

FINAL REPORT

**DESIGN AND CONSTRUCTION OF APPARATUS
FOR MEASURING RATE OF WATER EROSION OF SEDIMENTS**

**FDOT BC354 RPWO #12
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Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

SI (MODERN METRIC) CONVERSION FACTORS (from FHWA)

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in²	square inches	645.2	square millimeters	mm ²
ft²	square feet	0.093	square meters	m ²
yd²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km ²

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m ³
yd³	cubic yards	0.765	cubic meters	m ³

NOTE: volumes greater than 1000 L shall be shown in m³

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm²	square millimeters	0.0016	square inches	in ²
m²	square meters	10.764	square feet	ft ²
m²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi ²

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.314	cubic feet	ft ³
m³	cubic meters	1.307	cubic yards	yd ³

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m ²	0.2919	foot-Lamberts	fl

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

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16. Abstract The objective of this project was to construct two devices to measure the erosion rate of soft rock, cohesive and cohesionless materials. The first device, termed the RETA (Rotating Erosion Test Apparatus), circulates water around a cylindrical sample and the shear stress applied to it is correlated to erosion rate. Five devices have been constructed of which four are currently operational at FDOT's SMO. The second is a recirculating flume (SERF – Sediment Erosion Recirculating Flume) that can test a wide variety of materials. An electronic sensor array accurately measures the elevation of the test sample that is located flush with the flume's lower surface. As water flow over the sample, erosion of the surface is detected by the sensors and initiates minute movement upwards of the specimen until it is again flush with the surface. This operation is controlled by LABVIEW software which signals the stepping motor to raise the sample discrete distances. The total amount of steps is converted into a vertical distance and compared to the imposed shear stress on the sample, thereby obtaining an erosion rate. Data obtained from both units shows good results and it is expected that they will provide valuable information to bridge designers with regards to scour susceptibility.			
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Executive Summary

Near surface sediments in Florida range from cohesive muds and clays to cohesionless sands to softer rock materials such as lime rock, coral, consolidated sandstone, and coquina. The water erosion properties of these “non-sand” materials (henceforth referred to as non-cohesionless bed materials) differ greatly from one type to the next. Many of the rock materials found in Florida are not considered “scour-resistant” by the Federal Highway Administration’s (FHWA) classification as defined in the FHWA Hydraulic Engineering Circular No. 18 (HEC-18). Thus, these materials are treated as cohesionless sediments for the purpose of estimating design scour depths. In many cases, this yields overly conservative scour depth estimates that translate into excessive costs in the construction of new bridges and/or the retrofitting of existing bridges. Under contract to the Florida Department of Transportation (FDOT), the University of Florida developed and constructed two different test apparatus for measuring the rate at which sediments erode when subjected to flowing water. These apparatus and their associated test procedures are described in this report.

This report is divided into two distinct parts. Part I covers the Rotating Erosion Test Apparatus (RETA) and Part II covers the second apparatus, Sediment Erosion Rate Flume (SERF). Five of the RETAs have been constructed, one is located at the University of Florida and four are at the FDOT State Materials Office in Gainesville, Florida. Only one SERF exists at this time, and it is located at the University of Florida.

PART I
ROTATING EROSION TEST APPARATUS
(RETA)

INTRODUCTION:

When water flows over erodible sediment such as sand, clay, soft rock, etc. with sufficient speed the sediment is eroded. It is of scientific and/or engineering importance to be able to estimate the rate at which this erosion occurs. As an example, the penetration depth of a bridge pier foundation that is to be located in, and supported by, the sediment requires knowledge of how much the channel bed will be lowered during a design flow event. In order to make these estimates the rate at which the sediment erodes as a function of the shear stress being applied by the flowing water must be determined. The Rotating Erosion Test Apparatus (RETA) was designed to provide this information for sediments with sufficient bonding strength to support their weight such as stiff clays, sandstone, limestone, coquina, etc. A 4 in long cylindrical sediment sample (either 2.4 in or 4 in diameter) is taken from the site and sent to the laboratory where it is tested in the RETA. A $\frac{1}{4}$ in diameter hole is drilled through the axis of the sample and a support shaft inserted and attached to the sample. The other end of the shaft is attached to a torque measuring load cell through a slip clutch as shown in Figures 1 and 2. The sample is lowered into a slightly larger cylinder (with a sleeve insert) and the annulus between the sample and the insert filled with water. The outer cylinder, which is connected to an electric motor by pulleys and a belt, is rotated in order to create a shear stress on the surface of the sample. The shear stress increases with increasing angular speed of the outer cylinder.

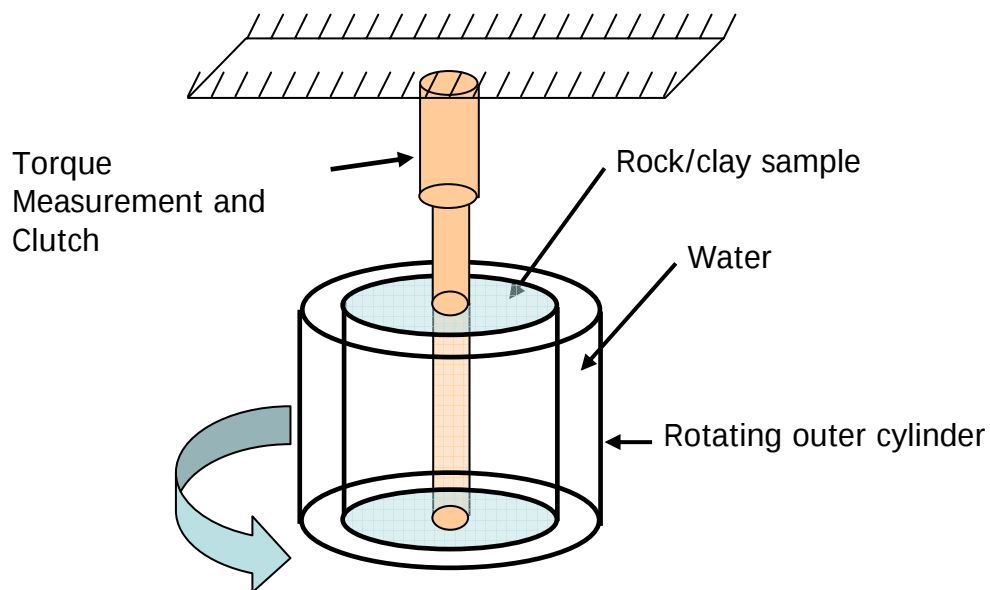


Figure I - 1. Schematic Drawing of the Rotating Erosion Test Apparatus (RETA).



Figure I - 2. Photograph of the RETA, Viewed from Above.

