



Transportation Research Synthesis

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PREFERRED AGGREGATE BASE COURSES FOR LOW-VOLUME ROADS

Prepared by CTC & Associates LLC

MnDOT's Class 5 virgin aggregate is widely used in the base course of the state's rural pavements. The Local Road Research Board and the MnDOT Office of Materials and Road Research are interested in learning about the preferred aggregate base courses used for low-volume asphalt and concrete pavements in states with climates that are similar to Minnesota's, particularly in how other state transportation agencies' preferred aggregate bases compare to MnDOT's Class 5 virgin aggregate.



To inform an analysis of other aggregate base courses, researchers surveyed selected state transportation agencies about their preferred aggregate for low-volume asphalt and concrete pavements and a secondary aggregate that is used nearly as frequently as the preferred aggregate. This Transportation Research Synthesis presents the findings from the survey and compares the characteristics, specifications and performance of the materials. Results from a limited literature search supplement the survey results.

Technical Advisory Panel

Richard West, Technical Liaison
Otter Tail County, Minnesota

Matt Mullins, Principal Investigator
CTC & Associates LLC

Mark Linsenmayer, Principal Investigator
CTC & Associates LLC

Leif Halverson, Project Coordinator
MnDOT Office of Research & Innovation

Eddie Johnson, Panelist
MnDOT Office of Materials & Road Research

The purpose of this TRS is to serve as a synthesis of pertinent completed research to be used for further study and evaluation by MnDOT and the Local Road Research Board. This TRS does not represent the conclusions of the authors, MnDOT or LRRB.

Preferred Aggregate Base Courses for Low-Volume Roads

Introduction

The Local Road Research Board (LRRB) and MnDOT Office of Materials and Road Research are investigating the preferred aggregate base courses used for low-volume asphalt and concrete pavements in states with climates similar to Minnesota's. MnDOT and LRRB are particularly interested in how the preferred aggregate bases of other state departments of transportation (DOTs) compare to MnDOT's Class 5 virgin aggregate, which is widely used in the state's rural pavements.

Selected state DOTs were surveyed about their preferred low-volume road base aggregates and a secondary type of aggregate used almost as frequently as the preferred material. This Transportation Research Synthesis presents the findings from the survey, including a comparison of the preferred and secondary aggregate base courses used to construct low-volume roads, the aggregate materials' specifications and an assessment of the materials' performance. The results of a limited literature search supplement the survey results.

Summary of Findings

This Transportation Research Synthesis is divided into two sections:

- Survey of practice.
- Related research.

Survey of Practice

An online survey was distributed to nine member states of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Materials and Pavements. Survey findings and the results of follow-up communications with selected respondents are presented below in three topic areas:

- Preferred aggregate base courses.
- Secondary aggregate base courses.
- Anticipated revisions to specifications.

Preferred Aggregate Base Courses

Aggregate Description

Tables 1 and 2, which begin on page 5, compare the material characteristics of MnDOT's Class 5 aggregate and the preferred base course aggregate from eight of the nine responding states. (The Illinois DOT respondent indicated the state does not specify base course aggregates for low-volume roadways.) Wyoming DOT uses only virgin or natural materials as its preferred aggregate. Other respondents reported that their agencies permit the use of recycled materials in their preferred base course aggregate.

Minnesota and five of the responding states (Indiana, Iowa, Michigan, Wisconsin and Wyoming) specify 1.5 inch as the maximum size for aggregate gradation blends. North Dakota and South Dakota DOTs specify a maximum size of 1 inch, and Montana DOT accepts aggregate as large as 2 inches.

Five states specify minimum crushed content with respect to a percent passing a specific sieve size: Four states (Indiana, Montana, South Dakota and Wyoming) specify a No. 4 sieve (4.75 mm), and one state (Iowa) specifies a 3/8-inch sieve. Minnesota and Michigan specify a percentage of the maximum aggregate size.

Like MnDOT, Indiana and North Dakota DOTs limit shale. Durability requirements vary: Three states (Minnesota, South Dakota and Wyoming) place a 40 percent loss limit for Los Angeles (L.A.) abrasion testing; five states (Iowa, Michigan, Montana, North Dakota and Wisconsin) set the limit at 50 percent; and one state (Indiana) at 45 percent.

While only Minnesota limits acid-insolvent limestone or carbonate fines in specifications, respondents' specifications for overall fines content include an accepted range similar to the 3 to 10 percent limit that Minnesota specifies. Three DOTs apply slightly broader ranges: 3 to 12 percent (South Dakota); 2 to 12 percent (Wisconsin); and 3 to 12 percent (grading Class W) or 3 to 15 percent (grading Class L) (Wyoming).

Material Use and Specifications

Indiana, Iowa, Michigan and Wisconsin DOTs specifically allow recycled asphalt pavement, concrete pavement or industrial byproducts in some combination. Minnesota prefers virgin aggregate in these applications, and Wyoming DOT only accepts virgin or natural materials; Montana, North Dakota and South Dakota DOTs defer to physical requirements and tested characteristics without explicitly naming materials in the specifications.

Links to each state's specifications or specified details are provided in the **Detailed Findings** section of the report.

Performance Assessment

Respondents from all state agencies except Illinois DOT rated the effectiveness of their agencies' preferred aggregate base course in terms of drainage, resistance to rutting, resistance to freeze-thaw damage, durability and production cost. Each performance characteristic was rated on a scale of zero to 2, where zero = poor, 1 = acceptable and 2 = very good.

The Montana DOT respondent rated its aggregate as very good in every category. Respondents from Michigan and North Dakota DOTs provided the lowest average rating, with each characteristic rated as acceptable or poor. On average, aggregates performed at 1 for drainage; 1.4 for rutting resistance, freeze-thaw resistance and production cost; and 1.5 for durability.

Secondary Aggregate Base Courses

Respondents from three states—Iowa, Michigan and South Dakota—described a secondary base course used approximately 10 percent as often as the preferred aggregate base.

Aggregate Description

Table 4 (see page 12) compares the material characteristics of MnDOT's Class 5 aggregate and the three DOTs' secondary aggregate base courses. Iowa DOT uses a modified subbase, Michigan DOT uses open-graded drainage aggregate 4G, and South Dakota uses salvaged base course and gravel cushion.

The maximum size for aggregate gradation blends is 1 inch in South Dakota, 1.5 inch in Iowa and determined by individual contract in Michigan. Only the Michigan DOT respondent reported on the crushed content of the secondary aggregate, which is a minimum of 95 percent. Iowa and Michigan DOTs place a 45 percent loss limit

for L.A. abrasion testing. Iowa DOT's specification for overall fines content is 3 to 10 percent; Michigan, 3 percent; and South Dakota, 3 to 12 percent.

Material Use and Specifications

Iowa DOT's modified subbase, selected for its durability and drainage qualities, is used in urban settings where contractors must drive on the grade. Michigan DOT's secondary base is an open-graded base course (the primary base course is dense-graded) and is used under concrete pavements with edge drain systems. South Dakota DOT's salvaged, modified bases are used quite often in unspecified applications.

