# Implementation of **Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin** Department of Transportation SPR # 0092-07-21

Tuncer Edil, Ph.D Geo Engineering Consulting, LLC

**July 2010** WHRP 10-07

#### **IMPLEMENTATION RECOMMENDATIONS**

OF

## DETERMINATION OF SHEAR STRENGTH VALUES FOR GRANULAR BACKFILL MATERIAL USED BY THE WISCONSIN DEPARTMENT OF TRANSPORTATION

#### Submitted to the

WISCONSIN HIGHWAY RESEARCH PROGRAM WISCONSIN DEPARTMENT OF TRANSPORTATION

Ву

Geo Engineering Consulting, LLC 3100 Lake Mendota Dr Unit 503 Madison, Wisconsin 53705

June 30, 2010

#### IMPLEMENTATION RECOMMENDATIONS

#### PROBLEM STATEMENT

Implementation of research results is an emphasis area of the Wisconsin Highway Research Program (WHRP) Steering Committee. The WHRP Geotechnical Technical Oversight Committee decided in their April 11, 2007 meeting to complete implementation work on Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin Department of Transportation. The proposed recommendations follow.

#### **BACKGROUND**

The WHRP sponsored a project related to the implementation item. This projects is:

<u>WHRP 06-01 (0092-05-08)</u>: Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin Department of Transportation – Tuncer Edil and Craig Benson, Department of Civil and Environmental Engineering, UW-Madison, December 2006.

This project directly relates to the objectives of the implementation plan and their findings form the knowledge base for the implementation plan. The draft final report of the project was submitted on December 29, 2006. The review comments were received on April 27, 2007. The Geotechnical Oversight Committee was satisfied with the research and a few technical revisions were required. These revisions have been all incorporated into the final report.

Friction angles ( $\phi$ ') obtained from the direct shear tests were related to the geologic origins and physical characteristics of the sands. The thirty sands were differentiated into four strength groups based on shear strength and deformation behavior. Sands comprising each strength group share similar geologic origin and/or physical characteristics that contribute to similarity in the shear strength and deformation behavior. The lowest strength sands are comprised of quartz particles that have undergone extensive transport and physical weathering. These particles are mechanically weathered from the underlying Cambrian and St. Peter Sandstones and are well-rounded, medium to fine in size, and uniformly graded. The highest strength sands, derived primarily from outwash of the Wisconsin Glaciation, have undergone less transport and physical weathering, have lower quartz content, are more angular, are larger in size, and have broader gradation compared to the other sands.

A multiple regression model was developed that predicts  $\phi'$  of compacted sands in Wisconsin. The model predicts  $\phi'$  within  $\pm$  2° based on effective grain diameter (D<sub>10</sub>), maximum dry unit weight, and particle roundness. Variables included in the regression model were required to be statistically significant (p-value < 0.05), to have physical significance regarding effect on  $\phi'$ , and to be readily measured in the laboratory. The multiple regression model can be used to estimate  $\phi'$  for preliminary geotechnical design or to provide a reasonableness check on  $\phi'$  for granular backfill materials measured in direct shear.

There was no significant difference between  $\phi'$  obtained with small-scale direct shear and large-scale direct shear for gravel contents ranging from 0 to 30%. This suggests that tests on material where gravel is excluded can be used to define the shear strength of granular backfills having a gravel content < 30%.

Intra-laboratory and inter-laboratory testing was conducted to assess the bias, repeatability, and reproducibility of the shear strength of compacted granular backfill materials tested in direct shear using AASHTO T 236. Comparison of failure envelopes and friction angles from the intra-laboratory study showed that the test method is highly repeatable ( $\phi' \pm 0.12^\circ$ ) when conducted in a single laboratory by a single operator using the same equipment. In contrast, data from the inter-laboratory study showed high variability in the failure envelopes and friction angles, with  $\phi'$  varying by as much as 18.2° for a given backfill. Analysis of the data from the inter-laboratory study showed that the reproducibility of direct shear tests on granular backfill is 8.8°. The bias in  $\phi'$  is -2.7° when area corrections are not applied and -1.4° when area corrections are applied.