The torque cell measures the torque, T , developed on the sample. Knowing the radius, R , and length, L , of the test specimen and the measured torque, the average shear stress on the surface of the sample can be computed using the following equation.

$$\tau \equiv \text{Average Shear Stress} = \frac{T}{2\pi R^2 L}$$

The outer cylinder and sleeve is forced to rotate for a period of time (the duration of which depends on the erodability of the sample with more scour resistant samples requiring longer durations) then stopped. The sleeve with the water and eroded sediment is placed in an oven and the water evaporated. The dried sediment and sleeve are weighed and the combined weight subtracted from the known weight of the sleeve. Knowing the mass of the material removed and the duration of the test, the average rate of erosion can be computed using the following Equation.

$$\frac{\Delta r}{\Delta t} = \frac{\Delta m}{2\pi \rho R L D},$$

where

$\Delta r \equiv$ change in radius of sample during test ,

$\Delta t \equiv D \equiv$ duration of the test ,

$\Delta m \equiv$ mass removed from sample during test , and

$\rho \equiv$ dry mass density of the sample .

The rate of erosion is measured for a minimum of three (and preferably five) applied shear stresses and a plot of Erosion Rate versus Shear Stress made.

Components of the RETA Apparatus

The RETAs are composed of:

1. An electric motor connected to a flywheel and Plexiglas cylinder by a pulley and belt,
2. A Plexiglas removable insert that fits in the outer rotating cylinder,
3. A shaft to support the test specimen that is connected to a torque meter via a slip clutch,
4. A control system that operates the motor and monitors the cylinder angular speed and torque exerted on the test sample by the water and
5. A cabinet to house and support the system.

Drawings for the components of the RETA system are provided in Appendix IA.

RETA Control System

A control system was developed for the RETA that allows either the **Torque** or a **Rotational Speed** to be specified. When the Torque is specified, the control system increases the rotational speed of the outer cylinder until the torque applied to the sample reaches the target level. It then maintains this torque until the unit is either stopped or the desired torque is changed. In this mode, if there is a change in anything that would impact the torque (such as a water temperature rise) the rotating speed will be adjusted so as to maintain the prescribed shear stress. In the Rotating Speed mode, the rotating speed is simply held at the desired constant value. Details of the control system including circuit diagrams are presented in Appendix IB of the report.

Torque Cell/Clutch Assembly

The torque cell is comprised of a moment arm attached to the support shaft for the sediment sample and a load cell (see Figure I-3). Two mechanical stops are used to 1) apply a slight pre-torque to the load cell and 2) prevent the applied torque from exceeding the limiting force on the load cell. An adjustable torque clutch is located between the sample and the torque cell. The purpose of the clutch is to prevent damage to the system if a fragment of the sample separates and lodges in the annulus. The slip torque is set at slightly higher than the maximum anticipated torque value under normal operation. If the torque exceeds the maximum anticipated value the clutch will slip and the control system turns off the outer cylinder drive motor.

The torque cell calibration should be checked periodically (every 6 months or 1000 hours of use) and recalibrated. The calibration procedure is outlined in Appendix IC.

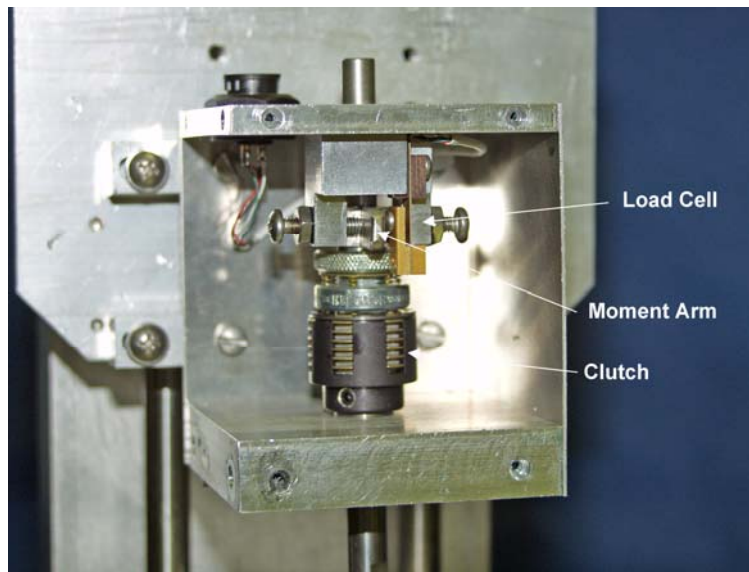


Figure I - 3. RETA Clutch and Torque Measuring System.

SEDIMENT SAMPLE PREPARATION AND TEST PROCEDURE

This section describes the methods and procedures for 1) preparing sediment samples for testing in the RETA, and 2) performing Rate of Erosion versus Applied Shear Stress tests.

Equipment Needed for Preparing and Testing Sediment Samples

1. Rotating Erosion Test Apparatus (RETA). RETAs for testing 2.4" and 4" diameter by 4" long sediment samples.
2. Calipers for measuring the diameter and length of the sediment samples.
3. Precision Balance capable of measuring mass with an accuracy of 1 mg.
4. Wet Saw for cutting the sediment samples.
5. Stopwatch for measuring the duration of the test.
6. Drill Press for drilling a hole along the axis of the test samples.
7. Lathe for truing the diameter of the test samples.
8. Drill Chuck, a modified three prong lathe chuck for securing and centering a cylindrical rock sample in the drill press.
9. Calibrated Volumetric Cylinder large enough to contain the rock sample (>800 ml).
10. Drying Oven capable of achieving temperatures of 140° F.
11. Drying Dish to dry the sediment eroded from the sample.
12. Spray Bottle with distilled water.
13. Two Plexiglas RETA Inserts per RETA apparatus. These thin-wall Plexiglas inserts are placed inside the rotating cylinder to reduce the effort required to collect and measure the sediment removed from the rock core during the test.

Determination of Sample Physical Properties

1. Place the sample in the drying oven, set the temperature of 140° F for at least 16 hours. After 15 hours in the oven, weigh the sample hourly with the balance. The sample is considered dry when the change in mass is less than 0.1% during a period of one hour. Record the final sample dry mass, $m_{(dry)}$.
2. Measure the diameter and length of the sample at a minimum of three locations with calipers. Calculate and record the average diameter and length of the sample.
3. Place a sufficient volume of water in a graduated container such that it will completely cover the sample (when the sample is placed in the container with the water) and record the volume of the water, $V_{(water)}$.
4. Place the sample in the graduated container and immediately record the volume of the water plus the dry sample, $V_{(water + dry sample)}$.
7. Leave the sample submerged in the container for a period of 16 hours. Cover the container to minimize evaporation.
8. After 16 hours of submersion, record the volume of water and sample, $V_{(water + sat sample)}$ then lift the sample out of the water and allow the excess water to fall from the sample into the cylinder until the water ceases to drip.
9. Using the balance obtain and record the mass of the saturated sample, $m_{(sat)}$.
10. Keep the sample submerged until the test.