Links to specifications for each secondary base course aggregate are provided in the **Detailed Findings** section of the report.

Performance Assessment

Performance ratings for South Dakota DOT's secondary base match the highly ranked performance of its primary aggregate. Michigan DOT's secondary aggregate performed slightly better than its primary aggregate, exceeding the primary aggregate in terms of drainage. Iowa DOT's secondary material received a lower rating than its primary aggregate.

Anticipated Revisions to Specifications

Four respondents described changes their agencies are considering for aggregate specifications in the next decade. Indiana DOT may adjust gradations for permeability considerations, and Michigan DOT may adjust gradations to reduce waste from crushing operations. Wisconsin DOT is considering adjusting freeze-thaw requirements to eliminate special provisions for a group of geologically similar counties. Wyoming is condensing and streamlining its specifications.

Related Research

Supplementing the survey results and specifications from survey respondents are documents sourced through a limited literature search. Several reports focus on Minnesota research, including a 2017 project that investigates recycled unbound base and asphalt surface materials, and a 2016 journal article that evaluates base layer aggregate gradations for the Class 5 and permeable aggregate base specifications used by MnDOT. Nationally, a 2013 NCHRP synthesis summarizes important aspects and effective practices related to material selection, design and construction of unbound aggregate layers. A 2019 Wisconsin DOT report provides a quantitative assessment of the use of recycled asphalt pavement and recycled concrete aggregates as base layers in hot-mix asphalt pavements.

Next Steps

Going forward, MnDOT may wish to consider:

- Following up with selected respondents to explore approaches used or gather additional information about agency practices in connection with aggregate base courses.
- Examining the use of recycled content as a preferred low-volume base course option. Four agencies—Indiana, Iowa, Michigan and Wisconsin DOTs—allow recycled materials in the preferred aggregate base course for low-volume roads. South Dakota DOT's secondary aggregate—salvaged base course and gravel cushion—has performed well, according to the respondent.

Detailed Findings

Preferred Aggregate Base Courses for Low-Volume Roads

Introduction

The Local Road Research Board (LRRB) and MnDOT Office of Materials and Road Research are investigating the preferred aggregate base courses used for low-volume asphalt and concrete pavements in states with climates similar to Minnesota's. MnDOT and LRRB are particularly interested in how the preferred aggregate bases of other state departments of transportation (DOTs) compare to MnDOT's Class 5 virgin aggregate, which is widely used in the state's rural pavements.

To inform a comparison of other state transportation agencies' aggregate base courses with MnDOT's Class 5 virgin aggregate, selected state DOTs were surveyed about the material specifications and the primary and secondary aggregate base courses used in their states. This Transportation Synthesis Report presents the findings from the survey, including a description of the aggregate, details about the use of these materials and relevant specifications, and an assessment of the performance characteristics of agencies' preferred aggregates. The results of a limited literature search supplement the survey findings.

Note: While MnDOT specifications allow for the use of virgin and recycled Class 5 material, this investigation focuses on a comparison of the Class 5 virgin alternative with other agencies' aggregates. Survey participants were provided with the following description of MnDOT's Class 5 virgin aggregate:

Virgin material that passes a 1.5-inch sieve with 10 percent crushed quarry material, with up to 10 percent shale (with 7 percent mass or less passing sieve No. 200) or 7 percent shale (if over 7 percent mass passes a No. 200 sieve), a maximum 40 percent Los Angeles Rattler (L.A.) loss from carbonate, and 10 percent maximum insoluble residue for carbonate aggregates passing a No. 200 sieve.

See page 9 for a link to the MnDOT specifications.

Survey of Practice

An online survey was distributed to nine member states of the American Association of State Highway and Transportation Officials (AASHTO) Committee on Materials and Pavements:

- Illinois.
- Indiana.
- Iowa.
- Michigan.
- Montana.
- North Dakota.
- South Dakota.
- Wisconsin.
- Wyoming.

All of these states responded to the survey. Survey questions are provided in [Appendix A](#). The full text of survey responses is provided in a supplement to this report. [Appendix B](#) provides the contact information for survey respondents.

Below is a discussion of survey results in the following topic areas:

- Preferred aggregate base courses.
- Secondary aggregate base courses.
- Anticipated revisions to specifications.

Specifications provided by respondents are included after the discussion of each topic area. Additional publications sourced through a limited literature research appear in the **Related Research** section that begins on page 16.

Preferred Aggregate Base Courses

Respondents provided descriptions of the typical aggregate used as a base course for low-volume roadways. Findings are presented in three topic areas:

- Aggregate description.
- Material use and specifications.
- Performance assessment.

Aggregate Description

The material characteristics of MnDOT’s Class 5 virgin aggregate and of respondents’ aggregate base courses are described below in two tables:

- Table 1 provides details of the preferred aggregate base material in Indiana, Iowa, Michigan and Montana.
- Table 2 provides details of the preferred aggregate base material in North Dakota, South Dakota, Wisconsin and Wyoming.

The Illinois DOT respondent reported that the agency does not specify an aggregate base course for low-volume pavements.

Table 1. Material Requirements of Preferred Aggregate Base Course for Low-Volume Roads

Material Characteristic	Minnesota	Indiana	Iowa	Michigan	Montana
Designation	Class 5	Indiana 53 (Class D or higher)	Granular subbase (crushed stone or gravel)	Includes dense-graded aggregates 21A and 22A	Crushed base course Type A
Material Type	Virgin	Natural or manufactured materials	Crushed virgin or recycled aggregate	Crushed carbonate; gravel; blast-furnace slag; or recycled concrete; dense-graded aggregate	N/A
Size, Maximum	100% passing 1.5-inch sieve	100% passing 1.5-inch sieve	100% passing 1.5-inch sieve	100% passing 1.5-inch sieve (21A); 100% passing 1-inch sieve (22A)	100% passing 2-inch sieve (5A); 100% passing 1.5-inch sieve (6A)

Material Characteristic	Minnesota	Indiana	Iowa	Michigan	Montana
Crushed Content, Minimum	10%	20% retained on No. 4 sieve (4.75 mm)	For gravel, 30% or more of materials retained on 3/8-inch sieve must have at least one fractured face.	25% (gravel, stone and crushed concrete)	At least 35% by weight of aggregate retained on No. 4 sieve has at least one mechanically fractured face.
Deleterious Materials	Max. 10% shale (with 7% mass or less passing No. 200 sieve) or 7% shale (if over 7% mass passing No. 200 sieve)	Max. 4% clay, 8% nondurable (including shale), 10% chert; % of coke and iron limited in certain applications	For virgin material, max. 1.5% alumina; max. 25% A Freeze value	N/A	N/A
Abrasion/Wear (L.A.), Maximum	40%	45%	50% (virgin material)	50%	50% (500 revolutions)
Insoluble Residue for Carbonates Passing No. 200 Sieve	Max. 10% (carbonates)	N/A	N/A	N/A	N/A
Fines, Passing No. 200 Sieve	3%-10%	5%-10%	0%-6% crushed stone, 3%-7% crushed gravel	4%-8% loss by washing	0%-8%

N/A Respondent did not provide this level of detail in the survey response; follow-up efforts to obtain this information were unsuccessful.

