

Comparison of Hand Held Gage and Unconfined Compression Results in Low Strength Cementitious Stabilized Materials

Isaac L. Howard¹, A.M.ASCE and Walaa Hassan Badran²

¹Assistant Professor, Department of Civil and Environmental Engineering, Mississippi State University, Starkville, MS 39762-9546; PH (662) 325-7193; FAX (662) 325-7189; email: ilhoward@cee.msstate.edu

²Graduate Research Assistant, Department of Civil and Environmental Engineering, Mississippi State University, Starkville, MS 39762-9546; PH (662) 325-3050; FAX (662) 325-7189; email: Whb106@msstate.edu

ABSTRACT

This paper compares measured shear strength of high moisture content soils stabilized with nine cementitious materials from two penetrometers and one miniature vane shear device to unconfined compression (*UC*) testing. Three fine grained soils of varying organic content were obtained from New Orleans and Mobile and tested at a water to cementitious ratio of 10; 2,844 readings were taken with each hand held gage on stabilized slurry slabs and 297 *UC* readings were taken for comparison. Test results indicated the miniature vane shear device was the most accurate but the least precise. Accuracy of the two penetrometers was similar, though precision varied. Shear strength over prediction with the hand held gages became prevalent with increasing organic content. The motivation for the work was to have a rapid method to assess strength development in a family of materials where correlation of hand held gages to *UC* measured strengths isn't readily available.

INTRODUCTION

The objective of this paper is to compare shear strength test results of high moisture content fine grained soils stabilized with multiple cementitious materials from three hand held gages to unconfined compression (*UC*) testing. Two of the gages are penetrometers and one gage is a miniature vane shear device. Hand held gages of these styles are used in many applications, whereas correlations to shear strength (s_u) measured in conventional fashions (e.g. unconfined compression) are not always readily available. Hand held gages historically have been most commonly employed to evaluate consistency of unstabilized cohesive soils. FDOT (2000) indicates miniature vane shear (torvane) and pocket penetrometer tests should only be used as an index of s_u for clay samples.

This paper deals with a category of low strength material where limited information exists in literature, especially in terms of shear strength correlation of hand held gage measurements. Stabilization of high moisture content fine grained soils has been documented in literature for several years, though applications are

increasing. Applications include but are not limited to alternative disposal of dredged soils, re-use of dredged soils, contaminated sediments, emergency construction (primary purpose of the research), alternative controlled low-strength material (*CLSM*), mine tailings, aggregate production tailings, fill for geotextile tubes, and solidification for solid waste disposal.

Test methods for penetrometers and different types of shear devices are in various stages of development. As of April 2010, ASTM committee D18 had an open work item (WK27337) involving evaluation of the consistency and appropriate *UC* strength of soils using a pocket penetrometer. No standards are currently in place in this regard. Standards exist for some portable shear measurement devices, but no standard was found regarding use of a hand held and hand operated miniature vane shear device. ASTM D 2573 describes a test method for field vane shear testing in cohesive soils, while ASTM D 4648 describes a laboratory miniature vane shear test for soft to stiff saturated fine-grained clayey soils with an undrained shear strength less than 1 kg/cm². The device is motorized and has a four vane head with diameter to height aspect ratios of 1:1 and 1:2.

Literature documents use of hand held gages, though specific details of how the gages were used alongside calibration of readings using widely accepted shear strength measurement techniques for the type of material under investigation are not prevalent. Emery (1980) and MacKay and Emery (1994) provide details on a study involving lake bottom sediments in Ontario, Canada. The sediment contained 7 to 31% organics and had a moisture content of 29 to 75%. Laboratory testing was performed using a *Soiltest CL-700* penetrometer where stabilization additives were used at rates of 20 to 25%. Additives included portland cement, slag cement, cement kiln dust, lime kiln dust, hydrated lime, and flyash. Shear strength (s_u) calculated from penetrometer readings varied from 0.21 to 1.48 kg/cm² at 24 hr and from 0.61 to 2.20 kg/cm² at 168 hr. Specific test details and calibration of readings were not provided.

