# DEVELOPMENT OF A ¾-INCH MINUS BASE COURSE TYPE A SPECIFICATION FOR MONTANA

*Research Proposal*

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# 1 Problem Statement

Gravel bases are a critical component of roads, providing drainage, structural support, and load distribution to reduce pressures on subgrade soils. Montana specifications currently exist for a 2-inch minus (Grade 5A) and 1½-inch minus (Grade 6A) crushed base course (Section 701.02.4); however, gravel sources in Montana are becoming limited, particularly in the eastern regions of the state, making the option to use a ¾-inch gravel base desirable.

# 2 Background Summary

Highway base courses are typically constructed using crushed and processed aggregate. Roadway designers currently have a number of options for specifying the base course material on Montana Department of Transportation (MDT) highway projects. The engineering characteristics of these various options were thoroughly quantified by the Western Transportation Institute (Mokwa et al., 2007) using an extensive suite of geotechnical laboratory tests to evaluate the engineering properties of three crushed aggregates commonly used on Montana highway projects (CBC-6A, CBC-5A and CTS-2A). Engineering properties examined in this study included: compaction, durability, strength, stiffness, and drainage. These properties were quantified by synthesizing and analyzing results from the following laboratory tests: geotechnical index tests, direct shear, R-value, and permeability.

The most important engineering characteristics of any base course aggregate are strength, stiffness, and drainage capacity. Each of these properties can have a large impact on the performance of a flexible pavement. For example, increasing the strength and stiffness of the base course results in less rutting, smaller pavement deflections, and ultimately less cracking of the pavement surface. The damaging effects of water in the structural layers of roadways have been well documented. Specific modes of these damaging effects include pumping of fines, frost heave, asphalt stripping, and reduction of shear strength. Ensuring that a new aggregate gradation will perform at least as well as the currently specified base course aggregates is important in order to assure proper performance.

# 3 Benefits and Business Case

Crushed base courses are typically a cost effective component to pavements that reduce the amount of asphalt pavement needed for a road. For some projects, however, obtaining the material that meets the current specifications for 5A or 6A crushed base course is uneconomical. If adequate performance can be met with a ¾-in. minus crushed base course, as will be demonstrated with this research, then including a specification for this new base course will ensure Montana's transportation system continues to be cost effective.

# 4 Objective

The objective of the proposed project is to develop a standard specification for a new gravel base course with nominal maximum aggregate size of ¾ in. This objective will be met by conducting

a thorough review of other state base course specifications, formulation of a preliminary specification for Montana based on this information, and a suite of laboratory tests to characterize multiple sources of aggregate throughout the state of Montana to quantify their material properties and to make comparisons to existing data from similar tests run on traditional base course mixes from Montana.

# 5 Research Plan

The objectives of this research will be accomplished through a comprehensive program that begins with a review of other states' specifications to identify existing ¾-in. minus crushed base course specifications. Pertinent information from these specifications will be compiled and compared to MDT's 5A and 6A material specifications. Properties that will be incorporated in this evaluation include gradation, Atterberg limits, wear factor, and percentage of fractured faces. Acceptable values or ranges for these properties ensure the aggregate base will provide the functions of drainage and structural support. Trial mixes of ¾-in. crushed base course will be collected from select pits in Montana to identify appropriate limits for specification purposes. Laboratory testing will include sieve analysis, Atterberg limits, percentage of fractured faces, Proctor, relative density, specific gravity, R-value, direct shear and permeability tests.

## Task 0 – Project Management

The Principal Investigator for this project will manage the project in terms of contractual compliance, budget and schedule, administrative tasks, and communications with the Technical Panel. Mr. Eli Cuelho of WTI at Montana State University will serve as the Principal Investigator for the project. He will be the primary contact and assume the majority of the project management responsibilities.

Project management is important to ensure that the work proposed herein is completed on time, on budget and high quality. Management will generally be achieved through regular communication between the Principal Investigator, the MDT project manager, and research team members. The research team will submit brief and concise quarterly progress reports to describe accomplishments, status of the project and future plans. Major deliverables will follow MDT reporting requirements and formats and will first be sent to the Technical Panel for review and comment. A kick-off meeting will be held in Helena to discuss the various components of this project.

## Task 1 – Review of Other State's ¾-Inch Base Course Specifications

Base course specifications from all 50 states will be collected to determine their characteristics. Specific aspects of interest include gradation, fractured face count, Atterberg Limits, and durability. This information will be analyzed and synthesized to create a preliminary specification for a ¾-inch minus crushed base course.