Table 2. Material Requirements of Preferred Aggregate Base Course for Low-Volume Roads

Material Characteristic	Minnesota	North Dakota	South Dakota	Wisconsin	Wyoming
Designation	Class 5	Class 5	Base course or gravel cushion	N/A	Type II
Material Type	Virgin	Gravel, sand; may include limited quantities of fine soil particles as binding material	Durable particles of ledge rock, gravel, recycled concrete pavement; sand	Virgin crushed gravel or stone, crushed concrete, recycled asphalt	Crushed stone, crushed or natural gravel
Size, Maximum	100% passing 1.5-inch sieve	100% passing 1-inch sieve	100% passing 1-inch sieve	100% passing 1.5-inch sieve (crushed gravel or stone, crushed concrete); 100%	100% passing 1.5-inch sieve; 1/2-inch nominal maximum

Material Characteristic	Minnesota	North Dakota	South Dakota	Wisconsin	Wyoming
				passing 1.25-inch sieve (recycled asphalt)	
Crushed Content, Minimum	10%	N/A	Plus No. 4 sieve: 30% 1 cubic foot	N/A	Will soon require 100%; at least 50% of material on No. 4 sieve must have one or more fractured faces.
Deleterious Materials	Max. 10% shale (with 7% mass or less passing No. 200 sieve) or 7% shale (if over 7% mass passing No. 200 sieve)	Max. 12% shale with 10% fractured faces	N/A	Requires material be “substantially free of deleterious materials”	N/A
Abrasion/Wear (L.A.), Maximum	40%	50%	40%	50% for crushed stone and gravel	40%
Insoluble Residue for Carbonates Passing No. 200 Sieve	Max. 10% (carbonates)	N/A	N/A	N/A	N/A
Fines, Passing No. 200 Sieve	3%-10%	4%-10%	3%-12% (fraction passing No. 200 sieve no greater than 2/3 of the fraction passing No. 40 sieve)	2%-12%	3%-15% (grading Class L); 3%-12% (grading Class W)

N/A Respondent did not provide this level of detail in the survey response; follow-up efforts to obtain this information were unsuccessful.

Material Use and Specifications

Additional information from respondents is presented below about their agencies’ preferred aggregate base course materials, their uses and relevant specifications. This information was gathered through survey responses, follow-up communication with selected respondents and a review of specifications.

Illinois

Material Use: Illinois DOT does not specify an aggregate base course for low-volume pavements in most conditions. The agency designates roadways with a design traffic level of under 400 average daily traffic (ADT) as Class IV, and 400 to 2,000 ADT as Class III. For Class III and IV asphalt pavements, and for concrete and composite low-volume pavements of small quantities (for example, less than a city block in length), base

specifications are not provided. Instead, the agency requires that a granular subbase or improved subgrade be used as a working platform on locations where poor soil conditions exist.

Specifications:

Special Provision for Aggregate Subgrade Improvement, Memorandum, Illinois Department of Transportation, January 8, 2016.

<http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Specialty-Lists/Highways/Design-&-Environment/BDE-Special-Provisions/80274.pdf>

From the memorandum: This special provision was developed by the Bureau of Materials and Physical Research to allow the use of gravel in fills over 24 inches in thickness.

Chapter 44, Pavement Design, Bureau of Local Roads and Streets Manual, Illinois Department of Transportation, June 2018.

<http://www.idot.illinois.gov/Assets/uploads/files/Doing-Business/Manuals-Guides-&-Handbooks/Highways/Local-Roads-and-Streets/Local%20Roads%20and%20Streets%20Manual.pdf>

Section 44-1.01 provides pavement design definitions (page 1468 of the PDF). A flowchart of pavement type selection is shown in Figure 44-1E (page 1476 of the PDF).

Indiana

Material Use: Indiana DOT uses Indiana 53 as a base for asphalt and concrete pavements of all design volumes. Specifications indicate that base courses are required to be Class D or higher. For higher-volume roadways, the agency includes a drainage layer above the base course. In installations using slag for separation layers, the material must meet a fines requirement of 10 percent to 12 percent passing sieve No. 200.

Specifications:

Section 301, Aggregate Base, 2020 INDOT Standard Specifications, Indiana Department of Transportation, 2020.

<https://www.in.gov/dot/div/contracts/standards/book/sep19/300-2020.pdf>

This section describes use of coarse aggregate, Class D or higher placed on a prepared subgrade.

Section 901, PCC Materials, 2020 INDOT Standard Specifications, Indiana Department of Transportation, 2020.

<https://www.in.gov/dot/div/contracts/standards/book/sep19/900-2020.pdf>

Subsection 904.03(a) (page 948 of the specifications, page 40 of the PDF) provides the quality requirements for aggregates. Subsection 904.03(e) (page 952 of the specifications, page 44 of the PDF) provides the size requirements for Indiana 53.

Iowa

Material Use: Iowa DOT uses a granular subbase of crushed virgin or recycled aggregate with good durability and drainage properties.

Specifications:

Section 4121, Granular Subbase Material, Standard Specifications with GS [General Supplemental] 15009 Revisions, Iowa Department of Transportation, October 15, 2019.

<https://iowadot.gov/erl/current/GS/content/4121.htm>

This section describes the agency's subbase material and gradation requirements for crushed material and gravel.

Aggregate Gradation Table, Standard Specifications with GS [General Supplemental] 15009 Revisions, Iowa Department of Transportation, October 15, 2019.

<https://iowadot.gov/erl/current/GS/content/Appendix.htm#AggregateGradationEnglish>

Categories 12a and 12b of this aggregate gradation table describe granular subbase.

Michigan

Material Use: The respondent noted that the agency specifies a dense-graded aggregate base for the asphalt pavements typically constructed for local streets; material types include aggregates 21A and 22A (used under asphalt pavement that has no edge drain system), crushed carbonate, gravel, blast-furnace slag or recycled concrete aggregates.

Specification:

Section 902, Aggregates, 2012 Standard Specifications for Construction, Michigan Department of Transportation, 2012.

<https://mdotjboss.state.mi.us/SpecProv/getDocumentById.htm?docGuid=cfe35495-4208-4015-8a44-3f9dc3b76cac&fileName=%22902%20Aggregate.pdf>

Gradation requirements for aggregates 21A and 22A are included in Table 902-1 on page 746 of the specifications (page 9 of the PDF); physical requirements are described in Table 902-2 on page 747 of the specifications (page 10 of the PDF).

