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PUTTING RESEARCH TO WORK

BRIEF

# Measuring Strength of Sands for Earth Walls and Reinforced Slopes

Wisconsin DOT uses local sands as backfill in mechanically stabilized earth walls and reinforced soil slopes, structures that support highways or that are adjacent to them. Sand is strong, drains well, and settles relatively little. Engineers measure the strength of soil backfill in terms of shear strength. The two properties that contribute to shear strength are cohesion (the ability of a soil to stick together) and internal angle of friction (the grain-to-grain frictional resistance).

Sand lacks cohesion, so a sand's friction angle is the only component of its strength. A sand exhibiting a high internal angle of friction has a higher shear strength, which results in more economical designs of roadway facilities. For example, the lower the friction angle of a sand, the more pressure it puts on the back of a retaining wall, resulting in a thicker wall design. Sand with a higher friction angle stands more easily on its own, and puts less pressure on a retaining wall, which means a thinner wall design can be used.

## What's the Problem?

Once design engineers know the friction angle of the sand fill they will be using, they can design walls appropriately to withstand the pressure of the fill without shifting or bulging. Until the early 2000s, WisDOT followed FHWA standards that indicated that if sands met certain criteria, it could be assumed that they had a friction angle of 34 degrees or higher. In 2002 and 2003, WisDOT performed direct shear tests of sands that had been used by the department and met FHWA requirements, and found that the sands had friction angles of 29 to 32 degrees, suggesting that some WisDOT facilities had factors of safety that were less than expected. Examination showed that many of the sands with lower friction angles had similar geologic history.

Past results of laboratory direct shear testing has indicated that the reliability and repeatability of the test is unclear—different laboratories may deliver different test results for the same sample. As a result of WisDOT's initial testing, the department lowered the sand fill friction angle used for wall design to 30 degrees if other criteria are met, but engineers did not have a complete picture of the range of friction angles that Wisconsin sands possess.

## Research Objectives

This research sought to evaluate a wide variety of Wisconsin sands to identify geological and physical characteristics that may correlate to shear strength, to develop repeatable direct shear test procedures (within the limits allowed by AASHTO test methods), and to assess the consistency of results from different state and commercial laboratories.

## Methodology

Investigators performed the following steps in this study:

- Selected 30 sand samples from around Wisconsin.
- Determined the physical characteristics and geologic profile of each sample.
- Tested samples via:
    - Direct shear test in 64-mm-wide boxes. The samples were compacted dry to specification, then inundated.
    - Direct shear test of larger particles in 305-mm-wide boxes; samples were compacted and inundated.
    - Triaxial compression test.
- Categorized sands into four classes according to shear strength.
- Submitted four representative samples to 10 laboratories for comparative direct shear testing.

**Investigator**

*"We developed a model that accurately predicts a sand's internal angles of friction from easily obtainable physical properties."*

–Tuncer Edil
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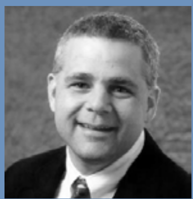
## Co-investigators



**Craig Benson**
UW-Madison

**Christopher Bareither**
UW-Madison

## Geotechnics TOC Chair

*"We were looking for representative shear strength values of sands from different sources around the state, and this research led to a simple method of estimating these values."*

**–Bob Arndorfer**
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Research shows that the friction angle of sand, a measure of its strength, can be determined accurately in the laboratory with equipment like these shear testing boxes, and can be correlated to geographic sources of sand fill from around Wisconsin.

## Results

This investigation found that there is a relationship between geologic deposit type and friction angles of compacted sands, and that weak and strong sands can be differentiated according to physical characteristics and geologic origin. Specific findings include:

- Wisconsin sands fall into four shear strength groups. Sands with the lowest friction angle are derived from the weathering of underlying sandstones and tend to be fine-medium, well-rounded and poorly graded. Sands with the highest friction angle come from more recent glacial activity and tend to be coarser-grained, well-graded or angular.
- Direct shear testing is highly repeatable within the same laboratory, when performed by the same technician using the same procedure.
- Test results from various laboratories vary dramatically, by as much as 18.2 degrees, with an average margin of variation of 8.8 degrees.
- A multiple regression model developed in this research can predict internal angle of friction with an accuracy of $\pm$ 2 degrees using easily identified physical characteristics: effective grain size, maximum dry unit weight, and particle roundness. This model can be used in the early stages of design, and its results can be validated by conducting laboratory direct shear testing.

## Further Research

The source of variation between laboratories was not identified, and could merit investigation. Evidence suggested that problems in specimen preparation may have been a factor.

## Implementation

WisDOT is reviewing its own shear strength data and samples, and is comparing the department's test methods with those used in this project to validate the research findings and procedures. Ultimately, the department will assemble shear strength data for sand sources from similar geologic regions around the state and use this data for preliminary design of walls and slopes within those geographic areas.

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