### Task 2 – Laboratory Testing of ¾-Inch Base Course Mixes from Montana

The preliminary specification from Task 1 will be used as the basis for samples collected throughout Montana. It is anticipated that eight samples of ¾-inch minus crushed base course will be used in this study from the various districts geographically located throughout Montana. If possible, it would be advantageous to obtain aggregate samples from the same areas as the study completed by Mokwa et al. (2007) so that comparisons of the various material properties can be made to aggregates obtained from the same sources. Final selection of the locations of the sources for these materials will be done in consultation with MDT but are anticipated to come from the following regions/districts:

- 2 samples from the Glendive district, one from near Miles City (Yellowstone region) and one near Glendive (northeast region of the state);
- 2 samples from the Missoula district, one near Missoula and one near Kalispell;
- 2 samples from the Billings district, one near Billings and one near Lewistown;
- 1 sample from the Butte district; and
- 1 sample from the Great Falls district.

Because a ¾-inch minus gradation is not commonly used for this application, it is anticipated that samples of Type 6A crushed base course (which is a 1½-inch minus material) will be collected and used to create new mixes to meet the ¾-in minus specification. Two gradations will be created from each sample collected from the 8 locations to make a total of 16 separate ¾-inch minus mixes. To do this, the aggregate samples from each of the eight sources will be re-graded to fit both the upper and lower bound of the preliminary ¾-inch minus gradation specification. The following characteristics and engineering properties of each of these 16 samples will be examined:

- particle size distribution,
- fractured face count,
- modified Proctor density,
- relative density (maximum and minimum index densities),
- specific gravity,
- R-value (tested by MDT),
- direct shear, and
- permeability.

### Task 3 – Data Analysis

A statistical analysis of average values from the various samples will be conducted using a two-sample, t-test to determine if apparent trends in measured laboratory test results represent true differences between the ¾-inch minus mixes and traditional CBC-5A and CBC-6A base course

aggregate blends. Information from this analysis will be used to determine whether the ¾-inch specification yields suitable materials for substitution of the CBC-5A and CBC-6A materials. Statistical comparisons will be made to evaluate the following parameters:

- initial stiffness ($k_i$) from direct shear tests,
- secant stiffness ($k_u$) from direct shear tests,
- effective friction angle ($\phi'$) from direct shear tests,
- strength/stiffness/stability from R-value tests, and
- permeability ($k$) from permeability tests.

Material properties of the ¾-inch minus base course will also be compared against traditional values for stiffness/strength/permeability properties typically sought for these materials by MDT.

### Task 4 – Reporting

A comprehensive final report that includes all data, analyses and recommendations will be written in conformance with MDT's standard research report format to thoroughly document the findings of this project. The report will be concise and include all pertinent information to aid state DOTs in adopting an efficient, effective, and reliable specification for a ¾-inch minus crushed base course aggregate. A draft report will be sent to MDT to be distributed to the Technical Panel for review and comment. The results of the project will also be disseminated, as appropriate, to the professional community through presentations at various conferences and/or through journal papers. A four-page "Project Summary Report" will be written and submitted to MDT near the end of the project to summarize the background, methodology, results and recommendations of this research. This summary report will be edited, published and distributed by MDT to be distributed to the Technical Panel for review and comment. Additionally, an "Implementation Report" will be written to summarize how the results from this research project were implemented, and a "Performance Measures" report will be written to summarize the benefit of this research in terms of cost savings to the department.

Two task reports will be written to summarize work associated with the following major activities.

- Task Report 1—Summarize results of ¾-inch base course specification review
- Task Report 2—Summarize results of the laboratory tests

Quarterly progress reports will be submitted to provide updates on the administrative aspects of the project, such as progress regarding the deliverables, schedule and budget.

## 6 MDT Involvement

Information, input, and/or data will be needed from MDT to accomplish the work outlined in Tasks 1 and 2 of this project. Specific involvement by MDT is elaborated on below.

- Task 1 – Once base course specifications from each of the states is compiled and summarized, input from MDT staff will be sought to review suggested specifications for a ¾-in. minus base course specification prior to moving forward with Task 2.
- Task 2 – Locations from where to obtain material samples will be finalized in consultation with MDT staff. MDT will also be responsible for gathering material samples from the gravel production facilities selected and shipping or delivering them to WTI's laboratory facilities in Bozeman, MT. Finally, R-value tests will be run at the DOT materials laboratory by MDT staff and the data sent to WTI to be used in the analysis.

# 7 Products

The products to be delivered during this project include the following items.

- Five quarterly progress reports.
- Two tasks reports.
- A draft final report and executive summary describing the research methodology, findings, conclusions, and recommendations, followed by a final report addressing comments and suggestions from the Technical Panel.
- A project summary report.
- An implementation report.
- A performance measures report.
- A specification for ¾-inch minus base course in approved MDT format.

