**15 October 2007**

**Committee D18 on Soil and Rock**
**Subcommittee D18.05 on Strength and Compressibility of Soils**

**Research Report D18-1014**

# Interlaboratory Study to Establish Precision Statements for ASTM D2166, Standard Test Method for Unconfined Compressive Strength of Cohesive Soils

**Technical contacts:**
Richard Ladd, Edgewater, Florida 32141
USA
386-424-1817
rladd@cfl.rr. com

John Germaine, Andover, Massachusetts 01810
USA
617-253-7113
jgermain@mit.edu

ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

## 1. Introduction:

An Interlaboratory Study program was conducted by the Institute of Standards Research (ISR) to establish a precision statement for numerous standards under the jurisdiction of ASTM's D18 Soil and Rock Main Committee. The program was funded by the Federal Highway Administration and the National Science Foundation as well as supported by in-kind monetary and service donations. The standard test method titled D2166 Standard Test Method for Unconfined Compressive Strength of Cohesive Soils was a part of that program.

## 2. Test Method:

The Test Method used for this ILS is D2166-91. To obtain a copy of D2166, go to ASTM's website, www.astm.org, or contact ASTM Customer Service by phone at 610-832-9585 (8:30 a.m. - 4:30 p.m. Eastern U.S. Standard Time, Monday through Friday) or by email at service@astm.org.

## 3. Participating Laboratories:

The following laboratories participated in this interlaboratory study:

| Laboratory Name & Address | Contact Person | Phone/Fax/E-mail |
|---|---|---|
| **"Triplicate" Laboratories** | | |
| Ardaman & Associates, Inc.<br>8008 S. Orange Avenue<br>Orlando, FL 32809 | Tom Ingra/<br>George DeStefano | 407-855-3860<br>Fax 407-859-8121<br>GDestaf@aol.com |
| Bowser & Morner, Inc.<br>4518 Taylorsville Road<br>PO Box 51<br>Dayton, OH 45401-2440 | James W. Fletcher | 937-236-8805 Ext 235<br>Fax 937-233-2016<br>bmi@bowser-morner.com |
| California State Dept. of Water Resources<br>Soils and Concrete Laboratory<br>1450 Riverbank Road<br>West Sacramento, CA 95605 | Mike Driller | 916-375-6012 (lab)<br>Fax 916-375-6020 (lab) |
| GeoSyntec Consultants<br>Geomechanics & Environmental Laboratory<br>Holcomb Bridge Business Center<br>2658 Holcomb Bridge Road<br>Suite 110<br>Alpharetta, GA 30201 | Barry E. Sigmon | 770-645-6575 |
| Geotechnics, Inc.<br>544 Braddock Avenue<br>East Pittsburgh, PA 15112 | David Backstrom | 412-823-7600<br>Fax 412-823-8999 |
| GZA Geoenvironmental, Inc., MA<br>320 Needham Street<br>Newton Upper Falls, MA 02164 | Marty Molino | 617-630-6394<br>Fax 617-965-7769 |
| Los Angeles Dept. of Water and Power<br>510 East 2nd Street<br>PO Box 51111<br>Los Angeles, CA 90051-0100 | Joe Gunther | 213-367-8808<br>Fax 213-367-8823 |
| New York State Dept. of Transportation<br>Soil Mechanics Bureau, Bldg 7<br>1220 Washington Ave<br>Albany, NY 12232 | David Suits | 518-457-4794<br>Fax 518-457-8080 |