Sample Preparation

1. Measure, mark and cut a 4" long test sample from the sediment/rock core using a wet saw. Score or mark sample for cutting. Cut the core to length of 4" (using a wet saw for rock). Ensure that this procedure yields a flat 90° cut on both ends of the sample.
2. Drill a 5/16-in. hole through the center of the sample following the procedure outlined below:
 - a. Place the sample into the modified lathe chuck. Ensure that the chuck is centered with the drill bit in the drill press. Tighten the jaws of the chuck carefully so as not to fracture the sample. If the sample is out of round rotate the sample to insure that the chuck jaws are not located on a high point.
 - b. Begin drilling the hole slowly in increments, clearing the hole and the drill bit often. To prevent cracking of the sample, drill from both ends of the sample.
 - c. Once the hole is drilled halfway through the sample, mark an outline of the jaws on the sample then release the chuck, remove and invert the core. Be sure that the chuck jaws are at the same location on the core before tightening the chuck.
 - d. Repeat Step b to obtain a hole completely through the sample.

Roundness of the Sample

1. Insert the special threaded rod through the hole in the core. Place end platens next to the ends of the core followed by nuts and threaded end pieces. Note that one of the end pieces has a conical shaped indentation in the end (for the Live Center on the lathe). The indentation must be oriented out (away from the core).
2. Place the core-shaft assembly in the lathe. The end piece without the indentation is placed in the lathe chuck. The live center is inserted into the indentation on the other end piece.
3. The lathe is started and the cutting tool advanced along the core taking the LEAST CUT POSSIBLE. Subsequent cuts are made until the core diameter is approximately

true. The out-of-roundness should not exceed 1/32". When finished remove the assembly from the lathe and the core from the shaft.

4. After preparing a sample from the raw FDOT boring, the sample must undergo a pre-spin in the RETA to remove any loose material that may have accumulated from the boring, cutting, drilling and lathe processes.

Pre-Test Run

Two types of RETA testing apparatus exist: one for testing 4" diameter samples and one for testing 2.4" diameter samples. Employ the correct apparatus for the size of sample to be tested.

1. Secure the glide plate in the top position on the slide-rail system.
2. Place the Plexiglas RETA insert in the outer cylinder.
3. Fill the insert with water to a height of approximately 1.5" (approximately 1/3 full).
4. Place the following components on the support rod in the order presented: (1) rotating cylinder lid, (2) top nut, (3) top platen, (4) rock sample, (5) bottom platen, and (5) bottom nut. Position the bottom nut such that it is flush with the bottom of the support rod.
5. Center the sample such that the edges of the sample are flush with the edges of the platens. Tighten top nut to secure sample between platens.
6. Screw the support rod to the shaft on the bottom of the guide plate housing and lower the guide plate and sample into the test position. Lock the guide plate at the testing position.
7. Attach the lid of the rotating cylinder with the Allen head screws.
8. Fill the insert with water through the hole in the center of the lid until water reaches the upper rim of the top platen.
9. Set the desired torque on the RETA Control Box. Recommended Pre-Test Torques are given in Table 1..
10. Press the ON button on the RETA Control Box. The cylinder RPM will increase at a controlled rate until the desired torque on the core is reached.
11. Once spinning begins, check the water level. The sample should remain immersed to the upper rim of the top platen. Add water to adjust level if necessary.
12. Start the stopwatch and data logger (recording RPM and Torque).
13. Run the RETA for 15 to 20 hours.
14. After the allotted pre-spin time, turn off the motor and allow the water within the annulus to cease motion.
15. Detach the lid of the rotating cylinder. Lift and secure the guide plate in the top position on the slide rail.
16. Gently remove the threaded rod and sample from the guide plate.
17. Gently remove the bottom nut and platen and carefully slide the sample off the support rod.
18. Gently rinse the sample removing all loose material.
19. The sample is now ready for the pre-test determination of physical properties described in the following section. Before proceeding to the next procedure, clean the machine by removing and cleaning the insert, cleaning and drying the rotating cylinder, cylinder lid, support rod, and platens. Eroded material need not be collected after the pre-spin.

Erosion Rate Test Procedure:

1. Place the Plexiglas insert into the rotating cylinder on the RETA.
2. Fill the insert with water to a height of approximately 1.5" (approximately 1/3 full).
3. Measure and record the temperature of the water, $Temp_{(init)}$, with the thermometer.
4. Place the following components on the support rod in the order presented: (1) rotating cylinder lid, (2) top nut, (3) top platen, (4) rock sample, (5) bottom platen, and (5) bottom nut. Position the bottom nut such that it is flush with the bottom of the support rod. Center the sample such that the edges of the sample are flush with the edges of the platens. Tighten top nut to secure sample between platens.
5. Screw the support rod to the shaft on the bottom of the torque cell housing
6. Lower the guide plate and sample into the test position. Lock the guide plate at the testing position.
7. Attach the lid of the rotating cylinder with the Allen screws.
8. Fill the insert with water through the hole in the center of the lid until water reaches the upper rim of the top platen.
9. Set the desired torque on the RETA Control Box.
10. Start the data acquisition recording, then press the START Button on the Control Box. The RETA RPM will advance at a controlled rate until the prescribed torque is reached. The RPM will be automatically adjusted throughout the test to maintain the specified torque.
11. Once spinning begins, check the water level. The sample should remain immersed to the upper rim of top platen. Add water to adjust level if necessary.
12. When the RPM has reached its equilibrium value, start the stopwatch.
13. Observe the sound, appearance, vibration, and overall behavior of the apparatus while running. The control system will shut down the RETA if the torque exceeds a limiting value (such as will occur if a piece of the core is dislocated and lodges between the sample and the rotating cylinder). Never-the-less, if there is an unusual vibration or sound the test should be stopped by pressing the STOP Button on the Control Box.
14. Allow test to run for a minimum of 72 hours for hard rock samples and 24 hours for soft rock samples. Check the operation hourly, for the first 3 hours, then periodically thereafter.
15. Periodically (at least every 12 hours), check the instrument for any changes in sound, appearance, vibration, water level, and overall behavior. Stop the test if a significant change in any of these properties occurs and proceed to the next step. Alert the technician to possible problems with the apparatus.
16. Stop test (after either the allotted time or by the criteria set forth in Step 15) by turning off the motor and allowing the water within the rotating cylinder to come to rest. Stop the stop watch and record the duration of the experiment in minutes ($\Delta(\text{time})$).
17. Detach the lid of the rotating cylinder and raise the guide plate to a position where the sample just clears the water surface. Secure the guide plate on the slide rail and let the residual water and eroded materials collect in the insert beneath the sample. Measure and record the temperature of the water, $Temp_{(end)}$, with the thermometer. Carefully wash the excess eroded material off the sample, lid, platens, and support rod into the insert with a spray bottle filled with distilled water.
18. Once the sample has ceased dripping and all the excess eroded material accumulated in the cylinder, lift and secure the guide plate in the top position on the slide rail.

19. Remove the insert from the rotating cylinder. Be careful not to spill any water. If additional tests on the same sample are required, proceed to the next step; else, skip to Step 25.
20. Clean rotating cylinder with paper towel and install a new insert.
21. Go to Step 1 to begin new test. Once new test is started, return to Step 22 to process results from previous test.
22. Stir water in insert to suspend material from walls.
23. Empty insert into drying dish of known mass, $m_{\text{(dish)}}$. Rinse insert into drying dish with water bottle. Carefully remove all material on walls into drying dish.
24. Place the drying dish and accumulated material in the drying oven set to a temperature of 140° F for at least 16 hours. After 15 hours in the oven, weigh the sample hourly with the balance. The sample is considered dry when the change in mass is less than 0.1% in a period greater than one hour. Record the dry mass of the dish and accumulated material, $m_{\text{(dish-eroded)}}$.
25. Clean the RETA by removing and cleaning the insert, cleaning and drying the rotating cylinder, and clean and dry the rotating cylinder lid, support rod, and platens. The apparatus is now ready for a new sample.