# 8 Implementation

The results of this research will likely be ready for implementation immediately after the conclusion of the research. The results of this research will include a draft specification for a ¾-in. minus crushed base course that will be consistent with MDT's current specification format. The results will also include all the information required for a Major Revision, as shown in MDT's standard specifications revision process. It may be advantageous to monitor a few experimental sites to ensure adequate performance before full implementation. A meeting will be held in Helena to discuss implementation of these results, and an Implementation Report will be written.

# 9 Schedule

The estimated project schedule is depicted in Table 1. The total proposed duration of the project is 20 months, with an estimated start date of January 1, 2014, and an estimated completion date of August, 2016. A draft final report will be sent to the Technical Panel three months prior to the end date (by May 31, 2016) to provide sufficient time for review and revision. Task reports will summarize work associated with major activities and are shown in Table 1 as a green star. The data analysis task will be summarized in the final report. Quarterly reports will be sent to the Technical Panel during the months following the end of each quarter, as shown in Table 1.

Finally, an Implementation report and Performance Measures report will be submitted one month after the final report is complete.

| Work Tasks | Milestone Dates | 2015 | | | | | | | | | | | | 2016 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug |
| Project Commencement | Jan. 1, 2014 | ★ | | | | | | | | | | | | | | | | | | | |
| 1 – Specification Review | | | | | | | ★ | | | | | | | | | | | | | | |
| 2 – Laboratory Testing | | | | | | | | | | | | | | | | ★ | | | | | |
| 3 – Data Analysis | | | | | | | | | | | | | | | | | | | | | |
| 4 – Reporting (Qtr. reports due = ★) | | | | | ★ | | | ★ | | | ★ | | | ★ | | | ★ | | | | |
| 4a – Draft Final Report | May 31, 2016 | | | | | | | | | | | | | | | | | ★ | | | |
| 4b – Review & Address Comments | | | | | | | | | | | | | | | | | | | | | |
| 4c – Submit Final Report | Jul. 29, 2016 | | | | | | | | | | | | | | | | | | | ★ | |
| 4d – Impl. & Perf. Meas. Reports | Aug. 31, 2016 | | | | | | | | | | | | | | | | | | | | ★ |
| Project Conclusion | Aug. 31, 2016 | | | | | | | | | | | | | | | | | | | | ★ |

★ = Task Report

**Table 1: Project Schedule**

## 10 Budget

The requested project budget is $95,155. Schedule, budget, and staffing plans are based on state and federal fiscal year proportioning, as shown in Table 2. Indirect costs are calculated based on a negotiated rate of 25 percent. The budget itemized by individual tasks is listed in Table 3. The travel and supplies budgets are itemized in Table 4. Salary and benefit rates for individual staff members are listed in Table 5.

**Table 2: Detailed Budget by State and Federal Fiscal Year**

| Budget Category | State Fiscal Year | | | Federal Fiscal Year | | Total |
|---|---|---|---|---|---|---|
| | 2015 | 2016 | 2017 | 2015 | 2016 | |
| Salaries | $13,578 | $33,945 | $6,789 | $20,367 | $33,945 | **$54,312** |
| Benefits | $4,163 | $10,408 | $2,082 | $6,245 | $10,408 | **$16,653** |
| Supplies | $201 | $604 | $0 | $302 | $503 | **$805** |
| Laboratory Fees | $1,031 | $3,094 | $0 | $1,547 | $2,578 | **$4,125** |
| Travel | $115 | $0 | $115 | $115 | $115 | **$230** |
| **Direct Costs** | $19,089 | $48,050 | $8,986 | $28,575 | $47,549 | **$76,124** |
| **Indirect Costs** | $4,758 | $11,894 | $2,379 | $7,137 | $11,894 | **$19,031** |
| **Total** | **$23,846** | **$59,945** | **$11,364** | **$35,712** | **$59,443** | **$95,155** |

**Table 3: Budget Itemized by Task**

| Task | Cost |
|---|---|
| Task 0 – Project Management | $8,994 |
| Task 1 – Specification Review | $7,999 |
| Task 2 – Laboratory Testing | $43,482 |
| Task 3 – Data Analysis | $14,179 |
| Task 4 – Reporting | $20,502 |
| **Total** | **$95,155** |