| | | |
|---|---|---|
| Rust Environmental & Infrastructure, Inc.<br>11785 Highway Drive, Suite 100<br>Cincinnati, OH 45241 | Steven Zhou | 513-483-5335<br>Fax 513-733-8213 |
| USACE, Missouri River Division Laboratory<br>420 South 18th Street<br>Omaha, NE 68102-10103 | Holly Hankins | 402-444-4309<br>Fax 402-341-5448 |
| USACE, Ohio River Division Laboratory<br>12275 Sebring Drive<br>Cincinnati, OH 45240-2714 | Kenneth Henn | 513-589-3608<br>Fax 513-589-3619 |
| USACE, South Atlantic Division Laboratory<br>611 South Cobb Drive<br>Marietta, GA 30060 | W. Lane Tison | 770-919-5296<br>Fax 770-919-4977 |
| USACE, Southwestern Division Laboratory<br>PO Box 36045<br>4815 Cass Street<br>Dallas, TX 75242 | Jack C. Cronkrite | 214-905-9130 Ext 15<br>Fax 214-905-9135 |
| USACE, Waterways Experiment Station<br>Soils Testing Facility<br>Geotechnical Laboratory<br>3909 Halls Ferry Road<br>Vicksburg, MS 39180-6199 | P.J. Griffing | 601-634-2607<br>Fax 601-634-4219 |
| USDI, Bureau of Reclamation<br>Earth Sciences & Research Lab Group<br>Bldg 56, Entrance E11, Mail Code D-8340<br>Denver Federal Center<br>Denver, CO 80225 | Betty Kunzer | 303-445-2339<br>303-236-3730 Ext 423<br>Fax 303-236-4679<br>bkunzer@ibr8gw80.usbr.gov |
| Woodward-Clyde Consultants, Totowa<br>45 H Commerce Way<br>Totowa, NJ 07512 | Gregory E. Thomas | 973-812-1818<br>Fax 973-812-8640<br>Gethoma0@wcc.com |
| **"Single Test" Laboratories (Although actually performed triplicate tests for this test method)** | | |
| Atlas Soils, Inc.<br>1400 East Tremont Street<br>PO Box 130<br>Hillsboro, IL 62046 | David H. Kimmle | 217-532-3959<br>Fax 217-532-3212 |
| French & Parrello Associates, P.A.<br>Building #3<br>670 North Beer Street<br>Holmdel, NJ 07733 | David Calnan | 732-888-7700<br>Fax 732-888-7852 |
| GEI Consultants<br>1021 Main Street<br>Winchester, MA 01890-1943 | Todd Moline,<br>Laboratory Supervisor | 781-721-4000<br>Fax 781-721-4073 |
| GeoTesting Express<br>1145 Massachusetts Ave<br>Boxborough, MA 01719 | W. Allen Marr | 978-635-0012<br>Fax 978-635-0266<br>wam@geocomp.com |
| GZA Geoenvironmental of NY<br>364 Nagel Drive<br>Buffalo, NY 14225 | Robert Redenbach | 716-685-2300<br>Fax 716-685-3629<br>rred@gza.com |
| Soil Technology, Inc.<br>7865 NE Day Road, West<br>Bainbridge Island, WA 98110 | Richard Sheets | 206-842-8977<br>Fax 206-842-9014 |

| | | |
|---|---|---|
| Terracon Consultants, Inc.<br>14700 W. 107th Street<br>Lenexa, KS 66215 | Kenneth D. Jorgensen | 913-492-7777<br>Fax 913-492-7443 |
| University of California, Berkeley | Michael F. Riemer | 510-642-7457 |

**4. Description of Samples:**

There was one sample of targeted results used for this study. The material is a rigid polyurethane foam with density of approximately 0.09 g/cm$^3$. All specimens used for this study were obtained from a single block of material. The Massachusetts Institute of Technology Department of Civil and Environmental Engineering machine shop machined specimens to dimensions of approximately 2 inches in diameter and 4 inches in height. The specimens were randomized and three specimens were distributed by the ISR project management team to the participating laboratories.

**5. Interlaboratory Study Instructions**

Laboratory participants were mailed the test program instructions. For other standard test methods within the ISR test program, laboratories either performed triplicate testing or single tests on the materials. In the case of this testing, foam specimens were provided to the laboratories ready for testing. Since no specimen preparation was necessary and therefore significantly less time was required for this method, all the laboratories were asked to perform triplicate unconfined compression testing.

For a copy of the instructions, please see Attachment A.

**6. Description of Equipment/Apparatus[1]:**

For information on the equipment/apparatus used by each laboratory, please see Attachment B.

**7. Data Report Forms:**

Each laboratory was provided with a data report form for the collection of data. A summary table with all the results from the completed forms, as well as a copy of each completed form is provided in Attachment C.

Please note: The laboratories have been randomly coded and cannot be identified herein.

**8. Statistical Data Summary:**

Twenty-four laboratories submitted data from testing three specimens of foam. Sets of data outside of three standard deviations (i.e. "outliers") were removed. The statistical analysis was then performed on the remaining twenty-two sets of data using ASTM E691. A summary of the statistics calculated using ASTM E691 is provided in Attachment D.

**9. Precision and Bias Statement:**

[1] The equipment listed was used to develop a precision statement for D2166-91. This listing is not an endorsement or certification by ASTM International.

The Research Report is generated to support the Precision and Bias paragraph for ASTM D2166.

**10. Precision and Bias**

10.1 *Precision*—Criteria for judging the acceptability of test results obtained by this test method on rigid polyurethane foam (density about 0.09 g/cm3) is given in Table 1. These estimates of precision are based on the results of the interlaboratory program conducted by the ASTM Reference Soils and Testing Program.[5] The precision estimates will vary with the material/soil type being tested, and judgment is required when applying these estimates to soil.

