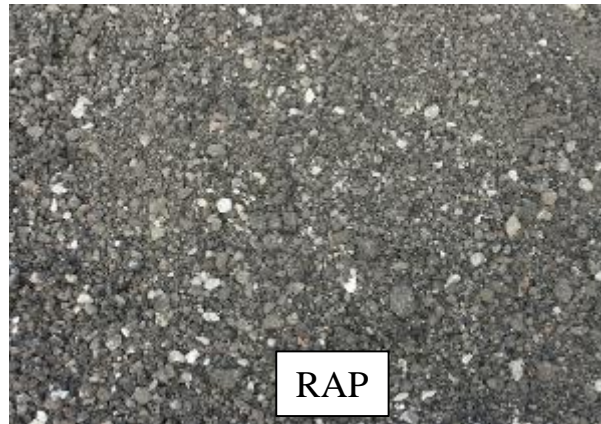
https://pubs.usgs.gov/of/2011/1119/pdf/OF11-1119_report_508.pdf

INTRODUCTION

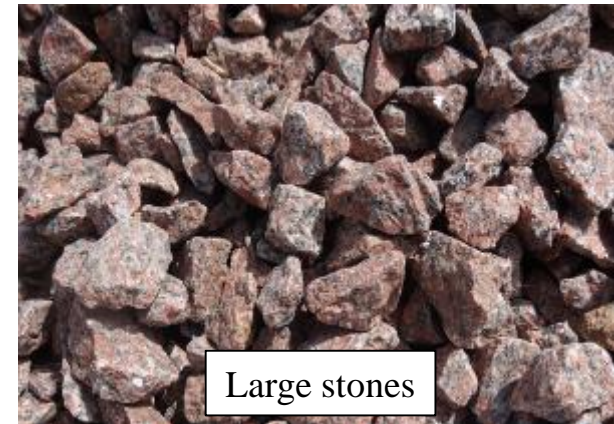
- Recycled concrete aggregate (RCA)
 - Old & failed rigid pavements
 - Demolished structures
- Recycled asphalt pavement (RAP)
 - Old & failed asphalt pavement surfaces
- Large stones
 - Majority of particles > 25 mm



