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OFFICE OF TRANSPORTATION SYSTEM MANAGEMENT

TECHNICAL SUMMARY

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PROJECT COST:
$199,000

Open graded aggregate bases have improved drainability and similar structural stability to traditional dense graded base layers.

Optimizing Aggregate Foundation to Improve Concrete Pavement Performance

Researchers identified aggregate base properties necessary to optimize concrete pavement foundation performance. A 1.4 gravel-to-sand ratio produced the best combination of drainability and stability, while open graded bases had better subsurface moisture characteristics than dense graded bases with similar structural stability.

What Was the Need?

The quality of a pavement's aggregate foundation layer is critical for its long-term performance. The stiffness of the aggregate foundation, its stability over the long term and how well it drains are significant factors influencing pavement durability. If the aggregate foundation has low stiffness or poor stability, it may not provide adequate support for the pavement. Poor drainage can significantly reduce the strength of the base during spring thaws, and standing water underneath concrete due to poor drainage can lead to deterioration of the concrete itself.

It is difficult to maximize stiffness, stability and drainability simultaneously. Improving one factor often comes at the expense of the others. Understanding how these factors relate to one another can help MnDOT to optimize aggregate properties and improve pavement performance.

MnDOT's current design standards are based on MnDOT Pavement Design Manual Section 540 – PCC Thickness Design Using MnPAVE-Rigid, which is a portland cement concrete pavement design program that uses transverse cracking as the controlling distress. It is based on the Mechanistic-Empirical Pavement Design Guide, Version 1.1, a mechanistic-empirical design procedure that accounts for the effects of traffic loading and environment.

MnDOT wanted to improve guidelines for aggregate base layers by better understanding how the properties of the aggregate impact pavement durability.

What Was Our Goal?

This project sought to quantify the effects of various properties of aggregate base on the performance of concrete pavement foundation, refine MnDOT's guidelines for aggregate base to improve performance, and provide methods to compensate if suitable aggregate is not available.

What Did We Do?

Researchers used Enhanced Integrated Climatic Model software to quantify the impacts of moisture on the long-term performance of concrete foundations. EICM uses climate data from the MEPDG as its weather inputs in addition to mechanical and hydraulic properties of various base and subbase materials collected from the available literature.

Researchers also used a discrete element modeling approach to study how different gradations of aggregate with different ratios of gravel and sand pack together and the resulting impact on stability.

To better understand how design features (particularly base type and PCC slab thickness) and site factors affect field performance of concrete, researchers analyzed instrumented concrete pavement sections at MnROAD in accordance with designs from

continued

"During winter, a road's base is frozen and its strength will be high. But that strength drops during the spring thaw. A more open graded base drains better, so it doesn't lose as much strength when the weather warms up."

—Terry Beaudry,
Grading, Base, Pavement Reclamation, Recycling and Aggregate Engineer, MnDOT Office of Materials and Road Research

"Our overall objective is to improve aggregate base stiffness, stability and drainability for concrete base courses. A lot of times improving one comes at the expense of the other two, so this research was aimed at optimizing all three."

—W. James Wilde,
Professor, Minnesota State University, Mankato, Department of Mechanical & Civil Engineering

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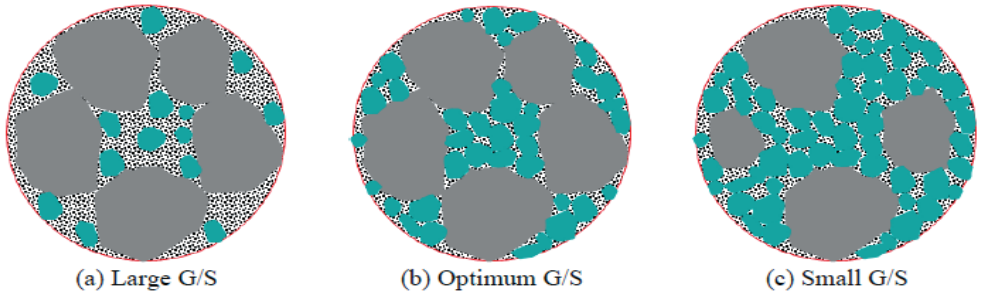

At optimum gravel-to-sand aggregate ratios, the optimized air void content maximizes stability. If the gravel content is too high (left), large air voids will cause instability and eventual deformation, while low gravel content (right) reduces durability and stability due to lack of stone-on-stone contact.

the Federal Highway Administration's Long-Term Pavement Program SPS-2 study. They collected data from these sections as well as from instrumented in-service pavement sections included in MnDOT's pavement management system.

Using that information, researchers refined MnDOT's guidelines for aggregate base material selection, which are found in Section 3138 of MnDOT Standard Specifications.

What Did We Learn?

By evaluating moisture effects and studying aggregate packing, researchers found that using permeable bases—particularly asphalt-treated permeable bases or cement-treated permeable bases—improved performance and reduced transverse cracking. Stronger support resulted in less roughness and joint faulting.

Open graded aggregate base layers observed at MnROAD had reduced subsurface moisture relative to traditional dense graded base layers while providing similar structural stability.

Both the pavement models and the MnROAD tests recommend a gravel-to-sand ratio of approximately 1.4 for open graded aggregate base. Specifically, 41 percent of material in the base should pass through a #4 (4.75 mm) sieve for the best combination of stability and drainability. Higher ratios result in larger air voids that reduce strength and eventually lead to increased deformation, while lower ratios reduce stability due to a lack of stone-on-stone contact.

What's Next?

This information should help MnDOT construct more financially effective pavement foundations, which will result in longer-lasting surface layers that will reduce repair and replacement costs and minimize maintenance-related travel delays. The research was presented at the Concrete Paving Association of Minnesota Workshop in March 2015.

The University of Illinois is currently working on an aggregate imaging system that would automatically analyze both size and shape properties of aggregates. In addition to size distributions, shape, texture and angularity are important aggregate properties, since angular and irregular-shaped rocks will lock together better than rounded ones. Field imaging methods are currently being developed for analyzing size and shape of large quantities of aggregate in the quarries and job sites.

It may be valuable to implement designs that meet these guidelines in test sections to confirm that their real-world performance matches the models. Implementation is supported by observing pavements constructed more than 10 years ago in accordance with the gradation-based guidelines developed in this report. Those pavements are performing better now than other pavements constructed according to traditional guidelines.

This Technical Summary pertains to Report 2015-42, "Cost-Effective Base Type and Thickness for Long-Life Concrete Pavements," published August 2015. The full report can be accessed at mndot.gov/research/TS/2015/201542.pdf.