CRITERIA FOR SELECTING APPLIED TORQUES AND EXPERIMENT RUN LENGTHS

Initially “Engineering Judgment” is required in the selection of the torques to be used for the tests. The more erodible the material being tested, the lower the maximum applied torque. Guidelines for the test torques and durations are presented in Tables 1 and 2. These values can be used for most samples. They should, however, be adjusted up or down if there are indications that the material is very scour resistant or easily eroded respectively.

Table I - 1. Test Torque and Duration for 2.4” Diameter Samples

Material	Pre-Test Run Torque (N mm)/Duration (hr)	3 Test Torques (N mm)	5 Test Torques (N mm)	Test Duration (hrs)
Stiff Clay	7/1	10, 15, 20	8, 11, 14, 17, 20	3-6
Soft Rock	20/12	10, 20, 30	10, 15, 20, 25, 35	24
Hard Rock	25/15	20, 30, 40	15, 20, 25, 35, 45	72

Table I - 2. Test Torque and Duration for 4” Diameter Samples

Material	Pre-Test Torque (N mm)/Duration (hr)	3 Test Torques (N mm)	5 Test Torques (N mm)	Test Duration (hrs)
Stiff Clay	10/1	16, 24, 32	14, 18, 22, 28, 32	3-6
Soft Rock	32/12	16, 32, 48	16, 24, 32, 40, 56, 72	24
Hard Rock	40/15	32, 52, 72	24, 32, 40, 56, 72	72

PART II

SEDIMENT EROSION RATE FLUME **(SERF)**

INTRODUCTION

The Sediment Erosion Rate Flume (SERF) is the second of two apparatus designed by the authors for the purpose of measuring the rate at which sediments erode when subjected to water flow-induced shear stress. This part of the report describes the flume, the sediment sample preparation and the test procedure.

Sediment Erosion Rate Flume (SERF) Description

This section describes the details of the SERF testing apparatus. Listed below are the major components of the flume and the data acquisition system followed by a detailed description of the complete apparatus assemblage.

- Two (2) 500 GPM Vertiflo pumps. One equipped with a GE Electronic variable frequency drive and the other equipped with a simple on/off relay.
- Aluminum flume, 2 in. x 8 in. (5.08 cm x 20.32 cm) cross sectional area, ½ in. (15.24 cm) wall thickness, and 9 ft. (2.74 m) in length.
- Five (5) rectangular flume sections. The first is 1 ft. long and contains a rectangular flow straightener. The second and third sections are 1 ft. and 2 ft., respectively. The 2 ft. section contains the first pressure tap. Following the 2 ft. section is the 1 ft. test section. The test cylinder is inserted into the bottom of this section and the transducer is mounted on the top. This section is also equipped with a window for viewing the experiment as it progresses. Following the test section is a 4 ft. section which contains the second pressure tap and temperature probe.
- Two (2) 1 ft. long aluminum transition sections located between the round CPVC pipes and the rectangular flume (at the flume entrance and exit).
- Connective Plumbing. (6 in. CPVC pipe from tank to pumps, 4 in. connective pipe from pumps to flume, 4 in. discharge hose from flume to tank).
- 1100 gallon stainless steel reservoir, equipped with baffles and a drain.
- SeaTek 12 element 5MHz ranging system.
- Servo Systems linear actuator (stepper motor) controlled by National Instruments (NI) motion control card and stepper motor interface.
- Sensotec +/- 2.5 psid pressure transducer, 0.1% accuracy with amplified output.

- Omega type T temperature probe.
- NI data acquisition system consisting of a PCI 60143 DAQ card and a SC-2345 signal conditioning terminal block capable of recording pressure and temp data.
- Watec auto-focus, color camera for real-time viewing and recording of the erosion test.

The SERF was designed as a rectangular cross-section flume since the shape allows the flow to become fully developed quickly, and a sectioned flume permits testing of numerous sections varying in length, design, roughness, etc. which can be easily inserted into the flume for a wide variety of testing scenarios. These scenarios could include the addition of an upstream sand injection section for the measurement of erosion rate in live bed/suspended load situations. It was also conceived that numerous test sections, each accepting a different sized sample diameter, could all be used in the SERF.

The testing apparatus consists of the flume, an 1100 gallon reservoir, and the connective plumbing. The flume is mounted on two 5.5 ft. stands, and stiff rubber has been inserted between the stands and the flume to reduce any vibration. Water is supplied to the flume from an 1100 gallon reservoir. The reservoir is equipped with a series of baffles to reduce the amount of turbulence in the tank and aid in the settling out of any suspended sediment. The tank is also equipped with a 2 ft. port on the top and a drain valve for ease of cleaning between tests. The piping between the tank and the two pumps is 6 in. sch. 80, CPVC, and the discharge from the pumps to the flume is carried through 4 in. sch. 80, CPVC.

The two 500 GPM motors are mounted on inertial bases, and the discharge end of each pump is equipped with expansion joints to inhibit movement and/or fracturing of the pipe due to pump movement or vibration. There is also a set of shut off valves at both the discharges of the tank and at the discharges of the motors which allow for increased flow control and prevent any backflow of water into the pumps. Water discharged through the pumps is carried through the 4 in. pipe and enters the flume through a 1 ft. circular to rectangular transition section.

As water enters the flume, it first passes through a 1 ft. long flow straightener. This reduces any turbulence or vortices which may be present in the flow and aids in the transition to a hydraulically smooth, fully turbulent flow. The flow passes through a second 1 ft. section followed by a section 2 ft. in length before it reaches the 1 ft. test section. The flow then passes over the sediment sample centered in the test section bed, proceeds through a 4 ft. long duct section, and exits the flume. At the exit of the flume is a 1 ft. rectangular to circular transition, which is bolted to a 4 in. rubber hose that transports the water back to the reservoir. Schematic drawings of the flume and its components are found in Appendix IIC.

Located in the center of the flume, the test section spans 1 ft. in length and supports the test cylinder containing the sample being analyzed (see Figures 3 and 4 in Appendix IID for photographs of the test section). The test cylinder consists of an acrylic cylinder secured by two compression plates. The top plate is mounted to the bottom of the test

section of the flume, while the bottom plate is attached to the top plate through four bolts. This supports and secures the cylinder in a compressive manner, permitting sample removal without disassembling the entire test section. In addition, the top of the test section is equipped with a port through which the SeaTek ultrasonic transducer is mounted (see Fig. IID5). Located on the side of the test section is a 1.4 in. diameter window through which a camera is able to display a real-time image of the sample eroding via a closed circuit T.V. system (see Fig. IID6 and IID7). The stepper motor is bolted to a variable elevation stand (mounted to the floor underneath the test section) and is easily positioned directly under the test cylinder. The sample is driven up by the motorized lead screw and plunger inside of the test cylinder. Bracketed to the motor stand, the Sensotec differential pressure transducer is connected to two pressure ports located on the underside of the flume. The pressure ports are positioned 2 ft. from the center of the test section and connected to the transducer through the use of brass compression fittings and clear, stiff tubing.