Minnesota

Specification:

Section 3138, Aggregate for Surface and Base Courses, Minnesota Standard Specifications for Construction, 2019 Edition, Minnesota Department of Transportation, June 2018.

<http://www.dot.state.mn.us/pre-letting/spec/2018/2018-spec-book-final.pdf>

Section 3138 provides the quality requirements for surface and base course aggregates, beginning on page 560 of the specifications (page 574 of the PDF).

Montana

Material Use: Montana DOT uses a crushed base course designated as Type A for all pavement types across the state. The agency requires that 35 percent by weight of the aggregate features at least one fractured face and specifies that the liquid limit must not exceed 25 for materials passing the No. 40 sieve.

Specification:

Section 701.02.4, Crushed Base Course Type "A," Standard Specifications for Road and Bridge Construction, 2014 Edition, Montana Department of Transportation, Montana Transportation Commission, 2014.

https://www.mdt.mt.gov/other/webdata/external/const/specifications/2014/2014_stand_specs.pdf

Section 701.02.4 provides the quality requirements for crushed base course Type A (page 438 of the specifications, page 466 of the PDF).

North Dakota

Material Use: North Dakota DOT uses Class 5 aggregate for both asphalt and concrete pavements.

Specification:

Section 816.02, Miscellaneous Aggregates, Standard Specifications for Road and Bridge Construction, North Dakota Department of Transportation, October 2014.

<https://www.dot.nd.gov/divisions/environmental/docs/supspecs/2014StandardSpecifications.pdf>

Section 816.02, which begins on page 466 of the specifications (page 474 of the PDF), provides specified gradations and physical requirements for Class 5 aggregate.

South Dakota

Material Use: South Dakota DOT prefers to use a material designated as base course under flexible pavements; gravel cushion is used under concrete. The two aggregate bases have the same specified gradations but different compaction and density requirements. Base course is compacted to 97 percent of the maximum dry density; gravel cushion is not compacted to a specified density.

Specification:

Standard Specifications for Roads and Bridges, South Dakota Department of Transportation, 2015.

https://dot.sd.gov/media/documents/2015_SDDOT_SpecBook.pdf

Section 260, Granular Bases and Surfacing, which begins on page 117 of the specifications (page 127 of the PDF), provides materials and construction guidance. Specific requirements of aggregates used for granular bases appear in Section 882, Aggregates for Granular Bases and Surfacing, which begins on page 547 of the specifications (page 557 of the PDF).

Wisconsin

Material Use: Wisconsin DOT prefers virgin crushed gravel or stone, crushed concrete or recycled asphalt for its standard base course. Crushed gravel or stone and crushed concrete require well-graded aggregate. The agency's specifications indicate that crushed stone and gravel must include 85 percent minimum virgin material. Crushed concrete must be at least 90 percent free of steel reinforcement and contain less than 10 percent asphaltic pavement and base materials. Reclaimed asphalt must include at least 75 percent asphaltic pavement or surfacing. Agency specifications also include detailed descriptions of reprocessed and blended material.

Specification:

Standard Specifications for Highway and Structure Construction, 2019 Edition, Wisconsin Department of Transportation, December 2018.

<https://wisconsin.dot.gov/rdwy/stndspec/mob-down/20stndspec.zip> (to download a PDF of the specifications)

Aggregate quality testing is discussed on page 37 of the specifications (page 46 of the PDF). Base course physical requirements are described on page 118 of the specifications (page 127 of the PDF).

Wyoming

Material Use: Wyoming DOT requires similar but not identical base courses for asphalt and concrete pavements, though the respondent noted that the state builds significantly more asphalt than concrete pavements. Both base courses use crushed stone and crushed or natural gravel. For asphalt, the Type II aggregate specifies a maximum of 40 percent L.A. abrasion loss, 18 percent soundness loss and plasticity of nonplastic. For coarse

concrete aggregate, the agency specifies the same 40 percent maximum L.A. abrasion loss, but a maximum of 12 percent soundness loss. Wyoming DOT has typically used natural stone and gravel with less than 100 percent crushed content but is moving to 100 percent crushed content in a current overhaul of specifications. In rare cases, if the contractor has no other options, grading Class J, 100 percent passing a 2-inch sieve, 0 to 15 percent passing No. 200, may be used.

Specification:

Standard Specifications for Road and Bridge Construction, 2010 Edition, Wyoming Department of Transportation, March 18, 2010.

<http://www.dot.state.wy.us/files/live/sites/wydot/files/shared/Construction/2010%20Standard%20Specifications/2010%20Standard%20Specifications.pdf>

Table 803.2.2-3 presents the gradation requirements of coarse aggregate for concrete (page 729 of the specifications, page 748 of the PDF). Table 803.4.4-1 describes the gradation requirements for Classes L and W, the agency’s preferred base aggregates (page 731 of the specifications, page 750 of the PDF).

Performance Assessment

Respondents from eight states rated the effectiveness of their agencies’ preferred aggregate base course for low-volume roads based on the following five performance characteristics:

- Drainage.
- Rutting resistance.
- Freeze-thaw resistance.
- Durability.
- Production cost.

Each performance characteristic was rated on a scale of zero to 2, where zero = poor, 1 = acceptable and 2 = very good. (N/A = not applicable.)

The Montana DOT respondent provided the highest ratings among respondents, rating the performance of the state’s preferred aggregate as very good in all categories. Respondents from Michigan and North Dakota DOTs provided the lowest average rating, with each characteristic rated as acceptable or poor.

The only poor ratings were given for drainage performance, a value selected by respondents from two states—Michigan and North Dakota. The Michigan DOT respondent explained that the state “predominantly” builds asphalt pavements for local streets with dense-graded aggregate bases; concrete intersections in such installations are common and require open-graded drainage courses. The Indiana DOT respondent did not rate drainage performance, noting that “drainage can vary.” Overall, drainage received an average performance rating of acceptable.

The four other performance characteristics received average ratings between acceptable and very good. Table 3 presents the survey results along with average ratings for each agency and each performance characteristic.

Table 3. Performance of Preferred Aggregate as Base Course for Low-Volume Roads

State	Drainage	Rutting Resistance	Freeze-Thaw Resistance	Durability	Production Cost	Average Rating
Indiana	N/A	1	1	1	1	1
Iowa	2	2	1	2	1	1.6
Michigan	0	1	1	1	1	0.8
Montana	2	2	2	2	2	2
North Dakota	0	1	1	1	1	0.8
South Dakota	1	2	2	2	2	1.8
Wisconsin	1	1	2	2	2	1.6
Wyoming	1	1	1	1	1	1
Average Rating	1	1.4	1.4	1.5	1.4	1.3

Secondary Aggregate Base Courses

Respondents from three states—Iowa, Michigan and South Dakota—described a secondary base course used approximately 10 percent as often as the preferred aggregate base. The Wyoming DOT respondent noted that the agency’s Type III secondary option was “rarely used.” Findings from Iowa, Michigan and South Dakota are presented in three topic areas:

- Aggregate description.
- Material use and specifications.
- Performance assessment.