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

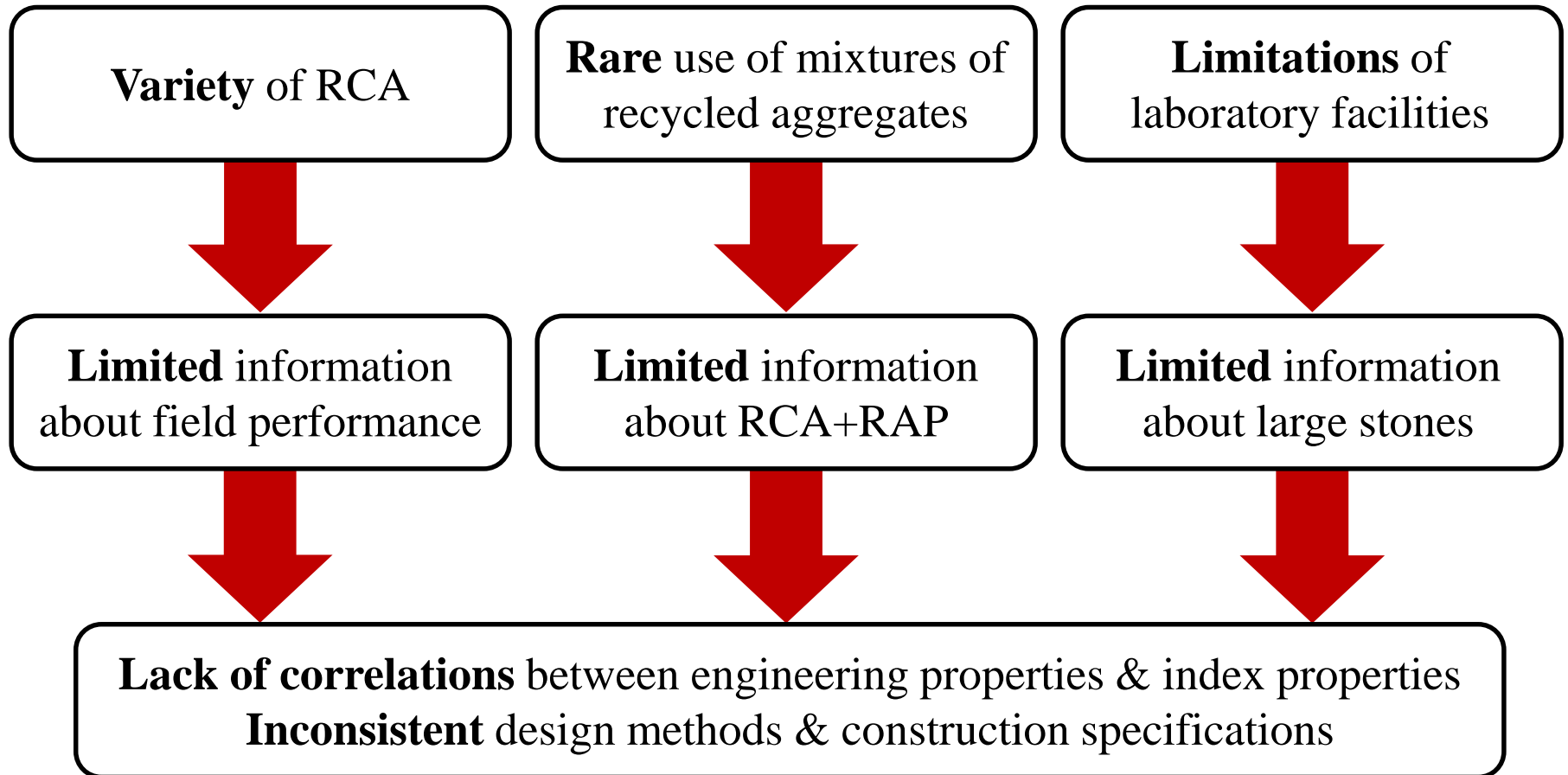


https://arthuge.com/dirt_sand_gravel_limestone_fill_sand_prices



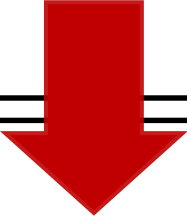
<https://greelysand.com/shop/decorative-stone-river-rock/granite-stone/>

