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RESEARCH PROJECT TITLE

Performance-Based Evaluation of Cost-Effective Aggregate Options for Granular Roadways

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Performance-Based Evaluation of Cost-Effective Aggregate Options for Granular Roadways

tech transfer summary

Laboratory and field tests, as well as a benefit-cost analysis, showed that hauling clean aggregates and mixing them with Class A aggregates could be an efficient way to reduce the costs of constructing and maintaining granular roadways in Iowa.

Problem Statement

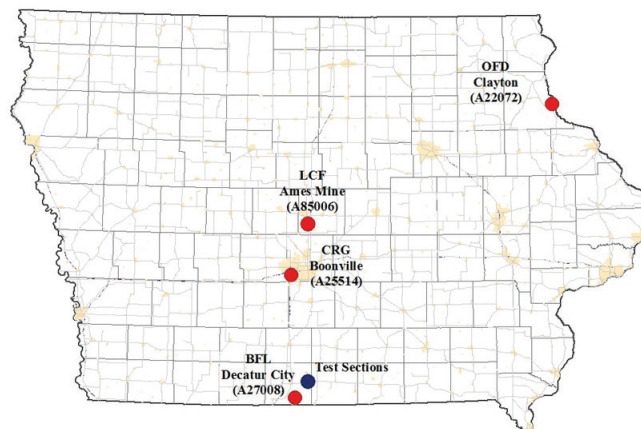
Iowa county engineers and Department of Transportation (DOT) personnel have observed considerable differences between regions of the state with respect to the level of performance that granular materials are able to provide. Thus, roads in some counties require more maintenance efforts and, therefore, have higher maintenance costs in comparison to other counties. A similar contrast occurs for the cost of new construction of granular roads.

However, to date there are no readily available tools to evaluate the costs versus field performance of granular road materials.

Goal and Objectives

The goal of the project was to determine the cost-effectiveness of hauling high-quality coarse (clean) aggregates to improve the performance and reduce the maintenance frequency on granular roadways in regions having only low-quality aggregates. The specific objectives were as follows:

- Evaluate the quality of aggregate materials collected from various Iowa sources
- Monitor the change in material properties over time and its impact on granular roadway performance
- Determine the relationships between material properties and performance of granular roadway materials
- Conduct a comprehensive cost analysis for each test section



Location of the aggregate resources and test site used in this study

Background

About 68,400 miles of granular roadways exist in the 114,000-mile road network in Iowa. Operation and maintenance of these granular roadways costs roughly \$270 million annually.

The sustainability of granular roadways is very important to the rural economy, since these roads provide access to rural land and enable the transportation of agricultural products. Any interruption in access via these granular roadways can have a significant impact on agricultural productivity and the economy of Iowa.

Heavy traffic loads and freeze/thaw cycles during the winter and spring seasons can cause extensive damage to granular roads. Freeze/thaw damage leads to material loss, gradation change, loss of crown, surface erosion, rutting, and potholes. The rate of deterioration (or damage) is directly correlated to the quality of the granular aggregate materials used in the granular roads.

Performance and long-term sustainability of granular roadways are dependent to a considerable degree on the quality of the aggregate materials used, which varies considerably from one source to another across Iowa. A wide range of granular material sources are available in Iowa, each producing different qualities, supply amounts, and prices.

Project Description

Aggregate materials were collected from four different locations in Iowa and used to build test sections on the same stretch of granular road in Decatur County, Iowa. Two main types of materials were used: Class A, which is a common aggregate type used for granular roadways, and clean large-sized aggregates. Seven test sections were built, consisting of three Class A sections and four sections that mixed by weight the local Class A aggregate with clean aggregates from various quarries.

The sections were labeled as follows:

- Bethany Falls Limestone (BFL) Class A (local)
- Lime Creek Formation (LCF) Class A
- Oneota Formation Dolomite (OFD) Class A
- 80% BFL Class A + 20% BFL Clean
- 70% BFL Class A + 30% LCF Clean
- 70% BFL Class A + 30% OFD Clean
- 70% BFL Class A + 30% Crushed River Gravel (CRG) Clean

The length of each test section was 500 ft except for one section (OFD Class A), which was 300 ft long, and each was 30 ft wide and 4 in. thick.



LCF Class A test section before construction on CR J22 in Decatur County, Iowa



OFD Class A test section during construction on CR J22 in Decatur County, Iowa



Local BFL Class A materials placed on the third test section



Close-up of CRG Clean materials, noting its round shape

The research team conducted laboratory and field tests between 2016 and 2019 to examine the link between quality and performance of granular aggregate materials used in granular road designs, using materials collected from various quarries in Iowa.

Laboratory tests included sieve and hydrometer analyses, Atterberg limits, compaction tests, gyratory compaction tests, and California bearing ratio (CBR) tests.

Field performance was evaluated via abrasion resistance, freeze/thaw resistance, density, material loss, modulus, gradation change, dust production, ride quality, and shear strength. Field tests include dynamic cone penetrometer (DCP), International Roughness Index (IRI), dust measurement, multichannel analysis of surface waves (MASW), lightweight deflectometer (LWD), and falling weight deflectometer (FWD) tests.