Aggregate Description

Table 4 summarizes selected material characteristics of MnDOT’s Class 5 aggregate and of the three DOTs’ secondary aggregate base courses.

Table 4. Material Requirements of Secondary Aggregate Base Course for Low-Volume Roads

Material Characteristic	Minnesota	Iowa	Michigan	South Dakota
Designation	Class 5	Modified subbase	4G (open-graded base course used under concrete)	Base course, salvaged, or gravel cushion, salvaged
Material	Virgin	Blended and nonblended virgin materials	Crushed carbonate; gravel; blast-furnace slag; recycled concrete	May be combination of subbase material, in-place base course, or mix of base material with max. 50% millings

Material Characteristic	Minnesota	Iowa	Michigan	South Dakota
Size, Maximum	100% passing 1.5-inch sieve	100% passing 1.5-inch sieve	Per contract documents	100% passing 1.5-inch sieve; 95%-100% passing 1-inch sieve
Crushed Content, Minimum	10%	For gravel, 75% or more of materials retained on the 3/8-inch sieve have at least one fractured face.	95%	N/A
Deleterious Materials	Max. 10% shale or 7% shale	Max. 4.7% alumina (No. 40 material); max. 15% C Freeze value (see conditions)	N/A	N/A
Abrasion/Wear (L.A.), Maximum	40%	45%	45%	N/A
Insoluble Residue for Carbonates Passing No. 200 Sieve	Max. 10% (carbonates)	N/A	N/A	N/A
Fines, Passing No. 200 Sieve	3%-10%	3%-10%	3%	3%-12% (fraction passing No. 200 sieve no greater than 2/3 fraction passing No. 40 sieve)

N/A Respondent did not provide this level of detail in the survey response; follow-up efforts to obtain this information were unsuccessful.

Material Use and Specifications

Additional information from respondents is presented below about their agencies' secondary aggregate as a base course for low-volume pavements, their uses and relevant specifications. This information was gathered through survey responses, follow-up communication with selected respondents and a review of specifications.

Iowa

Material Use: Iowa DOT uses a modified subbase with good drainage properties and durability in urban environments where project geometry may require the contractor to drive on the grade. The material is slightly coarser on its top gradation size than the preferred base aggregate (granular subbase material) to allow for some breakdown of the aggregate.

Specifications:

Section 4123, Modified Subbase Material, Standard Specifications with GS [General Supplemental] 15009 Revisions, Iowa Department of Transportation, October 15, 2019.

<https://iowadot.gov/erl/current/GS/content/4123.htm>

This section describes the agency's aggregate quality for blended and nonblended virgin materials.

Aggregate Gradation Table, Standard Specifications with GS [General Supplemental] 15009 Revisions, Iowa Department of Transportation, October 15, 2019.

<https://iowadot.gov/erl/current/GS/content/Appendix.htm#AggregateGradationEnglish>

Category 14 of this aggregate gradation table describes modified subbase.

Michigan

Material Use: Michigan DOT uses open-graded drainage aggregate 4G under concrete pavements with edge drain systems. The standard specifications do not assign values to 4G generally, instead noting for each gradation category that details are “referenced in contract documents.”

Specification:

Section 902, Aggregates, 2012 Standard Specifications for Construction, Michigan Department of Transportation, 2012.

<https://mdotjboss.state.mi.us/SpecProv/getDocumentById.htm?docGuid=cfe35495-4208-4015-8a44-3f9dc3b76cac&fileName=%22902%20Aggregate.pdf>

Gradation requirements for 4G aggregates are included in Table 902-1 on page 746 of the specifications (page 9 of the PDF); physical requirements are described in Table 902-2 on page 747 of the specifications (page 10 of the PDF).

South Dakota

Material Use: South Dakota frequently uses salvaged versions of its preferred aggregates—base course, salvaged, and gravel cushion, salvaged, in a few variations. Salvaged bases may be a combination of subbase material similar to base course, but larger in size, in-place base course, or a mixture of base material and up to 50 percent millings. Gradation requirements match those of standard base course and gravel cushion. Base course, salvaged, must meet a compaction density of a minimum of 95 percent of the target dry density with a minimum of 4 percent moisture uniformly blended throughout the depth of the material. Gravel cushion, salvaged, like the standard gravel cushion, is not required to meet a specified compaction density.

Specification:

Standard Specifications for Roads and Bridges, South Dakota Department of Transportation, 2015.

https://dot.sd.gov/media/documents/2015_SDDOT_SpecBook.pdf

Section 260, Granular Bases and Surfacing, which begins on page 117 of the specifications (page 127 of the PDF), provides materials and construction guidance. Specific requirements of aggregates used for granular bases appear in Section 882, Aggregates for Granular Bases and Surfacing, which begins on page 547 of the specifications (page 557 of the PDF).

Section 884, Milled, Reclaimed and Salvaged Material (page 550 of the specifications, page 560 of the PDF), presents requirements for the slightly larger size for the top gradation of base course, salvaged, and gravel cushion, salvaged.

Performance Assessments

Respondents from these three states rated the effectiveness of their agencies’ secondary choice for base courses based on the following five performance characteristics:

- Drainage.
- Rutting resistance.

- Freeze-thaw resistance.
- Durability.
- Production cost.

Each performance characteristic was rated on a scale of zero to 2, where zero = poor, 1 = acceptable and 2 = very good. (N/A = not applicable.)

Respondents rated all performance characteristics acceptable or very good except the production cost of Iowa DOT’s secondary aggregate, which was not rated. Iowa’s secondary aggregate performance assessment falls below the assessed performance of its primary aggregate in terms of drainage, rutting and durability. In follow-up communication with the Iowa respondent regarding drainage performance of primary and secondary choices, the respondent noted that increased crushed content of 75 percent retained on a 3/8-inch sieve in the secondary aggregate is specified for workability, which is particularly useful because of the higher content of fines passing a No. 200 sieve than for its preferred base, and Iowa does not believe this is a factor in drainability performance. Rather, these modified subbases are used in urban settings where contractors may drive on the subbase to avoid curbs, sidewalks and similar constraints, and that when these pavements are not well drained they are fully saturated.

The performance of Michigan DOT’s secondary aggregate is comparable to the performance of its primary aggregate, outscoring the primary aggregate only in terms of drainage. The respondent noted the “[r]isk of rutting or breakdown of aggregate if in situ unbound aggregate base is used [to construct] a haul road when using blast-furnace slag or crushed concrete aggregates. This could impact the ability of the drainage course to adequately drain.” The South Dakota respondent reported the highest overall performance in four of the five characteristics for its secondary aggregate, with ratings that matched those for its primary aggregate.

Table 5 presents the survey results along with average ratings for each agency and each performance characteristic.

