RESEARCH SUMMARY

DEPARTMENT OF TRANSPORTATION

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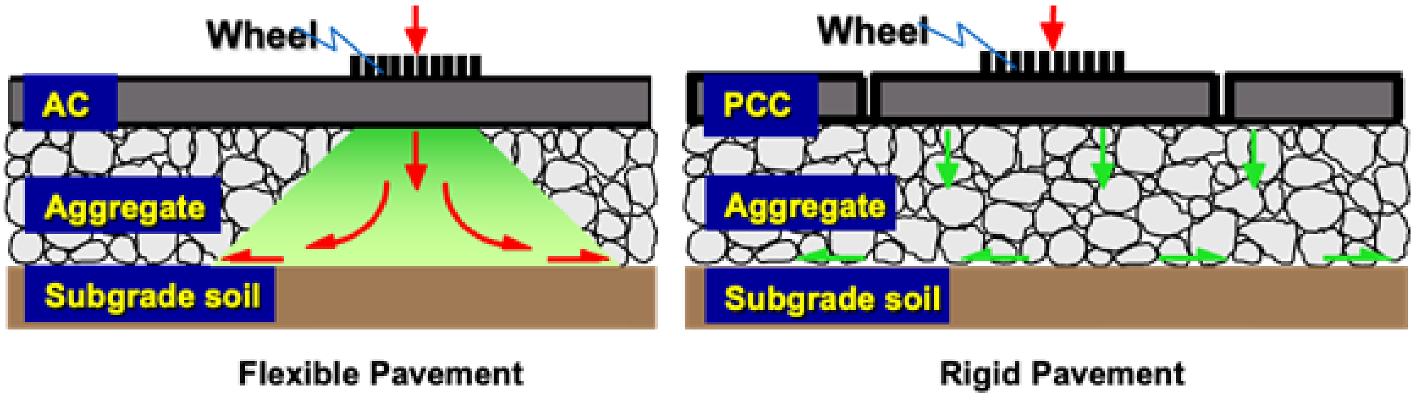

Evaluating Road Designs That Use Lower Quality Aggregate

Aggregate materials used in the base and subbase layers of pavements provide structural support and drainability to Minnesota roads. But the supply of locally available high-quality aggregate material is becoming increasingly scarce. This project explored sustainable and cost-effective solutions for constructing durable flexible pavement roads with lower quality aggregate material.

What Was the Need?

Aggregate base and subbase layers are critical to pavement performance, responsible for distributing vehicular loads, enhancing structural support, providing drainability and ensuring the durability of surface layers. The aggregate base layer, which is directly below the surface layer, typically consists of high-quality aggregate to ensure adequate load distribution. The subbase beneath the aggregate layer further distributes loads and improves drainage and frost resistance. Together, they influence the longevity, serviceability and maintenance needs of roads.

Acquiring high-quality aggregate in Minnesota is becoming increasingly difficult, and MnDOT and local agencies are interested in the feasibility of using lower quality aggregate in road foundations. This project evaluated pavement performance on roads constructed with aggregate materials of varying quality and a range of layer thicknesses. The results will provide state and local engineers with guidance for using local aggregate resources to design cost-effective flexible pavements.

What Did We Do?

This project integrated an aggregate index property (AIP) database, predictive modeling, pavement performance analyses and cost–benefit assessments to explore pavement foundation designs that use locally available materials. The comprehensive AIP database includes gradation, strength and durability properties for more than 1,100 aggregate sources across Minnesota.

To predict relationships between aggregate properties and key pavement design inputs, investigators developed and refined multiple linear regression and machine learning (ML) models.

Using three aggregate base and subbase quality classes (low, medium and high), investigators performed simulations using MnPAVE, a mechanistic-based design software tool. The analysis included varying traffic levels, asphalt layer thicknesses (4 to 8 inches), subgrade stiffness (2 to 10 ksi) and four representative climate zones in the state. Granular equivalency factors calculated the structural functioning of different aggregate materials and layer

“This project developed tools that state and local engineers could use to design roads that effectively balance performance and cost based on load requirements.”

—RAUL VELASQUEZ, RESEARCH ENGINEER, MnDOT GEOMECHANICS

thicknesses, which, when combined with the performance data, can guide design development that reduces overdesign while ensuring reliability.

A cost–benefit analysis using MnDOT’s historical bid price data identified optimal aggregate base and subbase thickness combinations for various design conditions. A comparison of performance outcomes and material costs for more than 40,000 design scenarios provided the most favorable combinations.

What Did We Learn?

The ML modeling significantly improved prediction accuracy for resilient modulus and shear strength by incorporating relevant aggregate properties such as gradation indices and optimum moisture content. This allowed for the categorization of aggregates into low-, medium- or high-quality classes.

Results of the MnPAVE simulations and cost–benefit analyses indicated that flexible pavements serving traffic levels below 1.5 million equivalent single axle loads (ESALs) can effectively perform for 20 years if using lower quality aggregate materials with proper aggregate base or subbase thicknesses, which offers a substantial reduction in construction costs and avoids a reliance on high-quality aggregate. However, for traffic levels exceeding 1.5 million ESALs, lower material quality cannot be overcome solely by increasing the thickness of the aggregate, indicating the need for a higher quality aggregate and/or a thicker asphalt surface.

Aggregate quality and thickness are the primary determinants of fatigue-related performance, and the subbase is most important for rutting prevention due to subgrade rutting. Using these principles, investigators created a flowchart to guide engineers and designers through incrementally adjusting aggregate base and subbase thickness combinations to minimize costs while still meeting load requirements for fatigue and rutting.

What’s Next?

Locally available lower-quality aggregate can be effective for low-volume roads. When traffic loads increase, the quality of aggregate predominantly determines fatigue performance, and subbase quality strongly affects rutting caused by subgrade permanent deformation. These results provide MnDOT and local agencies with information and a framework to make cost-effective design decisions that promote the efficient use of regional aggregate resources by preventing overdesign.

MnDOT will distribute these findings and encourage local agencies to use the flowchart, AIP database and MnPAVE mechanistic analysis and design tool to determine optimal pavement thickness designs. Further research focusing on field validations, expanded material testing, advanced mechanistic modeling, integration of predictive models into MnPAVE, and consideration of stabilized or reinforced unbound layers will improve pavement designs in Minnesota.

About This Project

REPORT 2025-43
“Pavement Design: Performance of Base Versus Subbase.”
Find it at mdl.mndot.gov.

CONTACT
research.dot@state.mn.us.

TECHNICAL LIAISON
Raul Velasquez, MnDOT,
Raul.Velasquez@state.mn.us

INVESTIGATOR
Erol Tutumluer, University of Illinois Urbana-Champaign,
Tutumlue@illinois.edu

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www.mndot.gov/research