#### SCOPE OF ACTIVITIES UNDERTAKEN

Historical direct shear test results completed by the Department appear to indicate 2-3 degrees less than UW's baseline  $\phi$ '-values. Further work was undertaken in cooperation with the WisDOT to compare the test results between the UW and the Department. All of this work is used to help the Department to reach a consensus on what the 'correct' values should be and how to proceed forward on this. It appears that there may be three areas causing discrepancies between results: operator differences/errors, procedural test differences or equipment differences/influences. The work entailed finding these differences, determining if they are allowed by AASHTO test procedures (and correcting, if they are not open to interpretation), determining the effect of the differences and refining AASHTO test requirements/procedures to ensure better correlation to Departmental lab test results. In view of the high inter-laboratory variability but highly repeatable intra-laboratory results, a careful review of testing procedures, especially as they relate to specimen preparation, was undertaken to have repeatable and consistent test results. The following testing and verification effort was completed:

- 1. Prior to any additional testing, appropriate UW and Departmental personnel jointly reviewed their respective test procedures and AASHTO specifications and determined if any deviations in test procedures are apparent between the groups. The goal of this task was to minimize procedural test differences. All further testing procedures were based on these agreed-upon test methods. The material used and the test procedure is given in Appendix A.
- 2. To eliminate equipment related variability, the person who performed the UW tests performed direct shear tests using the Department equipment on the split sample that was used to establish UW intra-laboratory test program.
- 3. Department personnel then performed the same test on the same sample following the same protocol on the Department equipment. Particular attention was directed to specimen preparation method.
- 4. Department personnel also performed the grain size, compaction and grain shape evaluations on the same sample to estimate  $\phi'$  based on the empirical regression model.
- 5. Similar testing of the same material was conducted by Departmental and UW personnel on UW test equipment, using the agreed-upon test procedures.
- 6. All testing was conducted with both parties present to look for differences in procedures, equipment or operator tendencies.

7. While/after testing is being completed, analyses were done to determine differences in methods and equipment. AASHTO and ASTM specifications were consulted to determine proper/allowable deviations and corrections made.

Based on this information/tests, a direct comparison of test results was made. The goals were to aid the Department in determining the 'correct'  $\phi$ ' and to modify the AASHTO procedures as needed to increase the potential of consultant laboratories to achieve similar test results.

#### RESULTS

#### **Operator Related Variability**

Table 1 gives a summary of the friction angle data (all without area correction) for split sample P1-S6 of the original study by Edil et al. (2007). Fig. 1 shows the effect of area correction on this sample as given in the original study (Edil et al. 2007). It shows that there could be 1-degree difference due to area correction. The friction angles reported in Table 1 are all without area correction. All tests were performed using normal stresses ranging from about 0.25 to 1.92 tsf, i.e., essentially in the same range of normal stresses. All of the tests included in Table 1 were performed on samples prepared air dry and subsequently inundated specimens and, with the exception of Test 4, all at a target dry unit weight of 106.4 pcf, which corresponds to 95% of the standard Proctor maximum dry unit weight for P1-S6.

Tests 1, 2, and 5 were performed on the UW equipment but by different operators. Test 1 by the UW operator was based on 5 tests at different normal stresses and the friction angle was compared to the angle obtained from the triaxial compression test (Edil et al. 2007). The replicate tests also indicated high degree of repeatability. It is, therefore considered, the reference test. The friction angle is 31 degrees. Test 2 was performed by graduate students without previous training in 5 different teams, each having two students. All of the operators were given the same instructions (see Appendix A). The strength envelopes generated by the graduate students are given in Fig.2 and their friction angles had a standard deviation of 1.8 with an average value of 32.9 degrees (ranging from 31 to 35 degrees). Test 5 was performed by the WisDOT operator using the UW equipment, which resulted in 27 degrees. Appendix B gives the strength envelopes, stress-relative horizontal displacement, and vertical displacement-relative horizontal displacement plots by the UW and WisDOT operators using the UW equipment.

Similarly, Tests 3 and 6 were performed on the WisDOT equipment but by different operators. There is a 2-degree difference between the friction angles determined by the two operators. Appendix C gives the strength envelopes, stress-relative horizontal displacement, and vertical displacement-relative horizontal displacement plots by the UW and WisDOT operators using the WisDOT equipment.

The data indicate that even with the same equipment there are differences up to ±4 degrees in friction angle depending on the operator.

#### **Equipment Related Variability**

Test pairs 1 and 6 and 3 and 5 are performed by the same two operators using two different equipment (i.e., UW and WisDOT equipment). In both cases, there is only 1-degree or less difference due to different equipment. Appendix D and C give the strength envelopes, stress-relative horizontal displacement, and vertical displacement-relative horizontal displacement plots by the UW and WisDOT operators, respectively, using the UW and WisDOT equipment.

The data indicate that the effect of equipment is less than 1 degree in friction angle irrespective of the operator.