RESEARCH MOTIVATION

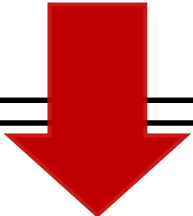


OBJECTIVES

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

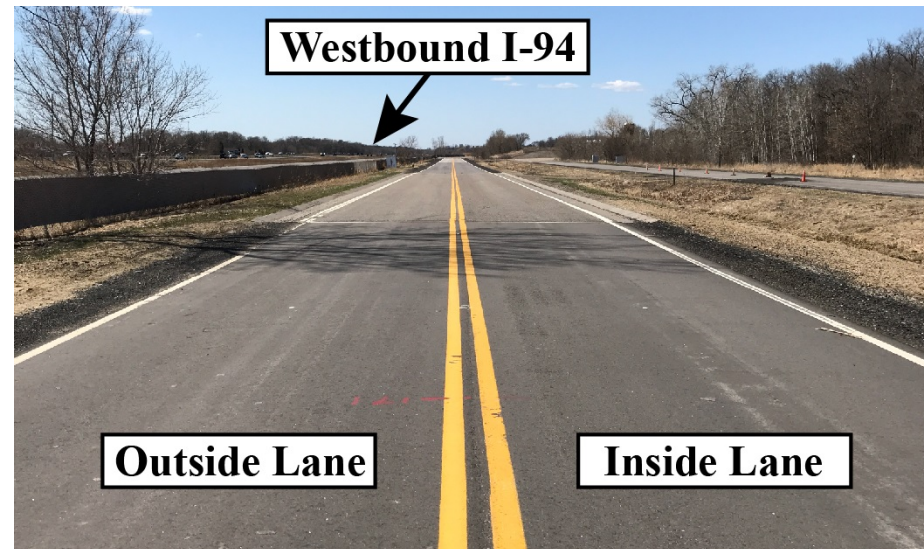
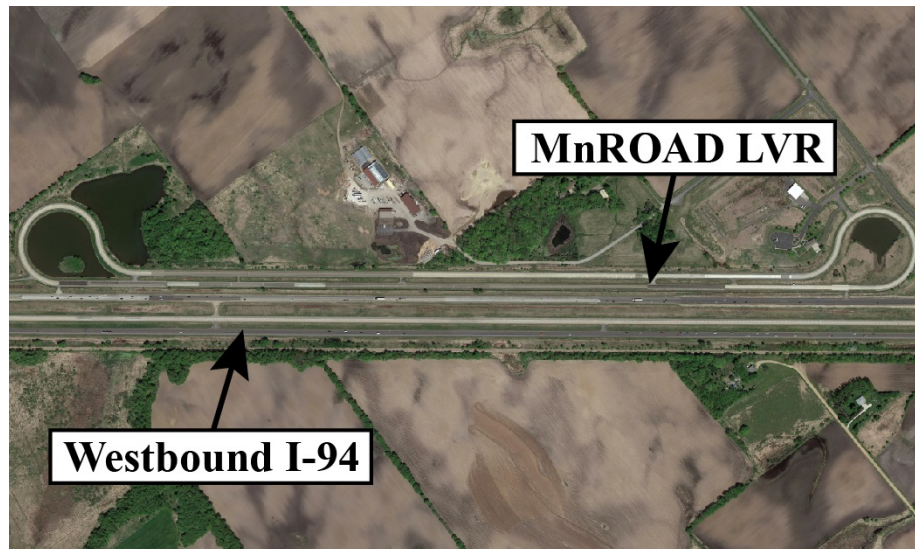
- **Task 1** – Literature review and recommendations
- **Task 2** – Tech transfer “state of practice”
- **Task 3** – Construction monitoring and reporting
- **Task 4** – Laboratory testing
- **Task 5** – Performance monitoring and reporting
- **Task 6** – Instrumentation
- **Task 7** – Pavement design 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

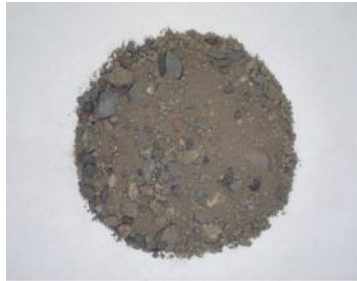
Recycled Aggregate Base				Large Stone Subbase		Large Stone Subbase with Geosynthetics				
185	186	188	189	127	227	328	428	528	628	728
3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	3.5 in Superpave	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	9 in LSSB	9 in LSSB	9 in LSSB	9 in LSSB
Sand	Sand	Clay Loam	Clay Loam			TX	TX+GT	BX+GT	BX	
				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



Sand Subgrade



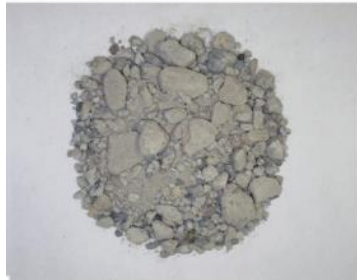
Clay Loam



Select Granular Borrow



LSSB



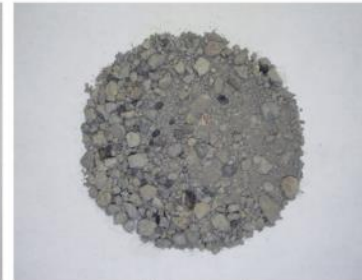
Coarse RCA



Fine RCA



Limestone



RCA+RAP



Class 6 Aggregate



Class 5Q Aggregate

1 in (25.4 mm)

