2009-21TS
Published December 2009

LRRB
LOCAL
ROAD RESEARCH
BOARD

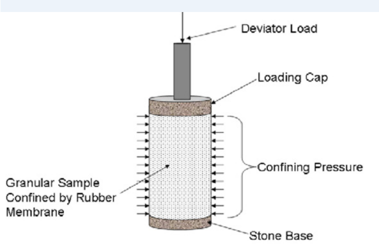
TECHNICAL SUMMARY

Technical Liaison:
Lee Amundson, Lincoln County
lamundson@co.lincoln.mn.us

Administrative Liaison:
Nelson Cruz Mn/DOT
nelson.cruz@state.mn.us

Principal Investigator:
Kimberly Hill, University of Minnesota

PROJECT COST:
$105,000



In the resilient modulus test, a cylindrical chamber is filled with a granular material and then subjected to pressure and stress.

RESEARCH
SERVICES SECTION

Mechanistic Modeling of Tests of Unbound Granular Materials

What Was the Need?

For a pavement to perform well, it is crucial that its base layer be well-designed. This layer is commonly composed of unbound aggregates, and designing this layer involves choosing aggregate grades and taking into account the thickness to which the layer will be compacted by machine rollers. Historically, design guidelines for aggregate layers have been based largely on past experience rather than mechanistic principles.

Recently, however, there has been an effort to use the American Association of State Highway and Transportation Officials Mechanistic-Empirical Pavement Design Guide to apply mechanistic principles to pavement design. Applying these principles requires evaluating existing tests used to measure the stiffness and strength of base layers composed of unbound aggregates. These tests include the California bearing ratio and resilient modulus laboratory tests as well as the dynamic cone penetrometer test for quality control in the field.

While there are a number of empirical correlations among the results of these tests, they are limited to the specific conditions under which the tests were performed. It would be helpful to have a more general, reliable, repeatable and well-defined mechanistic method for correlating test results. To develop this method, it would also be helpful to have a three-dimensional computer model that provides a detailed analysis of the mechanics of unbound materials. Specifically, the model should show how individual particles composing the aggregate interact with each other when subjected to different kinds of stresses, including how they resist deformation caused by uniform pressure and how they deform under different shearing stresses.

What Was Our Goal?

The objective of this study was to develop a mathematical model that provides a physics-based, mechanistic correlation between the California bearing ratio, resilient modulus and dynamic cone penetrometer tests. To accomplish this, researchers investigated and modeled relationships between the basic material properties of unbound aggregates, including the interaction of individual particles.

What Did We Do?

Researchers began by modifying existing computer code to model these three tests commonly used to characterize the granular materials that compose base layers. For the original code they chose software capable of creating 3-D models of detailed interactions between the individual particles in a granular material. This code, the 3-D discrete element model, or DEM, would allow researchers to investigate the effect of the basic physical properties of these particles on granular material test results.

Researchers modified this code by setting parameters for particles and algorithms for the simulation of their interaction. This preliminary model was then calibrated with existing laboratory and field data to enable it to better simulate real results. Finally, researchers further modified the model to determine mechanistic relationships between its results and particle properties.

What Did We Learn?

The calibrated DEM model achieved strong agreement between the results of the simulations and sample numerical and experimental studies on granular materials, and was shown to be capable of determining the effects on these tests of aggregate shape,

continued

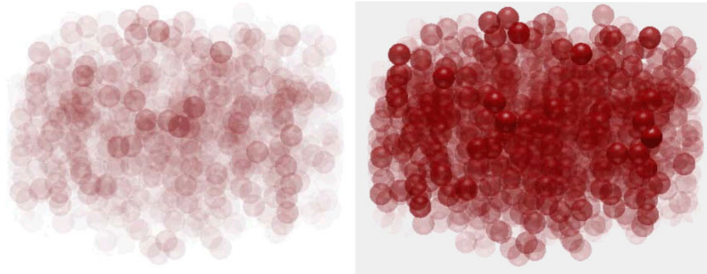
"This study is a good beginning to developing a model that will give engineers better information on the ability of base layers to withstand loads so that we can properly design roads with longer life spans."

–Lee Amundson,
Lincoln County Engineer

"We found that the dynamic cone penetrometer and resilient modulus tests may to some extent be measuring different things. The relationship between these tests will consist not of a single equation but of various correlations for different types of materials."

–Kimberly Hill,
Assistant Professor, University of Minnesota Department of Civil Engineering

Produced by CTC & Associates for:
Minnesota Department of Transportation
Research Services Section
MS 330, First Floor
395 John Ireland Blvd.
St. Paul, MN 55155-1899
(651) 366-3780
www.research.dot.state.mn.us



Color intensity is used to indicate the relative magnitude of interparticle force distributions for the resilient modulus test during the rest period (left) and during maximum deviator stress (right).

coefficient of friction, gradation, stiffness and other properties as well as the statistics of interaction between particles.

Using this model, researchers found that the penetration depth of the dynamic cone penetrometer test is highly affected by the shapes of the particles, while the resilient modulus test is affected by the stiffness of particles and level of applied stress. The model also showed that the interaction between particles in granular materials varies significantly for different loading conditions.

Overall, the code shows promise for the development of mechanistic-based correlations between common granular materials test results as well as a more comprehensive mechanistic understanding of these test results.

What's Next?

While the model described in this report serves as a strong foundation for future research, more work is needed to fully develop a mechanistic model for tests of unbound materials. Researchers need computers with more power than is currently available to perform computations on the larger sample sizes necessary to fully develop this model. One possible solution to this problem is to develop more efficient DEM code capable of parallel processing between multiple computers.

More research is also needed to quantify different particle shapes and their effect on the characteristics of granular materials as well as the effect of specimen preparation techniques and other initial conditions.

Finally, because the current model assumes that aggregates are dry, researchers are planning a second phase of this study that takes into account the presence of moisture, mud and small particles such as sand; these factors can significantly affect the behavior of aggregates.

This Technical Summary pertains to the LRRB-produced Report 2009-21, "Mechanistic Modeling of Unbound Granular Materials," published June 2009. The full report can be accessed at http://www.lrrb.org/PDF/200921.pdf*. For more information on Mn/DOT's implementation of mechanistic-empirical pavement design, please see* http://www.dot.state.mn.us/materials/pvmtdesign/mepdg.html.