Table 5. Performance of Secondary Aggregate as Base Course for Low-Volume Roads

State	Drainage	Rutting Resistance	Freeze-Thaw Resistance	Durability	Production Cost	Average Rating
Iowa	1	1	1	1	N/R	1
Michigan	1	1	1	1	1	1
South Dakota	1	2	2	2	2	1.8
Average Rating	1	1.3	1.3	1.3	1.5	1.3

N/R No response.

Anticipated Revisions to Specifications

Four respondents described changes their agencies are considering for aggregate specifications in the next 10 years:

- Indiana DOT is considering changing requirements to address permeability goals. Current gradation specifications allow both permeable and impermeable materials; future specifications may detail separate permeable and impermeable gradation options.

- Michigan DOT may adjust gradation requirements for open-graded drainage courses to mitigate the percentage of waste material generated by crushing and processing aggregates.
- Wisconsin DOT may change testing requirements to extend freeze-thaw testing to all counties rather than limiting it to the state's 22 limestone-heavy counties, and to eliminate sodium sulfate soundness test requirements statewide.
- Wyoming DOT is revising its specification documentation to streamline and condense specifications in a new edition. Base aggregate specifications may be affected.

Related Research

Below are the results of a limited literature search on aggregate base performance and evaluation. Resources are organized according to the following topics:

- Minnesota research.
- National research.
- Other state research.

Minnesota Research

MnROAD Cells 16-23 (Phase II): Forensic Investigation Into Recycled Unbound Base and Asphalt Surface Materials, Hyung Jun Ahn, Chelsea Hanson, Dave Van Deusen and Benjamin Worel, Minnesota Department of Transportation, June 2017.

<http://www.dot.state.mn.us/research/reports/2017/201715.pdf>

From the abstract: This report presents the findings from an eight-year performance evaluation of eight cells (Cells 16-23) built at the Minnesota Road Research Facility (MnROAD) in 2008. The constructed cells were used for two performance evaluation studies of: 1) unbound base materials (i.e., recycled asphalt pavement (RAP), recycled concrete aggregate (RCA) and taconite) and Class 5 aggregate as the road base material and 2) surface materials that include warm mix additives (WMAs), RAP and different binders with different performance grades. The eight cells were tested via a surface distress survey, rutting tests, falling weight deflectometer tests, international roughness index (IRI) tests and friction tests. Disk-shaped compact tension (DCT) tests also were performed using the mixture samples, and the performance of the unbound base materials (Cells 16-19) was evaluated using light-weight deflectometer (LWD), dynamic cone penetrometer (DCP) and gradation tests. After eight years of service (approximately 5.6 million equivalent single-axle loads), the cells remained in good condition in terms of their resistance to surface distresses, rutting, stiffness, IRI values and friction. Consequently, it was difficult to compare the performance of the various unbound materials and mixtures. The unbound recycled materials and taconite performed as well as the Class 5 aggregate base material in terms of the gradation, DCP and LWD test results. All mixture types, regardless of RAP content, binder grade or the presence of WMA, exhibited similar performance.

Recycled Materials in Unbound Aggregate Base Layers in Minnesota, Local Road Research Board, Minnesota Department of Transportation, September 2016.

<https://lrrb.org/media/reports/TRS1604.pdf>

From the introduction: The purpose of this Transportation Research Synthesis (TRS) is to provide an overview about the use of recycled materials in the base layers of pavements, and the design of these layers when using recycled materials. While the primary focus is on local streets and county roads, attention was also given to pavements constructed by state highway agencies. This TRS has at least two intended audiences: the Local Road

Research Board (to aid in directing further research that may be needed) and engineers at local highway and street agencies (to assist in their immediate needs for guidance regarding recycled materials in maintaining their road networks).

The objectives of this TRS include the following:

- Summarize the current research and practice in the use of recycled materials in pavement base layers.
- Provide information to local agency pavement engineers to encourage the use of recycled materials where appropriate, and to promote realistic expectations of differences in construction and in long-term performance.
- Develop recommendations for the Local Road Research Board regarding future research and the most effective use of research funding in this topic.

“Optimizing Stability and Stiffness Through Aggregate Base Gradation,” W. James Wilde, Erol Tutumluer, Yuanjie Xiao, Terry Beaudry and John Siekmeier, *Transportation Research Record 2578*, pages 12-20, 2016. Citation at <https://trid.trb.org/view/1394165>

From the abstract: The primary objective of this paper is to present the analysis and evaluations conducted as part of the associated research and to recommend improvements to base layer aggregate gradations for the Class 5 and permeable aggregate base specifications used by the Minnesota Department of Transportation. Improved aggregate classes are presented, considering gradation and aggregate shape properties. An analytical gradation analysis was introduced to establish an effective level of gravel-to-sand ratio of 1.4. Other analyses presented in this paper include the use of a revised resilient modulus model that was used in a Monte Carlo simulation to develop probabilities for resilient modulus values depending on gradation and season in Minnesota and the use of the Mechanistic–Empirical Pavement Design Guide for comparing gradation and gravel-to-sand ratio with expected pavement performance. The gravel-to-sand ratio of 1.4 was identified with the following analysis methods: a coordination number and packing analysis, a discrete element model for load-carrying capacity, and a pavement performance analysis using the Mechanistic–Empirical Pavement Design Guide software.

Performance Monitoring of Olmsted CR 117 and 104 and Aggregate Base Material Update, Matthew A. Lebens, Local Road Research Board, Minnesota Department of Transportation, June 2015. <http://www.dot.state.mn.us/research/TS/2015/201528.pdf>

From the abstract: The objective of this project (LRRB #899) is to perform a follow-up performance monitoring study, over a five-year period, of several test sections on two low-volume roads, Olmsted County Road (CR) 104 and CR 117, southwest of Rochester, Minnesota. Three different crushed limestone base types were used in the construction; namely (1) Standard Class 5, (2) Permeable Aggregate Base (PAB), and (3) Class 5 Modified. The performance monitoring study included the following monitoring activities: traffic counts, falling weight deflectometer (FWD), automated pavement distress surveys (Pathways), visual pavement distress surveys, and cone penetrometer (CPT) testing. The research effort on this project has indicated that the Class 5 modified base material is the best performing of the three base types and may be considered an effective substitution for conventional Class 5 crushed limestone base materials of the type commonly available in Olmsted County, Minnesota. Test section 2, constructed with PAB base (with similar traffic as test section 1) is also performing well. The data has led to an addition to the latest Minnesota Department of Transportation (Mn/DOT) standard specification 3138 of a new gradation category named CLASS 5Q.

“Open-Graded Aggregate Base (OGAB) Controlling Subsurface Moisture Regime and Structural Stability From MnROAD Instrumentation Data,” Yuanjie Xiao, Erol Tutumluer and W. James Wilde, *Second Transportation and Development Congress 2014*, May 2014.

