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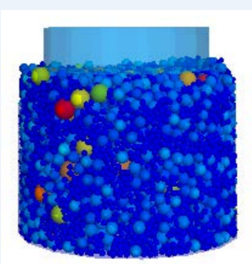
LRRB COST:
$54,950

TOTAL PROJECT COST:
$109,900



Researchers created a three-dimensional computer model simulating the interaction of an LWD loading plate with aggregate particles.

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# Quantifying Moisture Effects During Pavement Foundation Testing Using Numerical Modeling

*This project developed a model that provides a method for estimating the effects of moisture and particle size distribution on LWD and DCP testing. Better quality assurance will lead to smoother, more cost-effective and more durable roads.*

## What Was the Need?

During construction, the foundation layers of roads—consisting of gravel, sand and other materials—are tested to make sure they adequately support the pavement surface. Weak layers can shorten pavement life. Two common devices used in these field tests are the dynamic cone penetrometer and the lightweight deflectometer. The DCP estimates shear strength by measuring the penetration of a cone into the foundation material, while the LWD estimates stiffness by measuring the deflection of the material surface in response to a falling weight.

Test results from both devices are influenced by the particle size distribution and moisture content of the foundation material. Laboratory tests on a number of commonly used granular materials have helped establish relationships between these factors and modulus, a measure of a material's resistance to compression.

Despite advances, there is still only minimal understanding of the mechanisms governing these relationships. It is important to better understand these mechanisms in order to better estimate the behavior of new materials, because conducting physical tests for every possible material would be prohibitively expensive and time-consuming. Research was needed to develop computer models to determine how the strength and stiffness of materials varies with particle size distribution and moisture. Establishing these relationships will help engineers more accurately estimate acceptable target values for DCP and LWD tests.

## What Was Our Goal?

The first phase of this research, Project 2009-21, developed a three-dimensional computer model of how individual particles of dry unbound aggregates behave during certain lab and field tests. The goals of this second phase were to build on this mechanistic model to increase its range of applicability—by adding the LWD as a modeled test device and by accounting for the effects of moisture—and to incorporate the model into a commercial software package.

## What Did We Do?

Researchers developed three models of particle-to-particle interactions to better understand the effects of moisture content and particle size distribution on DCP and LWD test results.

- The first model is based on liquid bridge theory, which establishes how liquid connections between particles result in attractive forces between particles. Related to the surface tension of water, this type of force is called suction, or negative pore pressure.
- The second model adapts an empirical relationship established in previous research linking soil moisture content, mixture composition, and measured negative pore pressure.

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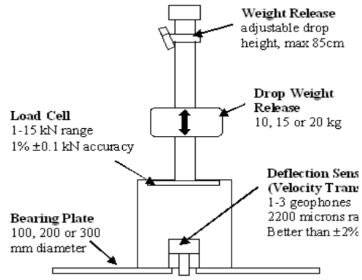


Researchers established models that will help determine the effects of moisture on the results of tests using the lightweight deflectometer (left). The LWD can be used in the field (right) to assess a foundation material's stiffness by measuring deflections in response to a dropped weight.

- The third model combines the first two models and also includes a particle friction coefficient, which researchers used to represent the fine particle content in a relatively coarse granular base, since a greater number of fine particles decreases friction between particles.

Researchers validated and refined these models by comparing their numerical results to the results of physical testing conducted in Project 2009-12. These models also rely on data from Project 2012-01 and an ongoing MnDOT project, "Cost-Effective Base Type and Thickness for Long-Life Concrete Pavements," which is expected to be complete in December 2014. Researchers also adapted these models for use in established commercial software, which broadens their ability to be used in related applications.

## What Did We Learn?

Of the three models, the third model best represented the range of behaviors measured by the DCP and LWD tests. That model agreed qualitatively with experimental data and associated target values from previous research, which demonstrated the importance of quantifying the volumetric distribution of particles, water and voids.

This third model can be used to predict behavior for a relatively narrow range of base materials as defined by MnDOT's Class 5 specifications. With some improvement, specifically in how the fine particles and moisture parameters are represented by the friction and suction coefficients in the force model, this framework can be extended to a wider range of granular bases, including recycled materials.

## What's Next?

An in-progress MnDOT project, "Implementation of Geosynthetics During Pavement Design and Construction," is incorporating the results of this project into commercial modeling software to help quantify the influence of geogrid materials on pavement performance. A related proposed project would develop the use of digital camera imaging for rapidly determining aggregate size and shape properties, which are key inputs into performance-based models. These models help determine DCP and LWD target values for new and recycled materials more efficiently and effectively than testing protocols based solely on laboratory tests.

*"This project delivered a new numerical tool that has been added to commercial software, which we're using to help optimize pavement designs—ultimately leading to better use of resources and more cost-effective pavements."*

**—John Siekmeier,**
Research Engineer,
MnDOT Office of Materials

*"Paired with digital image analysis, the model developed in this project has the potential to revolutionize the construction standards for using moist unbound materials in pavement foundations."*

**—Kimberly Hill,**
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*This Technical Summary pertains to the LRRB-produced Report 2014-13, "Quantifying Moisture Effects in DCP and LWD Tests Using Unsaturated Mechanics," published February 2014. The full report can be accessed at* http://www.lrrb.org/PDF/201413.pdf.