MONITORING AND CONTROL OF THE SERF

Due to the complexity of the instrumentation, the experiment is managed through LabView software at a computer station. This section will cover the major software and hardware components, as well as the various control structures and data acquisition techniques used for this research. Procedures for determining the initiation of motion and pump control startup are provided below.

Using the SeaTek ultrasonic transducer, elevations of the sample and of the test section bed are determined. Of the twelve transducers contained within the SeaTek, four measure the outside bed elevation and eight measure the inner bed elevation. (A diagram of the transducers is provided in Fig. II-1).

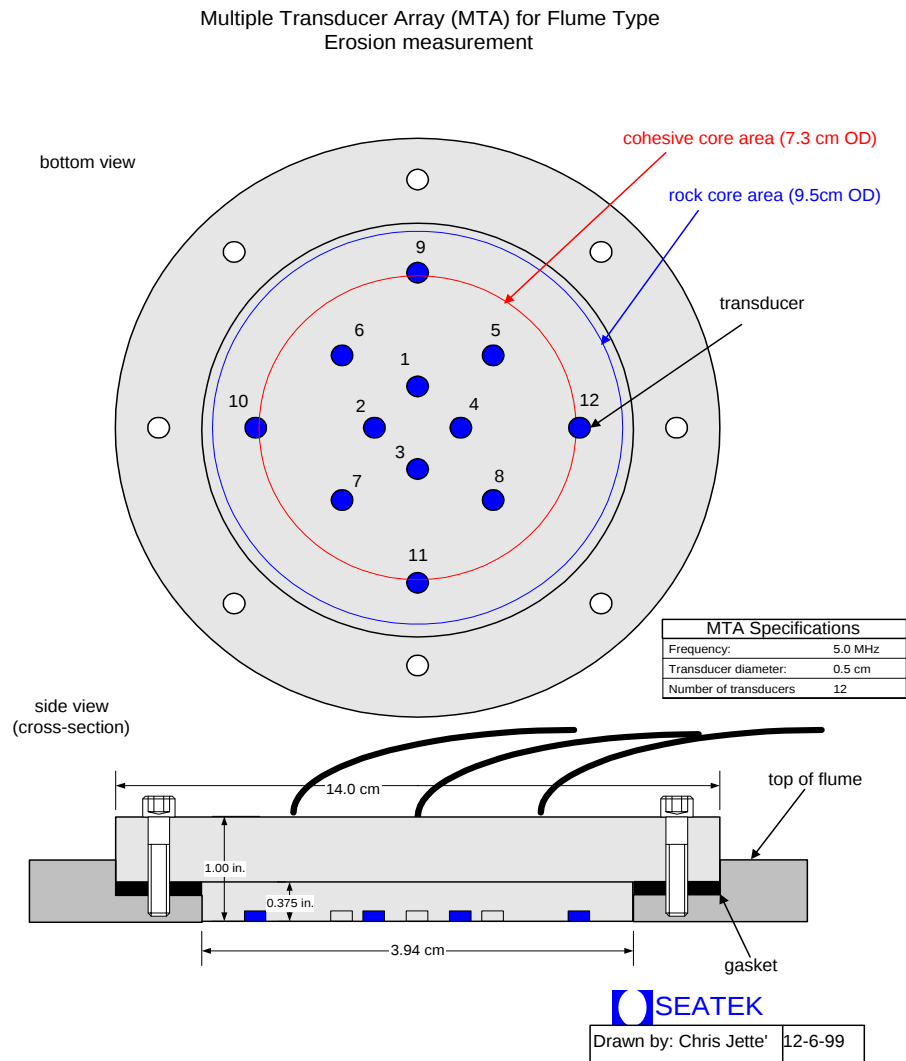


Figure II - 1. Schematic Diagram of the SeaTek Transducer Array.

The output data from the SeaTek control is typically averaged over twenty sample readings (user defined). That is, the output value for a particular channel is the average of twenty return signals for that channel. These distances are inputted into a LabView program, and an average of the sample surface elevation is calculated and compared against an average of the flume bed surface elevation. If the difference is greater than 0.5 mm, the program signals the stepper motor to move the sample to where it is flush with the bed. Once completed, a new set of numbers is retrieved from the SeaTek and the process repeats. If the stepper motor oversteps the desired amount, (due to erroneous SeaTek data or particle stacking), the LabView program will step the sample down to where it is flush with the bed. For samples expected to erode in large pieces or behave irregularly, the program averages the sample elevations excluding the highest and lowest values. In addition, signals from potentially faulty transducers can be easily removed from the data set.

Once the program obtains the elevations and moves the motor (if required), the program records the shear stress, elapsed time, distance stepped, average pressure, and average

temperature to a text file. The pressure and temperature are recorded using a data acquisition PCI card and a signal conditioning terminal block. The signal conditioning reduces the amount of noise in the signal and allows for a more accurate average. The data from these two instruments is constantly streaming; however, when a data file is written it takes 100-500 readings (user specified), determines the mean of these readings, and then records this value into the data file. If motion is not initiated within a user defined time increment, a data file is written recording the same parameters from above, allowing the user to review data to ensure that all of the measurements recorded remain constant.

While the experiment is underway, a camera positioned at the test section window displays the erosion process as it progresses. This is viewed via a television in the control office, which also records the video image to a high-8 video recorder. Although the program is capable of running continuously without input from the user, there is still need for human control to ensure proper testing. In particular, if large chunks of sediment break off from the sample, and the sample consequentially protrudes into the flow, the test should be stopped and restarted. Also, the ability to have each test backed up on video is a very useful advantage. This allows for future researchers or designers to see exactly how a certain material will erode under the specified conditions.

The two pumps used for the erosion rate and critical shear stress testing are each controlled separately by the lab technician running the test. If a “soft” sample, such as a soft clay or sand, is being tested, the use of only one pump is required and the variable frequency drive pump is used. This pump is controlled using a keypad in the control room, and its speed is increased by slowly increasing its frequency. The full range of the frequency drive pump is 60 Hz, and the incremental steps may be set as low as 0.01 Hz. For “hard” samples such as rock or stiff clay, both pumps may be used. First the variable speed pump is slowly brought up to full speed. Once it begins operating at 60 Hz, the variable speed motor is shut down and the on/off pump is started. The variable speed motor is then slowly stepped up until the desired velocity and shear stress is achieved.