10.1.1 The data in Table 1 are based on three replicate tests performed by each test laboratory. The single-operator and multilaboratory standard deviation shown in Table 1, Column 4, were obtained in accordance with Practice E 691. Results of two properly conducted tests performed by the same operator on the same material, using the same equipment, and in the shortest practical period of time should not differ by more than the single-operator *d2s* limits shown in Table 1, Column 5. For definition of *d2s* see Footnote D in Table 1. Results of two properly conducted tests performed by different operators and on different days should not differ by more than the multilaboratory
*d2s* limits shown in Table 1, Column 5.

10.2 *Bias*—There is no accepted reference value for this test method, therefore, bias cannot be determined.

[5] Research Report RR: D18-1014 contains the data and statistical analysis used to establish these precision statements and it is available from ASTM Headquarters.

**TABLE 1 Summary of Test Results from Each Laboratory (Compressive Strength Data on Rigid Polyurethane Foam (density about 0.09 g/cm$^3$))**

| (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|
| Number of Triplicate Test Laboratories | Test Parameter[A] | Average Value[B] | Standard Deviation[C] | Acceptable Range of Two Results[D] |
| *Single-Operator Results (Wiithin-Laboratory Repeatability):* | | | | |
| 22 | Strength, kPa | 989 | 42 | 120 |
| 22 | Strain, % | 4.16 | 0.32 | 0.9 |
| *Multilaboratory Results (Between- Laboratory Reproducibility):* | | | | |
| 22 | Strength, kPa | 989 | 53 | 150 |
| 22 | Strain, % | 4.16 | 0.35 | 1.0 |

[A] Strength = peak compressive stress and strain = axial strain at peak compressive stress.

[B] The number of significant digits and decimal places presented are representative of the input data. In accordance with Practice D 6026, the standard deviation and acceptable range of results can not have more decimal places than the input data.

[C] Standard deviation is calculated in accordance with Practice E 691 and is referred to as the 1s limit.

[D] Acceptable range of two results is referred to as the *d2s* limit. It is calculated as 1.960=2·1s, as defined by Practice E 177. The difference between two properly conducted tests should not exceed this limit. The number of significant digits/decimal places presented is equal to that prescribed by this test method or Practice D 6026. In addition, the value presented can have the same number of decimal places as the standard deviation, even if that result has more significant digits than the standard deviation.

RR: D18-1014

Attachment A:
[*Triplicate Lab Cover Letter*]

March 25, 1995

Subject: ISR - Foam Testing Program

Dear :

Thank you for participating in the ISR Standard Soil and Testing Program. We are now ready to begin testing (Phase 1) of the foam specimens by the triplicate laboratories.

Enclosed please find the following documents:

1) Protocol for Testing Foam Specimens Using Test Method D 2166-91, Unconfined Compressive Strength of Cohesive Soil;
2) copy of ASTM Standard D 2166-91; and
3) three copies of the data sheet entitled Standard Test Method for Unconfined Compression Test: ASTM D 2166-91

Also enclosed are three foam specimens.

The attached protocol contains all special instructions required to perform this testing program.

We need to have these results by May 12, 1995. Please mail your results to:

Dr. Jack Germaine
Massachusetts Institute of Technology
Room 1-353
77 Massachusetts Ave.
Cambridge, MA 02139

If you have any questions regarding these instructions, please contact Richard Ladd (904-424-0555), Bob Donaghe (601-638-1259) or Jack Germaine (617-253-7113 or e-mail JGermain@MIT.edu).

Your laboratory number for this test is _____.

Sincerely,

Richard S. Ladd,
Project Director

cc: Anne M. McKlindon

RR: D18-1014

[*Single Test Lab Cover Letter*]

March 25, 1995

Subject: ISR - Foam Testing Program

Dear :

Thank you for participating in the ISR Standard Soil and Testing Program. We are now ready to begin testing (Phase 1) of the foam specimens by the single test laboratories. For this testing protocol only, we are requesting that you perform triplicate tests. If this is not agreeable, then perform one test.

Enclosed please find the following documents:

1) Protocol for Testing Foam Specimens Using ASTM Designation: D 2166 - 91, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil;
2) copy of ASTM Standard D 2166 - 91; and
3) three sets of two data sheets per set, entitled Unconfined Compression Test: ASTM D 2166 - 91 on the first sheet, and 2nd Sheet included in the title for the second sheet.

Also enclosed are three foam specimens.

The attached protocol contains all special instructions required to perform this testing program.

We need to have these results by October 10, 1995. Please mail your results to :

Dr. Jack Germaine
Massachusetts Institute of Technology
Room 1-353
77 Massachusetts Ave.
Cambridge, MA 02139

If you have any questions regarding these instructions, please contact Richard Ladd (904-424-1817), Bob Donaghe (601-638-1259) or Jack Germaine (617-253-7113 or e-mail jgermain@mit.edu).