Kelly and Diethem (1996) used a pocket penetrometer to test stabilized sludge containing oil and grease after curing for 7, 14, or 28 days at ambient temperature in a sealed container. Testing was also performed via unconfined compression as per ASTM D2166. Cementitious additives incorporated were lime, fly ash, and Type II portland cement; additive contents were over 50% of the total sludge weight in many instances and were over 100% of the total sludge weight in some instances. No performance issues related to the penetrometer were provided.

Vaghar et al. (1997) tested harbor bottom sediments/organic deposits and marine clays from the *Boston Inner Harbor* leading to the *Ted Williams Tunnel* in Boston. The material dredged was used for construction on Spectacle Island after drying and compaction. The end criterion was an undrained shear strength on the order of 0.75 kg/cm². Chemical stabilization was performed with multiple materials by referencing wet sediment weight. Sediment properties were a wet bulk density of 1.18 to 1.25 g/cm³, moisture content of 260 to 270%, apparent specific gravity of 2.26, and a classification of *ML* to *OL*. Test specimens were remolded to in situ moisture, mixed with stabilization additives, dried under ambient air flow when spread in 75 to 100 mm lifts, and tested every 24 hours with a torvane shear and a pocket penetrometer until an average torvane reading of 0.20 kg/cm² was obtained

since this was the minimum value to support low ground pressure heavy equipment. This took approximately 40 hours for the treated samples. The untreated material achieved a shear strength of 1.71 kg/cm² when compacted to 93% maximum dry density (γ_d) and 21% moisture. When treated the material achieved 1.81 to 2.54 kg/cm² at densities from 83 to 92% of γ_d and moisture contents of 37 to 49%. Specific details related to calibration and use of the hand held gages wasn't provided.

Gassman et al. (2001) used a pocket penetrometer to determine time of set of *CLSM*. Tripathi et al. (2004) compared pocket penetrometer and torvane shear measurements for *CLSM* to Kelly Ball testing according ASTM D 6024 for estimation of bearing capacity. *UC* testing via ASTM D 4832 in 75 by 150 mm cylinders was also performed. Specimens were produced at water to cementitious material (*w/cm*) ratios of 0.69 to 1.14 containing 67.9 to 69.4% sand that used mostly fly ash with small amounts of portland cement as the cementitious blend. Shear strengths were on the order of 0.5 kg/cm² at 72 hr and up to 1.7 kg/cm² at 168 hr. The penetrometer used could measure readings allowing shear strength calculation up to 2 kg/cm² and the torvane could measure shear strengths up to 1 kg/cm². More scatter was reported with the torvane than the penetrometer but few other details were reported.

EXPERIMENTAL PROGRAM

An experimental program was developed to evaluate the precision and accuracy of hand held gages. Testing began in the spring of 2008 and concluded in the spring of 2010. Stabilized soil slurries were created by combining one soil, one or two cementitious materials, and water to create blends with 100% moisture (i.e. equal mass of soil and water) and 5% cementitious material referencing soil and water weight (i.e. *w/cm* ratio of 10). Other moisture and cementitious combinations have been tested but were not presented in this paper. The soils and cementitious materials tested are summarized in Tables 1 and 2. The stabilized soil slurry was used to produce 75 mm diameter by 150 mm tall specimens for unconfined compression (*UC*) testing using practices found in ASTM D 2166-06 and ASTM D 5102-04. Twenty-seven combinations were tested where eleven data points were collected as a function of time (297 total data points). *UC* test results were used as the control for comparison to hand held gage testing produced with the same materials as described in the following paragraph.

Table 1. Average Properties of Soils Tested

Soil	Origin	USCS	LL	PI	Organics (%)
1	New Orleans	CL to CH	52	35	4.2
2	New Orleans	CH to MH	101	58	25.6
3	Mobile	CH to OH	81	49	10.6

Slabs of stabilized soil slurry were produced and then tested with three hand held devices: 1) *Pocket Penetrometer (Ring)*, 2) *Pocket Geotester (Dial)*, and 3) *Pocket Vane Shear Set (Shear)*. For the remainder of the report they are referred to using the terms in parenthesis which were selected because they identify key features

of the devices. The *Ring* and *Dial* gages measure unconfined compressive strength, while the *Shear* gage directly measures shear strength. Instructions on use of the devices are provided by the manufacturers and were followed in this research.