TESTING AND ANALYSIS PROCEDURES

This section overviews the general procedure used to perform the erosion rate and critical shear stress experiments, and more detailed procedures may be found in Appendix IIA. The general procedures consist of pre-test procedures, sample preparation, critical shear stress testing procedures, and erosion rate testing procedures for cohesive, cohesionless, and rock materials. Pre-test and sample preparation procedures should be followed for both the critical shear stress and the erosion rate experiments. The procedure and explanation of all the control programs, such as the SeaTek transducer, pressure transducer, and the stepper motor movement programs, may be found in Appendix IIB. Finally, the methods used to reduce the data output from the data acquisition program are presented. It is recommended that the user first read through this entire section before a test is carried out, paying close attention to the equipment mentioned and referring to the photographs available in the appendices of this thesis, to ensure the procedures are carried out accurately and in the most efficient manner.

Overview of the Testing Procedure

To begin an erosion rate experiment, the tank is cleaned and filled with clean water. This water is then used to clean the flume by running both the pumps separately to discharge until the water in the flume is clear. Next, the flume is drained, and the sample (already placed into the test cylinder) is inserted into the test section, the motor stand is moved up and the plunger inside the tube is connected. The flume is then filled with water and allowed to run at a slow speed until all of the air bubbles in the flow have passed. The sample is then moved up to a position flush with or slightly below the bed elevation and the variable speed pump is turned on to the desired speed (the slowest speed for the test). Video recording should begin, and once the pumps are running, the control program should be opened and a data file should be created. This data file will record parameters such as shear stress, time, distance eroded, and temperature. Next, the program is started and data is logged.

After a prescribed amount of time at this speed, the program is stopped and the pumps are then increased to a new, faster speed. The program is started again, this time writing to a different file. The beginning clock time of each successive test should be recorded to correlate with the video file. The sample is then eroded for an amount of time and this process is repeated until a full range of shear stresses have been examined. Once the complete test is over, the erosion rates are determined and plotted against their corresponding shear stresses, and an erosion rate vs. shear stress curve is obtained.

To perform a critical shear stress experiment, the sample setup procedure should first be followed. Once the test sample is in place, the flume is then filled. For a critical shear stress experiment however, it is very important for the flume to be filled as slowly as possible to reduce the amount of sample disturbance. Once the flume is full, the sample is moved up to the point where it is flush with the bed. While the flow is stopped, the control program should be opened and used to make sure the sample is at an elevation flush with the bed. At this time, recording of the video image should begin to document the motion observed. Next, the variable speed pump is started at its lowest setting and is very slowly increased until sediment movement is observed. The velocity, shear stress, and type of movement should be recorded as well as the time at which movement was observed to correlate with the video file.

Data Analysis

The methods used to reduce the data output from the data acquisition program are outlined below. For each separate velocity (and related shear stress) test run, a separate data file should have been created. To reduce the erosion rate from this data file, the incremental distances (cm) stepped by the motor are summed and divided by the elapsed time of the test. If the incremental rate of erosion is desired, the incremental steps should simply be divided by the elapsed time of that step, found in the adjacent column in the data file. It is recommended that the technician running the experiments plot the incremental time against the incremental erosion rate to determine that a constant rate was observed. That is, the erosion rate should be a steady line after an initial equilibration period. If not, it should be noted in the lab manual, or the test should be run again for that particular shear stress. Once the erosion rate is validated, the entire column

displaying the shear stress should be averaged and a standard deviation computed along with the mode. If the standard deviation is large and there is poor agreement with the average and the mode, the test should be repeated. If a sample is not available for a second test, then either the shear stress corresponding to the mode should be used or the highest 10% of the known shear stress should be averaged and this plotted against the corresponding erosion rate. A plot of shear stress vs. rate of erosion should then be created using at least five data points. Along with this plot, the lab notes and video file of the tests should be included in the final report.

If a critical shear stress test was performed, the final data is simply the value of shear stress at which the sediment motion was first initiated. However, the data file recording the shear stress and the video file should be included in the final report. This is to display the actual sediment motion observed and to ensure that the velocity (shear stress) was increased at a slowly increasing rate.

APPENDIX IIA

DETAILED TESTING PROCEDURES FOR COHESIVE AND NON-COHESIVE SEDIMENTS IN THE SERF

Erosion Rate Pre-Test Procedure and Setup

1. Ensure that tank is clean and free of suspended materials. If tank is not clean, flush with hose, fill to 100 gal. Mark, drain, and repeat as necessary.
2. Fill tank with clean water and run flume (both pumps) to discharge at 20 Hz for 20-30 seconds or until water in flume is clear and free of bubbles and flume (and discharge hose) are completely full of water. Plunger inside of test cylinder should be at a high position to reduce the amount of water in tube when flume is drained.
3. While flume is full, drain water from pressure taps to ensure they are free of debris.
4. Drain flume by opening pump and tank valves and bleeding air from pressure taps.
5. Once flume is drained, move plunger to its closest position to the stepper motor.
6. Cover motor with plastic sheet to keep from getting wet.
7. Remove pins in motor stand and move motor/stand down until the pin connecting the plunger and the lead screw swivel can be removed.
8. Remove pin connecting lead screw and plunger and move the stand down to its lowest position.
9. Remove test cylinder by removing the 4 nuts on the bottom of the compression plate.
10. Clean test cylinder and plunger with water and grease plunger o-rings.
11. Insert plunger into test cylinder, pin connector end first, until plunger face is flush with test cylinder edge.
 - a. If a lab sample is to be prepared, push the plunger through the test cylinder until the o-ring closest to the pin connector is exposed outside of the cylinder. The lab sample should then be prepared or constructed inside of the cylinder.
 - b. If a sample is to be extracted into the cylinder, follow the instructions in the following section titled Sample Preparation Procedure.

- c. If a 2.3 in. rock core test is to be performed, follow the instructions in the Erosion Rate Test Procedure (for rock cores) section.

Sediment Sample Preparation Procedure

If a lab sample is to be prepared or constructed in the tube, the bottom of the plunger should be protruding outside of the cylinder so that the edge of the cylinder is centered between the plunger's two o-rings. Once the lab sample is prepared and ready to be tested, proceed to section titled "Erosion Rate Testing Procedure". If a Shelby tube sample is to be tested, follow the steps below for the proper sample preparation.

1. If a Shelby tube sample is in a metal containment tube longer than 10 in., the tube must be cut into smaller increments. (The test cylinder cannot support a sample longer than 10 in.). If a typical Shelby tube sample (30 in. long) is being tested, the tube should be prepared to be cut into three 10 in. length sections. If a 10 in. or smaller section of Shelby tube is obtained, proceed to step 3.
2. Before cutting, a diagram must first be made of the orientation of the sample and the cutting planes. Once this is done, the tube should be cut using a correctly sized pipe cutter. The sample is then sliced with a wire saw, or simply by using a piano wire.
3. The Shelby tube should then be placed in the hydraulic extractor, making sure that the correct size plunger is placed on the hydraulic piston and that the tube is inline and secured with the top plate. Proper orientation of the Shelby tube should be checked and documented.
4. Once the Shelby tube is secure, the test cylinder should be placed on top of the top plate. The plunger inside the test cylinder should be very close to the end of the cylinder touching the top plate. The plunger should be oriented face down, so as the sample is inserted into the test cylinder, the pin connection on the plunger will be protruding from the end of the test cylinder.
5. A second plate should be bolted onto the extractor to hold the test cylinder in place.
6. Once the tubes are in line and secured, the sample should then be SLOWLY extracted into the test cylinder. The extraction should proceed until the pin connection end and the bottom o-ring of the plunger are protruding outside of the cylinder. The two o-rings should appear centered from the cylinder edge.
7. Once the sample is completely contained inside the test cylinder, release the hydraulic press and remove both tubes from the extractor. A check should be made to ensure that the hydraulic plunger is not stuck inside the test cylinder, if so, be sure to gently remove it.
8. The test cylinder edges should then be wiped clean with a wet rag and lightly greased. The test cylinder is now ready to be inserted into the flume for testing.