#### **Estimating Friction Angle from Grain Size, Grain Shape and Compaction**

The WisDOT personnel determined grain roundness for P1-S6 following the procedure outlined in Appendix E for grain shape determination and the estimation of friction angle. Appendix F gives the roundness data developed by the WisDOT operator as well as the grain size, compaction, and roundness data developed by the UW operator. The physical properties needed for friction angle estimation are summarized in Table 2. Roundness is the least commonly determined property and the WisDOT number was remarkably the same as the UW number. The estimated friction angle based on the data is 31.8 degrees and close to the UW number. This is not surprising since the regression equation was developed based on the data generated by the UW operator.

Accurate determination of roundness implies that estimation of friction angle by the regression equation is reliable. The other two physical parameters (Effective grain diameter,  $D_{10}$  and standard Proctor  $\gamma_{dmax}$ ) are straightforward and commonly determined. The original study indicated that this method is accurate within  $\pm$  2 degrees.

#### **Updating Departmental MSE Wall Special Provisions and Bridge Manual**

Overall observation of the results indicates that the Department's own testing give results about 3 degrees lower than the UW test results. This may be considered erring on the safe side but may result in extra cost. The Department equipment is relatively old and data processing/analysis is a black box; however, it is clear that this is not the source of the discrepancy. The source of the discrepancy seems to be tied into the procedure followed. The observations made during the test at the WisDOT laboratory are listed in Appendix G. Some procedural changes can be introduced based on these observations. The original study found that the source of errors was related to specimen preparation and the density achieved (Edil et al. 2007). This may be a starting point for improvement.

The broader point is how to rely on direct shear test results obtained at other laboratories. Recommendations concerning the Department's current specifications regarding prescriptive  $\phi$ ' supplemented by direct shear testing as needed need to be reviewed and adjusted based on the research results and the described work. Perhaps, a list of procedural requirements could be provided and certification by the testing laboratory could be required. Because of the large inter-laboratory variability of  $\phi$ ' disclosed in the research, reliance on testing needs to be scrutinized and/or test protocols have to be tightened in Departmental publications. Research showed that sands comprising each strength group share similar geologic origin and/or physical characteristics that contribute to similarity in the shear strength and

deformation behavior. This information should be used to guide the Department relative to acceptable  $\phi'$  and testing methods in the specifications and design manuals. The use of the regression equation should be encouraged for natural sands in Wisconsin.

#### Additional Activities for Implementation

Updating Departmental publications relating to retaining wall friction angles and providing appropriate language will be the primary focus of this implementation work. However, dissemination of the information more actively is important. Such activities will include preparation of a brief bulletin with an explanatory commentary for Department personnel, backfill providers, and designers.

#### Reference

Edil, T.B., Benson, C.H., and Bareither C.A. (2007) "Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin Department of Transportation, WHRP Report #0092-05-08.

#### **RECOMMENDATIONS**

A review of the information in the original report <u>WHRP 06-01 (0092-05-08)</u>: Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin Department of Transportation and the information generated in this report lead to the following observations:

- 1.The measured friction angles for backfill materials in Wisconsin was never less than 32° and could be as high as 42°. Therefore, the current language in 14.10.1.3.2 Backfill for Reinforced Soil Zone of Bridge Manual "An angle of internal friction of 30 degrees can be assumed for this material without testing." seems too restrictive. As long as the source is one of the quarries or deposits covered in WHRP 06-01 (0092-05-08), this number is recommended to be changed to 32°.
- 2. The use of direct shear test is not recommended if it is desired to use an angle of internal friction greater than 30 degrees. Round robin tests and careful review of the WisDOT tests indicate that large spread of results. The source of variability is primarily related to specimen preparation and the operator. So different equipment and tightening the standard Direct Shear Test, AASHTO T-236 is not likely to improve this as the test comparisons were made based on tightened up procedure. This is a problem inherent in Direct Shear test. It is recommended that the friction angle formula method given in Appendix E be used. This method is accurate within  $\pm~2$  degrees for natural sands (not to be used with crushed aggregate) and has variability less than the direct shear testing. As a conservative measure, the friction angle estimated by this method can be reduced by 2 degrees but not less than 32 degrees.
- 3. If the department desires to continue, direct shear tests internally, the 13 procedural instructions given in Appendix A has to be adopted in addition to the general provisions of AASHTO T-236. The friction angle measured is typically 2 degrees lower and can be adjusted up.

- such cases, the 13 procedural instructions given in Appendix A has to be enforced in addition to the general provisions of AASHTO T-236.
- 5. Consolidated drained triaxial compression test is a more fundamental test, although was not evaluated in depth in this project, the Department should consider developing it for this purpose.