Citation at <https://trid.trb.org/view/1311259>

From the abstract: In an effort to study subsurface drainage and stability of a new open-graded aggregate base material (OGAB Special) under construction, PCC [portland cement concrete] pavement test sections (Cells 306 and 406) were constructed by the Minnesota Department of Transportation (MnDOT) on the 3.5-mile mainline interstate roadway segment at the MnROAD test facility in 2011. Both test cells consist of 6-in. thick PCC slab, 6-in. thick OGAB Special layer and 7-in. Class 5 (MnDOT traditional dense-graded) unbound aggregate underlain by clay subgrade. This paper presents the findings from analyzing field instrumentation data and falling weight deflectometer (FWD) test results to assess the effectiveness of the OGAB Special layer in controlling subsurface moisture regime and providing structural stability. For comparison, field test data were also collected and analyzed from MnROAD Cells 38, 53 and 54 that are located in the low-volume roadway segment and consist of PCC slabs of similar thickness and traditional dense-graded base layers (Class 5 or 6) underlain by clay subgrade. It was concluded from analysis results that the OGAB Special layer cannot only reduce the subsurface moisture content significantly but also provide comparable structural stability, as compared to traditional dense-graded (Class 5/6) base layers.

Recycled Unbound Materials, Tuncer B. Edil, James M. Tinjum and Craig H. Benson, Minnesota Department of Transportation, November 2012.

<https://www.lrrb.org/media/reports/201235.pdf>

From the abstract: The objective of this project was to characterize the properties of crushed recycled concrete (RCA) and asphalt pavement (RAP) as unbound base without being stabilized, to assess how RCA and RAP behave in the field and to determine how pavements can be designed using RCA and RAP. Issues to be considered include variability in material properties, purity of material, climatic effects, how to identify and control material quality, and leaching characteristics. This project included laboratory specimen and large-scale model tests and evaluation of field data from MnROAD test sections constructed using recycled materials. To identify the characteristics of RAP and RCA typically available in different parts of the country, samples were obtained from eight states: California, Colorado, Michigan, Minnesota, New Jersey, Ohio, Texas and Wisconsin covering a geographically diverse area. A conventional base course was used as a control material. The extensive investigation undertaken on RCA and RAP indicate that these materials are generally suitable for unbound base course applications and they show equal or superior performance characteristics compared to natural aggregates in terms of stiffness, freeze-thaw and wet-dry durability, and toughness. Their typical compositional and mechanical properties and their variability are defined in this study providing a basis for design considerations. Their relative differences from natural aggregate such as temperature sensitivity, plastic deformations, and water absorption and retention characteristics are also well established. It is noted that some RAP may be sensitive to temperature change that may lead to rutting. This aspect needs to be considered in design.

Best Value Granular Material for Road Foundations, Yuanjie Xiao and Erol Tutumluer, Minnesota Department of Transportation, January 2012.

<https://www.lrrb.org/pdf/201201.pdf>

From the abstract: This research study is aimed at evaluating pavement base/subbase performances of locally available aggregate materials (with gradations still falling within the MnDOT specified gradation bands) in Minnesota through mechanistic pavement analysis and design. The main objective of this study is to demonstrate that locally available aggregate materials can be economically efficient in the implementation of the available mechanistic-based design procedures in Minnesota through the MnPAVE mechanistic-empirical

flexible pavement design method. The goal is to develop the components of a new granular material best value software module to be added to the MnPAVE program. This report summarizes the detailed research findings from which the following conclusions can be drawn: (1) locally available aggregate materials with varying levels of quality can still properly serve traffic-level and environment-related loading from a mechanistic-empirical pavement design perspective provided that important aggregate properties, such as gradation and particle shape, are optimized; (2) potential shear failure in base and especially subbase need to be properly addressed as non-unique modulus-strength relationships were observed; and (3) the proper use of local materials can be quite cost-effective.

“Recycled Materials as Substitutes for Virgin Aggregates in Road Construction: I. Hydraulic and Mechanical Characteristics,” Dong-Hee Kang, Satish C. Gupta, Andry Z. Ranaivoson, John Siekmeier and Ruth Roberson, *Soil Science Society of America Journal*, Vol. 75, No. 4, pages 1265-1275, July 2011.

Citation at <https://dl.sciencesocieties.org/publications/sssaj/abstracts/75/4/1265>

From the abstract: This study evaluated the suitability of 17 mixtures of four recycled materials with aggregates as a replacement of 100 percent virgin aggregates in base and subbase layers of roads. Recycled materials tested were recycled asphalt pavement (RAP), recycled concrete material (RCM), fly ash (FA) and foundry sand (FS). Properties characterized were water retention, hydraulic conductivity, resilient modulus (MR), shear strength and leaching characteristics. In this paper, we discuss the hydraulic and mechanical characteristics of these mixtures. The shapes of the water retention curves of recycled mixtures were nearly similar whereas the saturated hydraulic conductivities of these mixtures were higher than that of 100 percent aggregates. This suggested that the drainage characteristics of these particular recycled materials mixtures with aggregates will be similar or better than that of 100 percent aggregates. Generally, addition of RAP, RCM and FA+RAP to aggregates increased MR values but addition of FS (fine material) to aggregate decreased the MR values. These results suggest that the stiffness of these particular RAP, RCM and FA mixtures of aggregates will be similar or better than that of 100 percent aggregates. Addition of RAP, RCM and FA+RAP to aggregates generally increased the cohesion values whereas friction angles mostly varied within a narrow range (38–49°). Addition of FS to aggregates, however, did not improve the shear strength of the mixtures. Based on these results, we concluded that FA, RAP and RCM mixtures will be good substitutes for virgin aggregates in base and subbase layers of roads.

“Mechanistic-Empirical Evaluation of Aggregate Base and Granular Subbase Quality Affecting Flexible Pavement Performance in Minnesota,” Yuanjie Xiao, Erol Tutumluer and John Siekmeier, *Transportation Research Record 2227*, pages 97-106, 2011.

Citation at <https://trid.trb.org/View/1093047>

From the abstract: Since high-quality aggregate materials are becoming increasingly scarce and expensive, optimizing the use of locally available materials for aggregate bases and granular subbases on the basis of cost and mechanistic properties linked to pavement performance has become an economically viable alternative. This study investigated the effect of quality of unbound aggregate material on conventional flexible pavement performance in Minnesota through a mechanistic–empirical pavement design approach. A comprehensive matrix of conventional flexible pavement layer thicknesses and mechanistic design moduli was carefully designed to conduct mechanistic analyses for the Minnesota Department of Transportation flexible pavement design program (MnPAVE) with the MnPAVE program for pavement sections in two climatic regions in Minnesota. The type and the quality classes of unbound aggregate materials, identified as high, medium and low, were characterized with stress-dependent resilient modulus ($M_{sub R}$) models from a statewide laboratory-tested aggregate $M_{sub R}$ database. Despite conventional wisdom to the contrary, in some cases the granular subbase material had much higher moduli than the aggregate base. The typical high, medium and low modulus values for the aggregate base and granular subbase layers, determined from the modulus distributions predicted

by the nonlinear finite element program GT-PAVE, were subsequently input during MnPAVE analyses to calculate fatigue and rutting life expectancies for the comprehensive matrix of pavement structures studied. From the results, use of locally available and somewhat marginal materials may be quite cost-effective for low-volume roads, provided that the 20-year design traffic level does not exceed 1.5 million equivalent single-axle loads. A high-quality, stiff subbase was also found to exhibit a bridging effect that better protected the subgrade and offset the detrimental effects of low base stiffness on rutting performance.