Erosion Rate Testing Procedure (for Cohesive or Cohesionless material)

Once the sample is inside the test cylinder, the top and bottom edges should be cleaned so they are free of debris and lightly greased.

1. The o-rings in the top and bottom test section compression plates should also be cleaned and lightly greased. If either o-ring is damaged or highly worn, it should be replaced.
2. Once the o-rings are in place, insert the test cylinder inside the top compression plate, making sure the o-ring is in place and is not being “pinched”.
3. The test cylinder should then be secured by mounting the bottom compression plate and hand tightening the 4 nuts onto the lead screws. The 4 nuts should then be gently tightened down with a wrench. Be sure to tighten the nuts slowly and across from one another, not in a circular pattern.
4. Ensure that the pin connector on the plunger is exposed below the bottom compression plate. If not, insert an oversized (longer) pin and pull the plunger down until there is sufficient room for the connection to be made.
5. With the motor lead screw in its lowest position, raise the motor stand to a position where the pin connection between the lead screw and the plunger can be made.
6. Once the plunger is connected, move the motor/stand to a position where the motor is closest to the bottom of the test cylinder without protruding the sample into the flumes cross-sectional area. Insert the pins into the stand to secure this position.
7. Fill the flume using the variable speed motor at the lowest possible speed (10-15 Hz). Make sure the sample is in the lowest possible position to reduce erosion/scour of the top surface.
8. Once the flume is filled, run the variable speed pump at 15 Hz for 10 seconds or until all bubbles in flow and on the SeaTek transducer are gone. The pump must be run at a speed greater than 10 Hz, because the pump cannot overcome the head of the water during the filling until a siphon is formed.
9. Remove pressure transducer from mounting bracket.
10. Drain pressure hoses for around 10 seconds to make sure they are free of debris.
11. Fill the upstream side of the pressure transducer with water using a syringe. Gently tap the transducer to ensure no air bubbles are present.
12. Open the upstream side pressure hose so that it is gently flowing and connect it to the pressure transducer by hand. The hose should be flowing to prevent any air from being trapped inside the transducer.

13. After the hose is connected, use a wrench and snug down the compression nut.
14. Open the hose valve completely and tap the hose near the transducer to make sure all bubbles are cleared. If bubbles appear out of the transducer, tap the hose until they have moved into the flume.
15. Repeat the **previous 5 steps** for the downstream side of the pressure transducer.
16. Once the pressure transducer is connected and the user is confident that no air bubbles are present, the sample should be moved upwards until it is flush or slightly lower than the flume bed.
17. The video image should be checked to confirm that there are no air bubbles present on the SeaTek transducer. If so, the variable drive pump should be run at a low speed (less than 5 Hz) to remove them.
18. Being recording the video for the experiment.
19. The SeaTek communication program (discussed below) should then be opened and a data run commenced.
20. After closing the dialog window for the SeaTek, the Erosion Rate Test Program should be opened from the computers desktop.
21. After reading through the instructions for this program, the pumps should be started at the lowest desired speed and then the program should be started as soon as the pumps reach their desired speed and steady state is achieved.
22. The data file name, pump speed, beginning time, end time, and velocity should be recorded in a lab notebook for each successive test.
23. Once the test is running, a velocity measurement should be taken using the ultrasonic velocity meter immediately downstream of the test section and recorded.
24. The test should be allowed to run until the desired time or desired erosion has been achieved. Once this point is reached, the LabView program should be stopped.
25. The time at which the program is stopped should be noted to correlate with the video file.
26. The pumps should then be run up to a second specified speed and the Erosion Rate Test Program should be run again, only this time with a new data file name.
27. Upon the completion of the second speed erosion rate test, at least two more tests should be completed for multiple points on the data curve of erosion rate vs. shear stress.

If the sample is to be run for an extended period of time, the emergency shut-off switch in the SERF control office should be activated. This will allow the pumps to be shut-off if anything were to go wrong during the testing.

Erosion Rate Testing Procedure (for a 2.3 in. Diameter Rock Core)

For testing a rock core sample of 2.3 in. diameter, the same pre-test procedures should be followed. Once all of the steps are carried out, the subsequent procedures should be followed.

28. The rock core should first be turned down on a lathe so that its diameter is a constant 2.215 in. The top and bottom surfaces of the sample must also be flat and perpendicular to the sides.
29. A 9/64 in. hole should then be drilled into the bottom side of the rock core and filled with a quick-set epoxy.
30. The rock core should then be saturated in a chamber under vacuum pressure to ensure full saturation prior to testing.
31. Once the sample has been allowed to soak, the rock core test cylinder should be assembled. The cylinder, plunger, and sample seat should all be cleaned and the plunger's o-rings greased.
32. The rock core should then be attached to the sample seat. (Drill a pilot hole into the center of the epoxy and secure the seat with a screw). The sample seat should then be secured to the plunger using the existing 2 holes and screws. The sample seat and plunger should then be inserted into the test cylinder and the cylinder filled with water. (See Figures II-D-8 and II-D-9 for photographs of the rock core test cylinder assembly).
33. With the rock core test cylinder below the level of the cylinder surface, the test cylinder should then be inserted into the flume and secured using the compression plates.
34. Once the rock core test cylinder is secured into the flume, steps 4 through 28 of the erosion rate test procedure (for cohesive and cohesionless) should be followed along with the instructions below.

Once the test cylinder is secured, the flume is full, and a test is ready to be run, the user should activate the emergency shut-off switch in the SERF control office. This will allow the pumps to be shut off if anything should go wrong with the testing. Each successive test should be run for a maximum of 12 hours or until a distance of 2 cm has been eroded, whichever comes first.

Critical Shear Stress Test Procedure

To perform a critical shear stress analysis, first the pre-test and sample preparations procedures previously mentioned should be followed. Steps 1-20 of the erosion rate test procedure should be followed also, only with a few slight modifications. First, as the

flume is being filled, it is very important that it be filled as slowly as possible and that the sample is in its lowest position to ensure no sample disturbance.

35. Once the flume is full, the erosion rate program should then be opened and run to ensure the sample is flush with the bed. Once this is done, the program should be closed and opened once again. Notes should be taken in the lab notebook throughout the testing of shear, observed motion, time, etc.
36. Once the program is writing data, turn on the pumps to a speed that will produce a shear stress much lower than the expected critical shear stress. Allow the flow to stabilize.
37. If no movement is observed, very slowly increase the pumps velocity, being sure to pause between velocity increments to allow for flow stabilization.
38. Once the critical shear stress has been reached and sediment motion is observed, record the velocity, pump frequency, shear stress and time in the lab notebook.
39. The pumps should then be increased above the critical shear value and the motion observed documented along with the same flow parameters and the time.
40. This process should be repeated until steady sediment motion is observed.
41. Once the test is complete, the data file should be recovered and the shear stresses verified.