### Recommended language for 14.10.1.3.2 Backfill for Reinforced Soil Zone in Bridge Design Manual

The material for infill in the reinforced soil zone shall be Grade 1 Granular Backfill as stated in 209.2 of the Wisconsin Specifications for Road and Bridge Construction except that 100% of the material shall pass the 3 inch sieve. An angle of internal friction of 30 degrees can be assumed for this material without testing taking into account potential under compaction during construction.

If it is desired to use an angle of internal friction greater than 30 degrees, it shall be determined by both the Wisconsin Regression Equation and direct shear testing. The standard Direct Shear Test, AASHTO T-236, on the portion finer than the No. 10 sieve, utilizing a sample of the material compacted to 95 percent of AASHTO T-99, Methods C or D (with oversized correction as outlined in Note 2) at optimum moisture content can be used to determine the friction angle. The additional requirements to AASHTO T-236 shall be incorporated to the procedures as given by the WisDOT. If this method is used the friction angle shall not be greater than the values given in the report WHRP 06-01 (0092-05-08): Determination of Shear Strength Values for Granular Backfill Material Used by the Wisconsin Department of Transportation for the same geological origin. The friction angle estimated by these methods shall not exceed 38 degrees for use in design. No testing is required for backfills where 80% of sizes are greater than 3/4 inch.

The plasticity Index shall not exceed 6. The backfill material shall be free from organic and other deleterious materials and free of shale or other soft poor durability particles. It shall not contain foundry sand, bottom ash, blast furnace slag or other potentially corrosive material. In addition, it shall meet the following electrochemical criteria:

Resistivity pH 4.5 -10 Chlorides Sulfates Greater Than 3000 ohm cm/H 4.5-10 Less Than 100 PPM Less Than 200 PPM

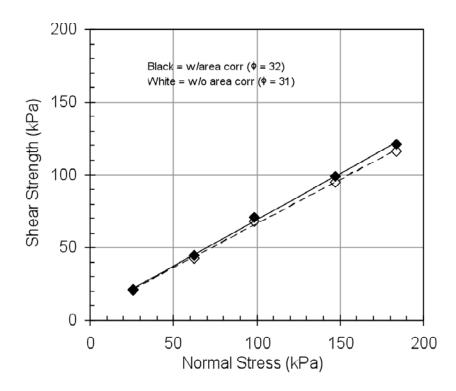


Fig. 1 UW Tests Demonstrating Effect of Area Correction (Edil et al. 2007)

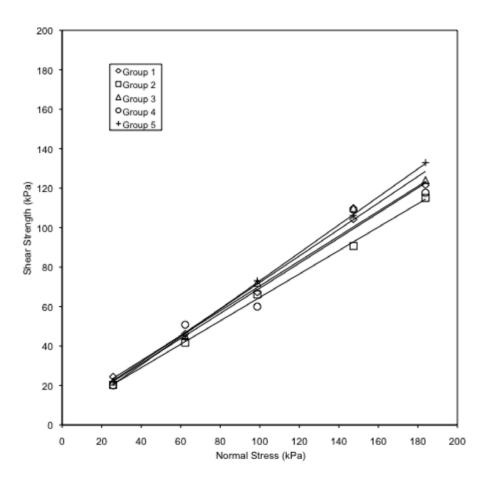


Fig. 2 UW Graduate Student Tests (Test No. 2 in Table 1)

Table 1. Summary of Friction Angle Data by Operator and Equipment

Test	Date	Equipment	Operator	Analysis	Water	Dry	Normal	Friction Angle
				Program	Content	Unit	Stress	(Degrees)
					(%)	Weight	(tsf)	
						(pcf)		
1	6/9/05	UW	UW	UW	0	106.7-	0.27-	31
						107.8	1.92	
2	10/20/07	UW	UW Grad	UW	0		0.27-	$32.9 \pm 1.8$
			Students				1.92	
			(6 teams)					
3	10/22/09	WisDOT	WisDOT	WisDOT	0	106.4	0.25-	27.9
							1.85	
4	5/7/09	UW	WisDOT	UW	0	102.4	0.68-	26.6
							1.85	
5	5/7/09	UW	WisDOT	UW	0	106.3	0.27-	27.2
							1.92	
6	5/13/08	WisDOT	UW	UW	0	106.4	0.25-	29.9
							1.78	

Notes: 1. Cohesion intercepts were about 0.5 tsf or less and ignored 2. UW Operator: Chris Bareither 3. WisDOT Operator: Bob Downing

Table 2. Prediction of Friction Angle from Physical Properties

Property	Value	Determined by
D <sub>10</sub> (mm)	0.17	UW
γ <sub>dmax</sub> (pcf)	111.9	UW
Roundness	0.62	UW
Roundness	0.62	WisDOT
Estimated Friction	31.8	Regression
Angle (degrees)		Equation