Your laboratory number for this test is _____.

Sincerely,

Richard S. Ladd,
Project Director

cc: John T. Germaine & Anne M. McKlindon

**ISR Reference Soils and Testing Program**

**Protocol for Testing Foam Specimens**
**Using**
**ASTM Designation: D 2166 - 91,**
**Standard Test Method for Unconfined Compressive Strength of Cohesive Soil**

## Introduction

The purpose of this document is to assist you in performing the unconfined compression tests on the foam specimens and completing the data sheet with the required information. This document supplements ASTM Test Method D 2166 - 91 by giving specific directions where the test method may permit different options. Do not begin testing until reading the attached ASTM standard (D 2166 - 91, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil) and this protocol.

For this test protocol only, we are asking the single test laboratories to run triplicates tests. In performing these tests all three specimens must be tested in one day, by one operator, and using one set of testing equipment.

## Additional Guidance to Supplement Standard

### Apparatus

To test these foam specimens, you will need a load cell readable to at least 1 lbf (5N). The capacity of the load cell should be at least 1000 lbf (5 kN). **WARNING**: The foam you are testing will strain harden (become stronger) dramatically after about 20% axial strain.

If a triaxial cell is used, the loading rod's (piston) seal(s) need to be removed to decrease friction.

Use a balance readable to at least 0.01 g for determining the mass of the specimen.

The devices used to measure the height and diameter of the specimens should be readable to 0.001 inches.

### Test Specimens

The foam specimens you have received are machined and relatively fragile. These specimens must be handled carefully and kept away from sunlight and heat.

Procedure

The axial strain rate should be approximately 1% per minute. Strain the specimen to at least 15% axial strain but not more than 20%. Remember that axial strains greater than 20% will result in much higher loads and may damage your load cell. Take and record readings (time, load, and deformation) at a rate of at least one reading every 20 seconds for the first 5 minutes of the test, and thereafter at a rate of at least one reading every two minutes.

For at least one specimen, take a picture of the specimen in the apparatus at the end of testing which shows the force and deformation measurement devices along with the specimen.

Do not determine the water content; i.e., oven dry these foam specimens.

Calculations

Report the axial strain to 0.1%.

Although the specimen will not bulge significantly during the test, calculate the average cross sectional area using section 8.2 of the standard.

Report

For each test, return the completed test data sheets and a stress-strain graph. If additional data points were taken or the data was electronically collected, attach this supplemental information.

Report the stress in the units typically used in your laboratory, we will convert your stress results to SI units.

**Completing the Test Data Sheet**

Figure 1 presents the first data sheet in a set of two data sheets. This data sheet has been divided into subsections to help you provide us with the information we need to analyze data from the different laboratories. We have provided/enclosed three sets of data sheets. You might want to make extra copy, just in case something goes wrong.

Section 1. Your individual ID Number is the ISR number that you will find on the transmittal letter. This number is randomly generated and will be different for each test method you perform. Only the project team will have access to laboratory ID's. The bucket number is not applicable for testing these foam specimens. You should assign test numbers sequentially between 1 and 3. The soil type will be "foam". The specimen number is written on the top of the specimen. For specimen description, observe the specimen and note any defects.

Section 2. Measure the specimen and record the data in the appropriate spaces. Remember to indicate the units you are using and the device used for the height and diameter measurements. Calculate the area and volume of the specimen.

Section 3. Determine the mass of the specimen.

Section 4. Calculate the total unit weight.

Section 5. Identify the equipment used for testing. This information must be the same for all three tests. For the load frame, include the manufacturer and model number. Indicate if a triaxial cell is used and, if so, the type of piston bearing. Document the degree of rotation of the upper platen. Record, as $W_{ds}$ the mass of any apparatus components which applies an axial force to the specimen and is not measured by the force transducer. This equipment may include the mass of the deformation measurement system (dial gauge or transducer, clamps, rods, etc.), piston, and upper platen (top cap).

Section 6. Record the time (or elapsed time), deformation and axial force readings. Calculate the axial strain and compressive stress. Compressive stress is the sum of the measured axial force plus the added mass ($W_{ds}$) divided by the corrected area. If you want to manually collect more data than space provided on the 1st & 2nd data sheets, use a extra copy of the 2nd data sheet. If you collect data electronically, or do computations with a computer, attach the results to the data sheets provided. It is not necessary to copy the data to the columns in Section 6 (1st sheet), or those on the 2nd sheet.

Section 7. Calculate and record the unconfined compressive strength, the axial strain at failure, the strain rate and height to diameter ratio. Also provide the required information relative to personnel involved (tested by, calc. by, etc.) and date.

Plot the stress strain curve.

Protocol: Figure 1