TASK 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

Investigators:

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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



NRRRA
National Road Research Alliance

June 2015

TECH TRANSFER “STATE OF PRACTICE” REVISED DRAFT REPORT

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

MaDOT Project TPF-(5341)

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The NRRRA pooled fund wants to provide guidance for the Phase II MaROAD research program. Led by six Executive Committee of nine DOT members, NRRRA will plan and oversee the entire lifecycle of MaROAD research, from the selection of research topics to communication and implementation of results. NRRRA will consist of the project teams: Faetha, Rigal, Gonszalcz, Perumara Mounassarani and Technology Transfer.

NRRRA members will help shape the MaROAD research program by guiding the selection of research projects, determining research needs, and helping agencies put the results into place.



Current NRRRA Agency Members

Develop Collaborate Research Implement

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

Introduction

The performance of the layers beneath the pavement surface (aggregate base, subbase, and subgrade) are very important for the long-term pavement performance since they help to distribute the vehicle loads in both rigid and flexible pavements (Little and Nair 2009). The aggregate base course is generally the first layer beneath the pavement surface course (Gonszalcz and Kolagunta 2001). It is made of coarse-grained materials to provide a stiff and permeable layer (Schuettepeltz et al. 2010, Haider et al. 2014, Cetra et al. 2014, Edil and Cetra 2015). Adequately stiff aggregate base course reduces the deformations and increases the lifespan of the pavement (Edil et al. 2012). The high stiffness of aggregate base layers improves the stability of the sublayer by improving the vertical load distribution (Zornberg 2017). Generally, virgin aggregates (VA) are used for an aggregate base course in a pavement system (Perkins et al. 2005).

About 1.33 billion tons of VA were produced in the US in 2017, and about 76% of the materials were used for pavement construction (USGS 2018). The price of VA has increased due to the high demand, depletion of natural sources and federal local restrictions regarding material production (ACPA 2010). Using recycled aggregate base materials can help the environment by reducing the consumption of natural sources, improving waste utilization and decreasing the greenhouse gas emissions and energy consumption (Lee et al. 2010). In addition, using recycled aggregate base materials can provide overall project savings by minimizing the transportation costs of VA and decreasing the disposal costs of the recycled materials (Gonzalez and Moo-Young 2004).

Recycled Aggregate Base Materials

Recycled asphalt pavement (RAP) (Figure 1) and recycled concrete aggregate (RCA) (Figure 2) have been used by some DOTs (Caltrans, IDOT, MaDOT, and WisDOT) in hot mix asphalt (HMA) mixtures and in aggregate base applications. Old asphalt pavement surfaces are milled to a specific depth (depending on the surface course thickness) and processed to obtain RAP (Edil 2011).

Existing hardened concrete from old pavement surfaces or from other structures such as buildings and bridges is crushed. Then, construction debris and steel used as a reinforcement are removed and the end product is called RCA (Edil et al. 2012, LFRB 2016). RAP and RCA materials can be either used at the same construction site or stockpiled for further applications. Producing and using these materials at the same construction site can help to reduce the cost and duration of the construction. Up to 30% of cost savings could be achieved by in-place recycling of aggregate base materials (Edil 2011).



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



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

Index Properties of RAP and RCA

Material characteristics such as mineralogy, gradation, angularity, and texture are different for each aggregate material (Tutumluer 2013). The index properties of RAP and RCA are highly affected by several factors such as the material source, aggregate type, and crushing operations. RAP and RCA can contain a variety of impurities, such as steel, wood, and tire residual which affect their index properties. The amount of the impurities is not constant and is affected by the original material source, removal and construction operations, and crushing methods (Jayakody et al. 2017).



NRRRA
National Road Research Alliance

June 2015

TECH TRANSFER “STATE OF PRACTICE” REVISED DRAFT REPORT

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

MaDOT Project TPF-(5341)

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NRRRA members will help shape the MaROAD research program by guiding the selection of research projects, determining research needs, and helping agencies put the results into place.