Table 2. Description of Cementitious Materials Tested

Material	Source	Description
1	Artesia, MS	Type I Portland Cement
2	Artesia, MS	Type III Portland Cement
3	Artesia, MS	Specialty Grind Portland Cement
4	Artesia, MS	Specialty Grind Portland Cement
5	Artesia, MS	Specialty Grind Portland Cement
6	Theodore, AL	Type I Portland Cement
7	Theodore, AL	Type III Portland Cement
8	Birmingham, AL	Ground Granulated Blast Furnace Slag
9	Cypress, CA	Calcium Sulfoaluminate Cement

Note: 75% of Material 8 was combined with 25% of Material 1 when used.

Shear stress was calculated using Eq. 1 or Eq. 2 depending on the gage used. The *Dial* gage has five attachments with A_F values of 1.0 to 15.5, the *Ring* gage has two attachments with A_F values of 1 to 16, and the *Shear* gage has three attachments with A_F values of 4 to 50. The maximum possible reading (R) and s_u for the devices, respectively, are: *Dial* (6.0 and 3 kg/cm²); *Ring* (4.5 and 2.25 kg/cm²); and *Shear* (10.0 and 2.5 kg/cm²).

$$s_u = \frac{R}{A_F(2)} \quad [\textit{Dial or Ring gage}] \quad (1)$$

$$s_u = \frac{R}{A_F} \quad [\textit{Shear gage}] \quad (2)$$

Where,

s_u = shear stress at failure (kg/cm²)

R = gage reading

A_F = attachment adjustment factor

Figure 1 contains photographs of each hand held device including attachments and a fully tested slab surface. Once the surface testing was complete, select slabs were removed from the molds and additional readings taken on the bottom, around the perimeter, and internally by slicing the slab and testing the exposed faces. Depending on strength gain of a given combination, twenty to forty readings could be taken per slab within each mold, requiring multiple molds per test combination. Soil 1 was tested with a protocol incorporating 236 readings, while soils 2 and 3 were tested with a protocol incorporating 40 readings. Nine combinations were tested per soil, requiring 2,844 readings per gage to complete the twenty-seven test cases.



(a) Tested Areas with Ring Gage



(b) Tested Areas with Dial Gage



(c) Tested Areas with Shear Gage



(d) Surface Completely Tested

Figure 1. Photos of Hand Held Gage Testing

Maturity was calculated based on a concept similar to ASTM C 1074 as shown in Eq. 3. For Eq. 3, T_i was taken as the air temperature surrounding the specimen during curing, rather than the more customary internal specimen temperature. Temperatures were measured every four minutes and all specimens were cured in 100% humidity at room temperature.

$$M(t) = \sum (T_i - T_o) \Delta t \quad (3)$$

Where,

$M(t)$ = Maturity accumulated up to time t (C-hr)

T_i = Air temperature measured during specimen curing (C)

T_o = Reference temperature (0 C herein)

Δt = Change in time for increment (hr)

TEST RESULTS

Figures 2 through 4 plot measured test results for cementitious material 1 with all four test devices; the same plots were created for all nine cementitious materials with all three soils. The data presented in these figures was used to evaluate the precision and accuracy of each hand held gage. Accuracy (proximity to true value) was evaluated by considering shear strengths calculated using UC data to be true values. Precision (proximity to each other) was evaluated by considering R^2 values from logarithmic trend lines.