A benefit-cost analysis (BCA) was conducted based on the construction and maintenance costs extrapolated to estimate cumulative costs per mile. Accordingly, the benefit-cost ratio, user cost savings, and maintenance cost savings values were calculated based on the BCA, and different service lives, discount rates, and maintenance frequencies were compared to continuing current maintenance practices.

Key Findings

Test Results

Laboratory test results of the virgin materials used in construction showed that Class A aggregates hauled from long distances and mixtures of local Class A and clean aggregates had higher abrasion resistances than those of local Class A (BFL) materials and local Class A (BFL) + clean aggregate (BFL) mixtures. Compared to the local aggregates, the higher quality aggregates hauled from longer distances exhibited relatively smaller changes in gradation and total breakage in laboratory gyratory compaction tests.

Based on the observations throughout construction and maintenance, it was concluded that the two sections consisting of mixtures of 70% BFL Class A + 30% LCF Clean and 70% BFL Class A + 30% CRG Clean had the best overall performance. The 70% BFL Class A + 30% CRG Clean section was more difficult to maintain due to the high angularity of the aggregate materials. However, this section performed well for a long period of time and became stiff after each blading occurrence.

Other field results included the following:

- Changes in gradation and increases in fines contents, in particular, had a significant impact on the performance of the granular roadways.



Dynamic cone penetrometer testing on a section



Lightweight deflectometer testing on a section

- BFL Class A and 80% BFL Class A + 20% BFL Clean had the maximum increases in the average fines content over the period of the study. The minimum average fines content was observed for the LCF Class A and OFD Class A.
- The 80% BFL Class A + 20% BFL Clean had the maximum decrease in the gravel-to-sand ratio while LCF Class A and OFD Class A had the minimum decrease in the average gravel-to-sand ratio value over time.
- The 80% BFL Class A + 20% BFL Clean experienced the highest total breakage while OFD Class A had the lowest total breakage values under traffic loads.
- The average values of IRI for all sections corresponded to a fair quality of smoothness except for 70% BFL Class A + 30% OFD Clean and 70% BFL Class A + 30% CRG Clean, which had poor smoothness quality. The average values of the IRI values over time showed that LCF Class A and BFL Class A had the best smoothness among all sections.
- The OFD Class A and 70% BFL Class A + 30% OFD Clean sections had more potholes compared to the other sections.

- Dustometer test results showed that the 70% BFL Class A + 30% CRG Clean section had the maximum dust production and LCF Class A had the lowest dust production.
- The various stiffness test results did not provide any clear or consistent correlations with the index properties of any of the test sections.

Benefit-Cost Analysis Results

The BCA showed that hauling LCF Clean and CRG Clean to be mixed with local BFL Class A material resulted in the most cost-effective method when considering the following performance criteria: change in fines content, gravel-to-sand ratio, gravel content, total breakage, and material and thickness loss.

Loss of materials and surface thickness was the most important aspect in the cost analysis of granular roadways, because this is the cause of several other problems such as surface distresses (potholes, rutting, etc.), dust production, and higher surface roughness.

Other BCA results included the following:

- The 70% BFL Class A + 30% LCF Clean was the most cost-effective section considering material and thickness loss, fines content, total breakage, FWD, and dust production as performance measures. Therefore, this section was selected as the most cost-effective section overall.
- The 70% BFL Class A + 30% CRG Clean was the most cost-effective section considering changes in the gravel-to-sand ratio and ride quality.
- Benefit-cost analyses were also performed for both truck and rail hauling, and the results showed that rail hauling was highly dependent on the locations of quarries, construction sites, and railway transition points.
- OFD Class A had the highest construction costs per mile due to the greater haul distance of OFD materials to the project site. The mixture of 80% BFL Class A + 20% BFL Clean had the lowest construction costs due to the proximity of the materials to the site and the smaller amount of aggregates required to build this section.
- OFD Class A required a smaller amount of aggregate materials for maintenance, and consequently was the least expensive section to maintain. The 70% BFL Class A + 30% OFD Clean required the most aggregate materials for maintenance and was, therefore, the most expensive section to maintain.

Recommendations for Future Research

- Labor costs and equipment time do not vary significantly between test sections that are 500 ft long. It is recommended that test sections in future studies be at least a quarter mile long to produce discernable differences between them.
- Future studies should examine a wider range of local quarry materials, traffic loads, and subgrade conditions by building new test sections in different regions.
- A new method of back-calculation should be developed to increase the accuracy of modulus values from the FWD data. It would be helpful to collect a sufficient database of back-calculated elastic modulus values with corresponding measurements of surface thickness, temperature, density, and Poisson's ratios to build a neural network model to better predict the elastic moduli.
- Additional benefit-cost analyses should be performed on construction and maintenance of low-volume roads with different materials, stabilization methods, or other conditions.

Implementation Readiness and Benefits

The results of this study showed that mixing clean and Class A aggregates, rather than using only Class A materials, could be an efficient way to reduce costs. Because these mixtures are larger in size, they require lower amounts (tonnage) of materials to achieve a specific thickness compared with Class A materials. This results in a decrease in the costs of aggregates and hauling.

Further, the spreadsheet developed in this study can be utilized to assess the benefit-cost analysis of a variety of granular roadway construction and maintenance alternatives.