**Table 4: Itemized Travel and Supplies Budget**

| **Travel** | |
|---|---|
| Trip 1: Kick-Off Meeting | |
| Vehicle rental | $50 |
| Per diem | $11 |
| Fuel | $54 |
| Trip 2: Implementation Meeting | |
| Vehicle rental | $50 |
| Per diem | $11 |
| Fuel | $54 |
| **Total Travel** | **$230** |
| **Supplies** | |
| Plastic bags | $150 |
| Shipping | $100 |
| Labels | $25 |
| Filter paper | $60 |
| Drying trays | $50 |
| Plastic containers | $400 |
| Gloves | $20 |
| **Total Supplies** | **$805** |

**Table 5: Staff Salary and Benefit Rates**

| Staff Person | Hourly Rate | Benefit Rate | Total Hours | Total Cost |
|---|---|---|---|---|
| Eli Cuelho | $47.17 | 31% | 680 | $42,019 |
| Research Assistant | $14.00 | 30% | 1497 | $27,245 |
| Business Manager | $39.94 | 33% | 32 | $1,700 |

# 11 Staffing

Mr. Eli Cuelho will be the Principal Investigator and will be the primary manager and sole point of contact with the MDT project manager. The Principal Investigator will be responsible for ensuring that the objectives of the study are accomplished, executing the project tasks, and preparing the written reports. A lab technician and graduate and/or undergraduate students will be employed to primarily conduct the various laboratory tests associated with this project.

The research team is well qualified, experienced and available to conduct this research, and, to the best of its ability, will deliver a quality finished product in a timely and efficient manner. The level of effort proposed for principal and professional members of the research team will not be changed without prior consent of the Technical Panel. The following subsections describe some of the qualifications and experience of project personnel in addition to each person's role in this study.

## Mr. Eli Cuelho, P.E.—Principal Investigator

Mr. Eli Cuelho is a Research Engineer and the Program Manager of the Infrastructure Maintenance and Materials program area at WTI. Mr. Cuelho is a licensed professional engineer in the state of Montana and is currently involved with a number of research projects related to the design and maintenance of transportation infrastructure. He has over 16 years of experience on a variety of research topics including geotechnical engineering, geosynthetic design, pavement design and analysis, subgrade stabilization, cost-effectiveness and cost–benefit analyses, large-scale field tests and remote sensing and data acquisition equipment.

Eli Cuelho has worked on a number of geotechnical- and/or pavement-related research projects, some of which include:

- Field Investigation of Geosynthetics Used for Subgrade Stabilization (Phases I and II)—the objective of these projects was to construct test sections in the field to investigate the relative benefit of various geosynthetics available on the market to an unpaved road built on a very weak subgrade, and to relate their performance to specific material properties.
- Experimental Assessment of Aggregate Surfacing Materials—the objective of this project was to quantify relative differences in important engineering characteristics of three crushed and processed aggregates in Montana.
- Developing a Standard Test Method for Measuring Geosynthetic-Soil Resilient Interface Shear Stiffness—the objective of this project was to develop a standard test method within ASTM to determine the interaction properties of geosynthetics that are embedded in soil and loaded under cyclic loads pertinent to transportation applications.
- Feasibility of Using a Gyratory Compactor to Determine Compaction Characteristics of Base Course Aggregates—the objective of this project was to explore the effectiveness of using a gyratory compactor to provide an accurate prediction of optimum in-place soil densities.
- Comparative Analysis of Coarse Surfacing Aggregates Using the Micro-Deval, L.A. Abrasion and Sulfate Soundness Tests—the objective of this project was to determine

whether the Micro-Deval test can be used to replace the Sulfate Soundness test to accurately measure the durability of aggregates used in pavement.

- Preventive Maintenance Treatments: A Synthesis of Highway Practice—the objective of this project was to identify existing and emerging technologies that could be used to enhance or replace current pavement maintenance approaches used by the Montana Department of Transportation.

As the Principal Investigator, Mr. Cuelho will participate in and provide oversight for all the components of this research project. He will coordinate with the Technical Panel as needed throughout the project and will write and review the technical memoranda and final report. Mr. Cuelho will oversee all aspects of this project to ensure that the project is executed with the highest quality.

### Graduate and Undergraduate Students

This research effort will be supported by qualified graduate and undergraduate research assistants, who will work part-time on this project throughout its duration. The students will assist with collecting and reviewing specifications, conducting laboratory tests, organizing and analyzing the data, and helping to synthesize information into the final report.

### Research Team Hours and Availability

It is anticipated that the proposed work associated with this research project will take 2,209 person hours. The number of hours committed to the project by each member of the research team during this time period is shown in Table 6. Key personnel assigned to accomplish the work associated with this project are generally available throughout the duration of this project. In the event that the level of effort proposed for the principal investigator requires significant modification, written consent will be sought from the Technical Panel to justify and approve this change.