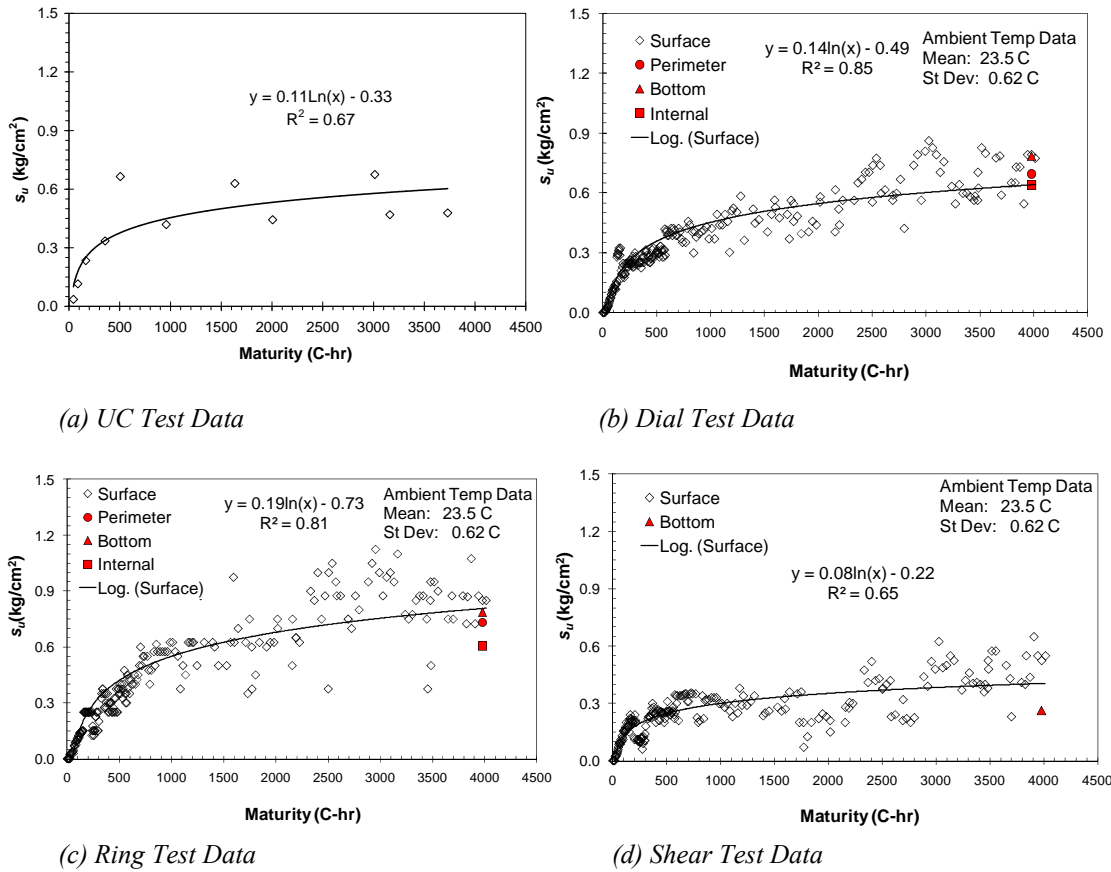


Figure 2. Cementitious Material 1 Test Results with Soil 1

Figures 5 through 7 were developed using all test data collected by plotting data into bins according to their gage to *UC* ratio; Figures 2 through 4 show one ninth of the complete data set. Shear strength was calculated at maturity values of 100, 500, 1500, and 3500 C-hr using the logarithmic trend lines for each hand held gage and for *UC* testing. The ratio of hand held gage shear strength to *UC* determined shear strength was then determined for all twenty-seven test cases at each of the four maturity values. Thirty-six data points were available per gage and per figure. As an example, one data point used to create Figure 5 would be produced by calculating maturity at 100 C-hr using the *UC* and *Dial* trendline equations shown in Figure 2 (0.177 kg/cm^2 and 0.155 kg/cm^2 , respectively) and taking the ratio (0.88).