Current NRRRA Agency Members

Develop Collaborate Research Implement

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

Introduction

The main working mechanism of a pavement is distributing the traffic and vehicle loads to the sub-layers. The quality of base, subbase, and subgrade layers underlying a surface course is significant for the long-term pavement performance (Little and Nair 2009). Subbase-course (Figure 1) is generally the second main load carrying layer after the base course. It is an optional layer and it is used to increase the efficiency of load distribution (Floppe et al. 2015) and to separate the base and subgrade layers. It is constructed to create a working platform over a weak and soft subgrade layer (Schuettepeltz et al. 2010) and to eliminate the water mitigation by capillary action (Zornberg 2012). Depending on the DOT, similar quality requirements are applied to both base and subbase layer aggregates. However, relatively lower-quality aggregates and more rounded particles than the base layer aggregates can also be used (Perkins et al. 2005, Zornberg 2012).



Figure 1. General structure of rigid and flexible pavements

The subgrade layer should be strong and durable enough to withstand the loads and to increase the designed service life of the pavement (Kazmee et al. 2016). Due to the front-beave and thru-weakening susceptibility of a fine-grained subgrade soil, a coarse-grained aggregate (Figure 2) layer is constructed to minimize the instability caused by the subgrade soil and to protect the upper layers (surface and base courses). The coarse-grained structure of the aggregate layer minimizes the capillary action and helps to evacuate the water coming from top layers easily (Uhlmeier et al. 2003).

Large Stone Subbase Materials

The application of large stone subbase (LSSB) materials for the subbase layers and working platforms has been investigated by Idaho DOT, Illinois DOT, and Wisconsin DOT (Uhlmeier et al. 2003; Kazmee et al. 2015; Kazmee et al. 2016). To improve the sustainability of the pavement systems, using alternative materials such as LSSB materials has been becoming popular. Large stones generally go through a single crushing operation. Thus, the amount of energy consumed to break up larger aggregates to obtain conventional aggregate gradations for the subbase construction can be reduced by LSSB-type of materials (Kazmee et al. 2015).



Figure 2. Fine- to coarse-grained aggregates (left to right) (<http://engineeringfeed.com/3-factors-affect-workability-fresh-concrete>)

Index and Engineering Properties of LSSB Materials

Due to their large-sizes and the limitations of the test equipment and laboratory facilities, the LSSB materials cannot be tested easily in the laboratory. However, several field observations have been made. Thus, limited information is available in the literature regarding their index and engineering properties (Kazmee and Tutumluer 2015).

Grain Gradation Characteristics

Since it is not practicable to sieve the large-size aggregates (e.g., LSSB) due to the limitations of the standard sieve sizes, the high-resolution image techniques can be performed to obtain their particle size distribution (Kazmee and Tutumluer 2015). In addition, several other morphological properties such as the elongation and angularity of particles can be observed by the imaging techniques. The angularity of aggregates increases as the crushing operations goes from the primary stage to further stages. In general, the large-size aggregates may have less angularity compared to the conventional aggregates because they generally go through a single crushing operation (Kazmee et al. 2016).

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

MnDOT Project TPF-5(341)

Task 3 – Construction Monitoring and Reporting

November 2018

Investigators:

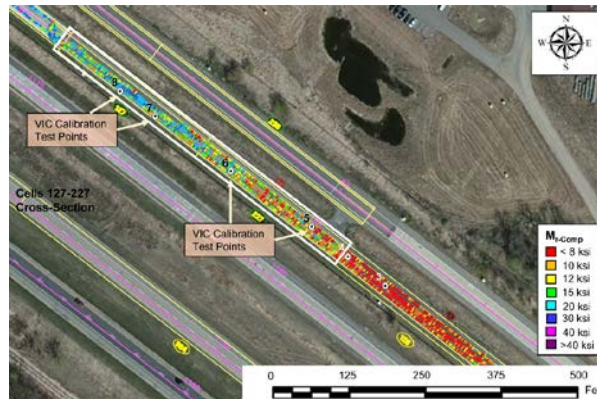
Bora Cetin – Principal Investigator
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William J. Likos – Co-Principal Investigator
Tuncer B. Edil – Co-Principal Investigator