**Table 6: Summary of Person Hours by Task**

| Name or Title | Role in Study | Task 0 | Task 1 | Task 2 | Task 3 | Task 4 | Total |
|---|---|---|---|---|---|---|---|
| Eli Cuelho | Principal Investigator | 80 | 80 | 120 | 160 | 240 | 680 |
| Research Assistant | Testing and Analysis | 24 | 80 | 1233 | 80 | 80 | 1497 |
| Business Manager | Project Adminstration | 32 | 0 | 0 | 0 | 0 | 32 |
| | **Total** | 136 | 160 | 1353 | 240 | 320 | **2209** |

## 12 Facilities

The Western Transportation Institute (WTI) is the nation's largest transportation institute focusing on rural transportation issues. The Institute was established in 1994 by the Montana and California departments of transportation, in cooperation with Montana State University–Bozeman. WTI is part of the College of Engineering at MSU and has a multidisciplinary

research staff of professionals, students, and associated faculty from the fields of engineering (civil/mechanical/industrial/electrical), computer science, psychology, fish and wildlife, business, biology and economics.

WTI integrates expertise from eight research areas: Infrastructure Maintenance and Materials, Road Ecology, Safety and Operations, Winter Maintenance and Effects, Systems Engineering Development and Integration, Logistics and Freight Management, Mobility and Public Transportation, and Transportation Planning and Economics. This research will be conducted within the Infrastructure Maintenance and Materials program area of which Eli Cuelho (the Principal Investigator for this project) is the program manager. The Infrastructure Maintenance and Materials program area at WTI conducts basic and applied research to address the immediate and long-term construction and maintenance needs of rural highway departments in the following areas:

- Materials—conduct research using new materials, such as geosynthetics or high performance concrete, to evaluate their benefit in new and rehabilitated highway structures.
- Maintenance—develop best management practices using cost–benefit analyses to help state highway departments select the most appropriate and cost-effective maintenance methods to extend the life of their facilities.
- Monitoring—test and evaluate instrumentation and remote sensing technologies to better monitor the condition of transportation infrastructure.

Additional information on WTI can be obtained from our web site at www.WesternTransportationInstitute.org.

### Laboratories

WTI and the Civil Engineering Department at MSU have extensive laboratory facilities including Geotechnical, Aggregate Materials, Asphalt, Concrete, Geosynthetics, Environmental, Structural, and Subzero Research testing labs, as well as a large-scale outdoor research and testing facility (TRANSCEND – www.transcendlab.org). These laboratory facilities are used for both teaching and research purposes. The geotechnical and materials laboratories are fully equipped to conduct a wide range of tests on soils and aggregates using AASHTO and ASTM standard methodologies. The laboratories contain fully functional and up-to-date equipment to conduct a wide variety of tests, including:

- soil index testing (e.g., gradation, Atterberg limits, AASHTO and ASTM material classifications, etc.),
- specific gravity tests,
- L.A. abrasion tests,
- gyratory compaction of asphalt and soil,
- small- and large-scale (12 in x 12 in) automated direct shear tests,
- computer-controlled consolidation testing,

- advanced triaxial testing,
- cyclic modulus testing of geosynthetics,
- x-ray computed tomographic (CT) scanning,
- environmentally controlled tests (accurate temperature control over a wide range, humidity control, UV radiation, etc.), and
- asphalt and concrete tests.

### Information Services

The research team regularly conducts literature and information gathering through the Carnegie Research Level 1 Library (Renne Library) on the MSU campus. In addition to an extensive collection of printed material, the library subscribes to dozens of databases and hundreds of refereed journals in print and electronic format. Specific items not accessible through these sources can be located and retrieved by the Interlibrary Loan service, which is affiliated with other research libraries across the United States. Typical sources used to aid literature searches include: TRID (Transport Research International Documentation), E-Science Server, Transportation Research Board Research Records and Annual Meeting CD-ROMs, Google Scholar, Google, and Montana Local Technical Assistance Program library.

### Administrative Services

The researchers at WTI are assisted by a highly qualified group of experienced support staff. Administrative staff members assist with budgeting, procurement, contracts, and accounting. Communications staff provides technical editing, layout, graphic design, and web page support. Information Technology staff maintains network servers and individual computers, software and hardware.

## 13 References

Mokwa, R., Trimble, N. and Cuelho, E. (2007) "Experimental Assessment of Aggregate Surfacing Materials, U.S. Department of Transportation, Federal Highway Administration, Washington, DC, Report No. FHWA/MT-07-011/8117-30, 74 p.