For *Soil 1* (Figure 5), 90% of the penetrometer (*Dial* and *Ring*) test results were either in the 0.25 to 0.75 bin or the 0.75 to 1.25 bin relative to *UC* test results. Both gages had approximately 50% of their readings in the 0.75 to 1.25 bin. The *Shear* gage test results fell into the 0.25 to 0.75 bin 86% of the time and in the 0.75 to 1.25 bin 14% of the time. Shear strength over prediction was not common in *Soil 1*; strengths were under predicted in the majority of instances.

For *Soil 2* (Figure 6), none of the *Dial* and *Ring* test results were in the 0.75 to 1.25 bin with the majority of results in either the 1.75 to 2.25 or the 2.25 to 2.75 bins. Conversely, the majority of the *Shear* test results (56%) were in the 0.75 to 1.25 bin

while 25% were in the 1.25 to 1.75 bin. Shear strength over prediction was common in *Soil 2* for both *Dial* and *Ring* readings. *Shear* gage measurements tended to be at or greater than *UC* readings. Behaviors in *Soil 2* were opposite to those in *Soil 1*.

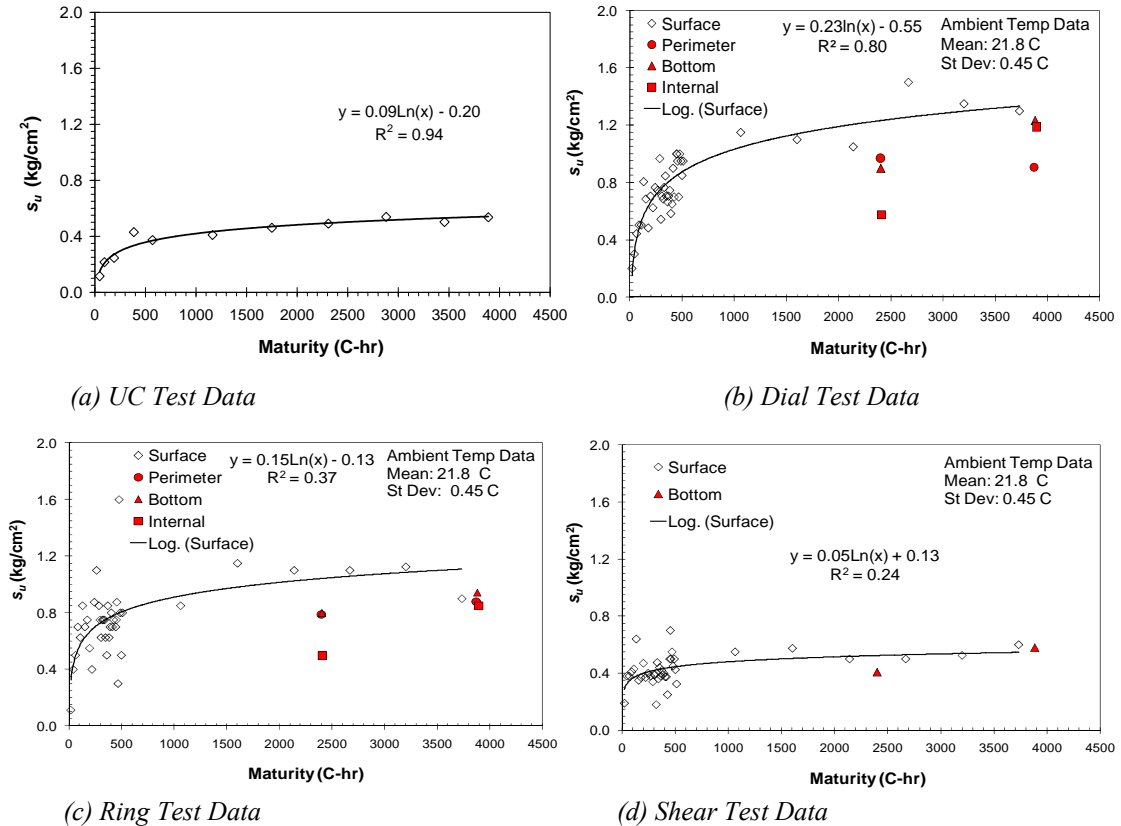


Figure 3. Cementitious Material 1 Test Results with Soil 2

For *Soil 3* (Figure 7), *Dial* and *Ring* test results were dispersed within multiple bins with no more than 33% of the *Dial* results nor more than 31% of the *Ring* results residing in any bin. *Shear* results were more concentrated with 64% of the readings occurring in the 0.75 to 1.25 bin. Shear strength was both over predicted and under predicted in *Soil 3*. The behavior in *Soil 3* was a mixture of the behaviors in *Soil 1* and *Soil 2*; organic content of *Soil 3* was between the values of the other soils.