(White and Vennapusa 2017)



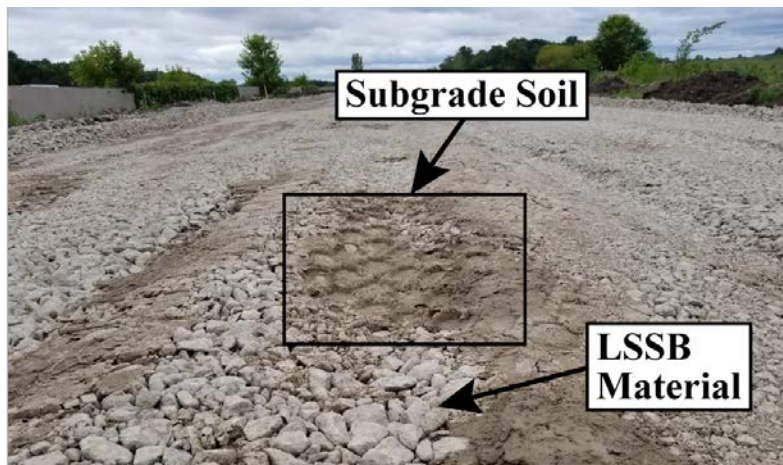
(White and Vennapusa 2017)



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

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

TASK 4

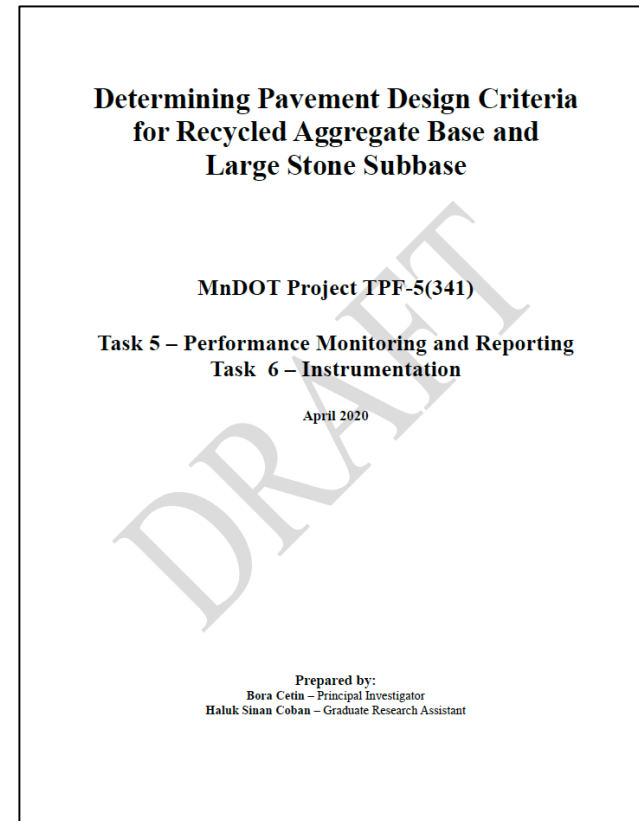
Laboratory Testing - Summary

- 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



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**

MnDOT Project TPF-5(341)

Task 5 – Performance Monitoring and Reporting
Task 6 – Instrumentation

April 2020

Prepared by:
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TASK 7

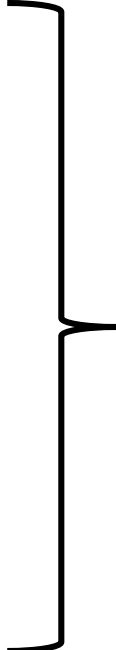
Pavement Design Criteria - Summary

- 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??

IOWA STATE
UNIVERSITY



MICHIGAN STATE
UNIVERSITY

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