National Research

NCHRP Synthesis 445: Practices for Unbound Aggregate Pavement Layers, Erol Tutumluer, 2013.

Report available at <https://www.nap.edu/catalog/22469>

From the preface: This study gathers information on the current state of practice and research on unbound aggregate. The study finds that no common practice exists among state transportation agencies. Accordingly, the report summarizes important aspects and effective practices related to material selection, design and construction of unbound aggregate layers. Prevalent agency practices are summarized and key lessons learned from research studies are highlighted.

Information for this study was acquired through a literature review and surveys of state and Canadian transportation agencies.

Other State Research

Illinois

“Characterization and Utilization of Recycled Concrete Aggregate From Illinois as a Construction Material,”

Prabir K. Kolay and Moses Akentuna, *Geo-Congress 2014 Technical Papers: Geo-Characterization and Modeling for Sustainability*, February 2014.

Citation at <https://trid.trb.org/view/1303435>

From the abstract: This paper presents the results of a study conducted to characterize and utilize the recycled concrete aggregates (RCA) from southern Illinois as a suitable construction material. Several concrete mixes consisting of 10, 20, 30, 40, 60 and 80 percent replacement of natural aggregate were prepared and tested for compressive strength after curing periods of 7, 14 and 28 days, and the results were compared with 100 percent natural aggregate concrete. The suitability of the RCA as a granular road base material was also determined. The results show that the compressive strengths increases with various curing period for all concrete mixes. The RCA base material had lower California bearing ratio (CBR) value compared with natural crushed rock base material, i.e., class CA 06. The durability parameters of the natural and recycled aggregate samples were also investigated by using sulphate soundness and microdeval tests.

Wisconsin

Evaluation of Recycled Base Aggregates, Hani Titi, Habib Tabatabai, Jessie Ramirez and Mohammad Sooman, Wisconsin Department of Transportation, July 2019.

<https://wisconsin.gov/documents2/research/0092-17-01-final-report.pdf>

From the abstract: This study intended to provide quantitative evaluation of the use of RAP [recycled asphalt pavement] and RCA [recycled concrete aggregates] as base layers in HMA [hot-mix asphalt] pavements. The study used field and laboratory testing programs and data from WisDOT PIF [Pavement Information/Inventory Files] database quantify the performance of base materials and test sections on pavements with CA, RCA and RAP base layers. ... Based on the results of this study, the research team believes that the performance of the HMA pavements with RCA (with the exception of STH [State Trunk Highway] 78) and RAP is

satisfactory/adequate and comparable with the performance of the HMA pavements with CA base course layers. The research team recommends that WisDOT continues the practice of using the RCA and RAP in base course layers of HMA pavements with implementing control measures listed in Chapter 7 of this report.

Appendix A

Preferred Aggregate Base Courses for Low-Volume Roads: Survey Questions

The following survey was distributed to selected state departments of transportation expected to have relevant experience with aggregate selection for base courses for low-volume roads.

Preferred Aggregate Base Course

1. What is your agency's go-to aggregate for base courses of concrete and asphalt pavements in low-volume, county and city locations? Please provide the name of the material and briefly describe its physical characteristics and what pavements it is used with.
2. Please provide a link to the specifications or send a copy of the pertinent specification to matt.mullins@ctcandassociates.com.
3. Please rate the effectiveness (0 as poor, 1 as acceptable, 2 as very good) of this material in the following performance characteristics:
 - Drainage.
 - Rutting resistance.
 - Freeze-thaw resistance.
 - Durability.
 - Production cost.
 - Other (please describe).

Secondary Aggregate Base Course

1. If your agency has another go-to aggregate used within 10 percent as often as the go-to for base courses of low-volume county and city asphalt or concrete pavements, please provide the name of this (those) material(s) and briefly describe its (their) physical characteristics and what pavements it is (they are) used with.
2. Please provide a link to the specifications of this (those) alternative material(s) or send a copy of the pertinent specification(s) to matt.mullins@ctcandassociates.com.
3. Please rate the effectiveness (0 as poor, 1 as acceptable, 2 as very good) of this (those) alternative material(s) in the following performance characteristics:
 - Drainage.
 - Rutting resistance.
 - Freeze-thaw resistance.
 - Durability.
 - Production cost.
 - Other (please describe).

Anticipated Revisions

1. Please describe any changes in this standard practice your agency is exploring or you anticipate in the coming decade.

Appendix B

Preferred Aggregate Base Courses for Low-Volume Roads: Contacts

Below is the contact information for the individuals responding to the survey for this report.

Illinois

Brian Pfeifer
Engineer, Materials
Illinois Department of Transportation
217-782-6585, Brian.Pfeifer@illinois.gov

Indiana

Matt Beeson
State Materials Engineer, Materials Management
Indiana Department of Transportation
317-522-9662, MBeeson@indot.in.gov

Iowa

Jeff De Vries
Testing Engineer, Construction and Materials
Iowa Department of Transportation
515-239-1926, Jeff.Devries@iowadot.us

Michigan

John Staton
Concrete Operations and Materials Engineer,
Pavement Operations
Michigan Department of Transportation
517-636-4948, StatonJ@michigan.gov

Minnesota

Terry Beaudry
Grading and Base Engineer, Materials and Road
Research
Minnesota Department of Transportation
651-366-5456, Terry.Beaudry@state.mn.us

John Bormann
Grading and Base Specialist, Materials and Road
Research
Minnesota Department of Transportation
651-366-5596, John.Bormann@state.mn.us

Montana

Zackary Stewart
Civil Engineering Specialist, Construction
Montana Department of Transportation
406-444-7606, ZStewart@mt.gov

North Dakota

Clayton Schumaker
Geotechnical/Research Engineer, Materials and
Research
North Dakota Department of Transportation
701-328-6906, CSchumaker@nd.gov

South Dakota

Tanner Fitzke
Surfacing Plans Engineer Manager, Planning and
Engineering
South Dakota Department of Transportation
605-773-3639, Tanner.Fitzke@state.sd.us

Wisconsin

Russell Frank
Supervisor, Concrete Materials Lab
Wisconsin Department of Transportation
608-249-7942, Russell.Frank@dot.wi.gov

Wyoming

Whitney Wise
Materials and Pavement Design Engineer, Materials
and Testing
Wyoming Department of Transportation
307-777-4075, Whitney.Wise@wyoming.gov