On rare occasion was a gage to *UC* ratio calculated below 0.25, and with exception of one cementitious material gage to *UC* ratios were rarely above 2.75. Figure 8 plots average gage to *UC* ratios excluding values below 0.25 and above 2.75 as a function of soil organic content. A clear trend was observed; as the organic content increased so did the gage to *UC* ratio. *Dial* and *Ring* readings were essentially linear, while the *Shear* gage ratio tapered off at higher organic contents. The data indicates organic content of the soil should be taken into account when considering use of hand held gages to measure shear strength.

Figure 8 data could be used as a calibration factor (multiply s_u by factor) for similar materials and stabilization material contents. Values of 1.25, 0.5, and 0.75

provide reasonable estimates for soils 1, 2, and 3 respectively when using the penetrometers. Values of 2, 0.75, and 1 provide reasonable estimates for soils 1, 2, and 3, respectively when using the miniature vane shear device.

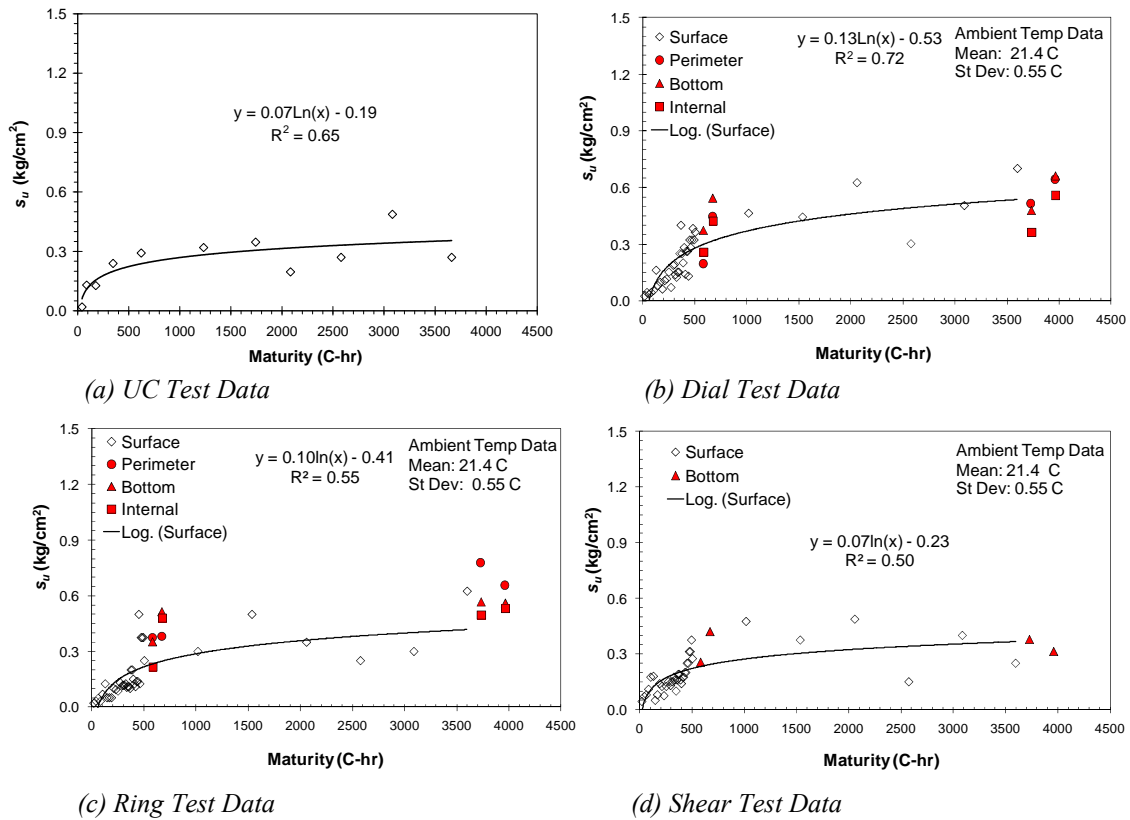


Figure 4. Cementitious Material 1 Test Results with Soil 3

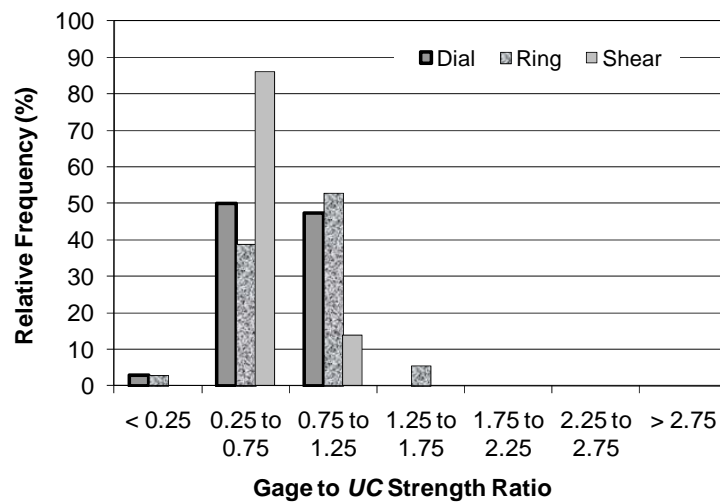


Figure 5. Gage Comparisons for Soil 1

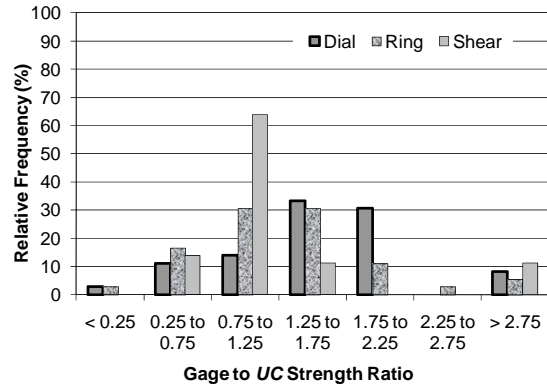
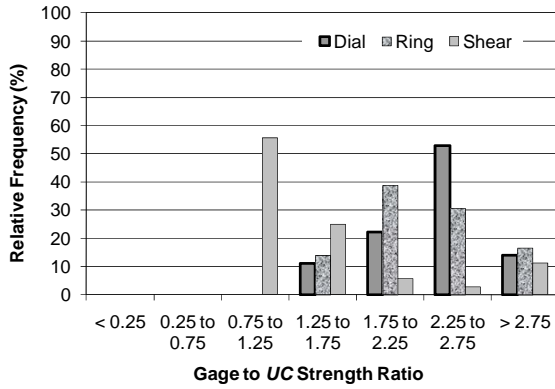


Figure 6. Gage Comparisons for Soil 2 **Figure 7. Gage Comparisons for Soil 3**

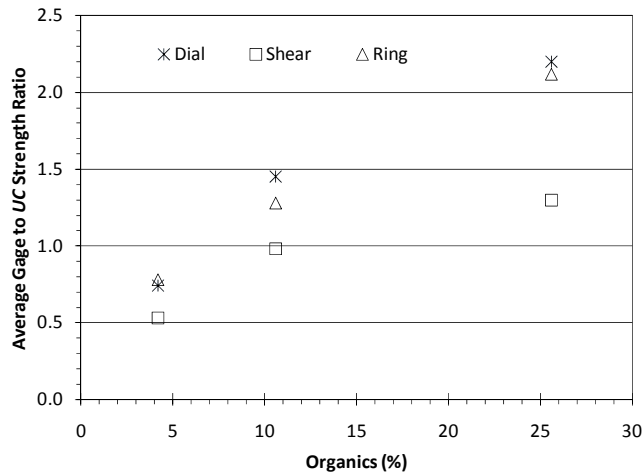


Figure 8. Gage Comparisons vs. Organics

A considerable amount of scatter can be seen in Figures 2 through 4 for all three hand held gages. This indicates precision of any one measurement with a hand held gage would be relatively low. Statistical variability of this data is underway to determine variation of readings at a given condition, which has not been included in this paper.

Table 3 provides average R^2 values from the logarithmic trend lines represented by Figures 2 through 4. The *Dial* gage was the most precise of the three hand held gages. The *Shear* device, in general, was the least precise of the gages as it had the lowest R^2 value in two of the three soils and for *Soil 1* it was only moderately more precise than the *Ring* gage.

Table 3. Average R^2 Values of Hand Held Gages

Soil	<i>Dial</i> Gage	<i>Ring</i> Gage	<i>Shear</i> Gage
1	0.77	0.58	0.64
2	0.42	0.29	0.18
3	0.61	0.61	0.52

SUMMARY AND CONCLUSIONS

Comparison of two penetrometers (*Dial* and *Ring*) and a miniature vane shear device (*Shear*) to *UC* testing was performed in this paper for the purpose of evaluating their precision and accuracy in measuring shear strength in cementitious stabilized fine grained soils with high moisture contents. Accuracy was observed to be a function of the organic content in the soil with measured shear strength increasing relative to *UC* data as a function of organic content for all three hand held gages. The *Shear* gage, in general, predicted the lowest strengths of the three gages and was the least affected by soil organic content. The *Shear* gage was the most accurate yet the least precise. The accuracy of the *Dial* and *Ring* gages were similar, though the *Dial* gage was more precise. If one were to use the gages in absence of calibration using *UC* measurements, the *Shear* gage would be recommended. Calibration using *UC* measured values is recommended on the material under investigation to avoid errors. The precision of the *Dial* gage coupled with calibration has the potential to produce data that is both precise and accurate.

ACKNOWLEDGEMENTS

This research was funded by the Department of Homeland Security-sponsored by the Southeast Region Research Initiative (SERRI) at the Department of Energy's Oak Ridge National Laboratory. Tim Cost, PE, FACI of *Holcim Cement* and Vince Perez of *CTS Cement Manufacturing Corporation* are thanked for material donation.

REFERENCES

- Emery, J.J. (1980). "Stabilizing Industrial Sludge for Fill Applications," 7th *International Congress on the Chemistry of Cement*, Paris, France, 644-648.
- Gassman, S.L., Pierce, C.E., and Schroeder, A.J. (2001). "Effects of Prolonged Mixing and Retempering on Properties of Controlled Low-Strength Material (CLSM)," *ACI Materials Journal*, 98(2), 194-199.
- MacKay, M. and Emery, J. (1994). "Stabilization and Solidification of Contaminated Soils and Sludges Using Cementitious Systems: Selected Case Histories," *Transportation Research Record: Journal of the Transportation Research Board*, 1458, 67-72.
- Kelly, D.S., and Diethelm, E.C. (1996). "Effects of Various Additives on the Solidification of Oily Sludges: A Bench-Scale Study," *Stabilization and Solidification of Hazardous, Radioactive, and Mixed Wastes: 3rd Volume, ASTM STP 1240*, 584-595.
- FDOT (2000). *Soils and Foundation Handbook 2000*. Florida Department of Transportation, Gainesville, FL, pp. 163.
- Tripathi, H., Pierce, C.E., Gassman, S.L., and Brown, T.W. (2004). "Methods for Field and Laboratory Measurement of Flowability and Setting Time of Controlled Low-Strength Materials," *Journal of ASTM International*, 1(6), 1-15.