APPENDIX II-B

DATA ACQUISITION AND PROGRAM OPERATION GUIDE

The following procedures describe in detail how the control and data acquisition programs should be operated. Aside from the procedures stated above, this section also includes guidelines for simple movement of the stepper motor, startup of the SeaTek communication program, as well as an outline of the LabView program so that the user can make necessary modifications if needed.

SeaTek Program

Before the start of any test, the SeaTek program must first be opened and a data run started. To open up the program, double-click on the desktop icon labeled SeaTek. This will bring up the communication program which allows the SeaTek to “talk” to the computer. Once this program is opened, the SeaTek should be turned. The SeaTek should **never** be turned on when the flume is empty. A dialog should appear on the screen that reads MTAS. If a “?” is typed and the enter key is struck all of the available commands for the SeaTek become available. For more information on this, the user is referred to the user’s manual accompanying this piece of equipment. Once the proper parameter values have been input into the SeaTek, the user should now type a “d” for data run and hit enter. The SeaTek should immediately start to output the twelve number array. The first string or two may be slightly off from the expected 5.0 cm due to the SeaTek calibrating itself, but after this, if the sediment sample is flush with the bed, all 12 numbers should be very close to 5.0 cm. Once this is verified, the program window should be closed due to the fact that the LabView programs cannot communicate with the SeaTek while the communication window is open. If the SeaTek program is outputting unsteady numbers, the user is again referred to the user’s manual. This manual describes the numerous parameters available along with troubleshooting techniques.

Stepper Motor Programs

To achieve simple up and down movements of the plunger (or the sediment sample), the LabView program labeled “Simple Move with Display” should be used. This program is also located on the desktop of the control computer and is opened simply by double-clicking the icon. Once the program is opened, the user should only enter a value into the “Target Position” space provided. This input value is the amount of steps the plunger will move up or down depending on whether the value is positive or negative. Once the number is input into the box, the arrow at the top of the screen should be pressed and the program will run. For small movements, the user is recommended to use values equal to or less than 1000 steps. This will move the plunger up approximately 1 cm. For larger movements the user is recommended to use values no larger than 5,000 steps. Steps larger than this can put a significant strain on the motor and will cause the internal gears to grind. Once the value is entered into the program, the user is able to repeatedly hit the run button until the plunger reaches the desired height. A good rule of thumb is, “When in doubt, use a step value half of which you think is sufficient.”

Erosion Rate Test Program

When the preceding steps have all been completed, and the test is ready to run, the following steps should be followed to run the control program and data acquisition for the

analysis of a sediment sample. The LabView program entitled Erosion Rate Testing Program on the control computers desktop should be opened. Once this is opened, the user should hit the run button at the top left corner of the screen. This will prompt the user to input a filename to which the data will be written to. It is recommended that the user name this file to represent the speed of the motors and the sediment sample (for instance, "redclay_20"). It is also recommended that the user take detailed notes in a lab notebook for a record of the data files. Once this is done and the O.K. button is pressed the program will run automatically until the user stops the program manually. While the pumps are off, it is recommended that the program run for a few seconds before the test is actually begun. This will ensure the sample is flush with the bed. Once the pumps are turned on, the program should be run and the old data file, "redclay_20," should be overwritten. After a desired amount of material has eroded or a given time has passed, the test should be stopped and the same process repeated for an increased flow velocity. The user should give this data file a new name and record this new flow rate and data file name in the lab notebook. This process should be repeated until at least five different flow velocities have been analyzed. The flow rates should include the ambient flow conditions and exceed the design flow conditions for the site where the sample was taken.

APPENDIX II-C SCHEMATIC DRAWINGS OF THE SERF

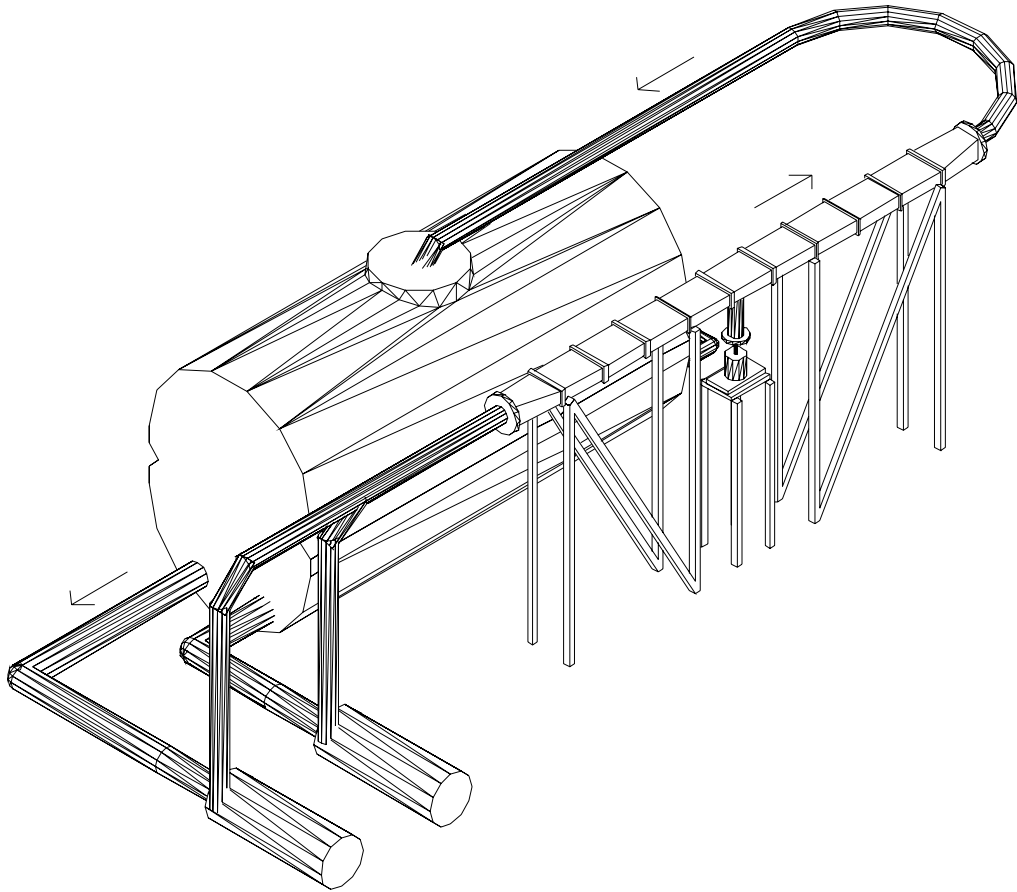


Figure IIC - 1. Schematic Drawing of the Sediment Erosion Rate Flume.

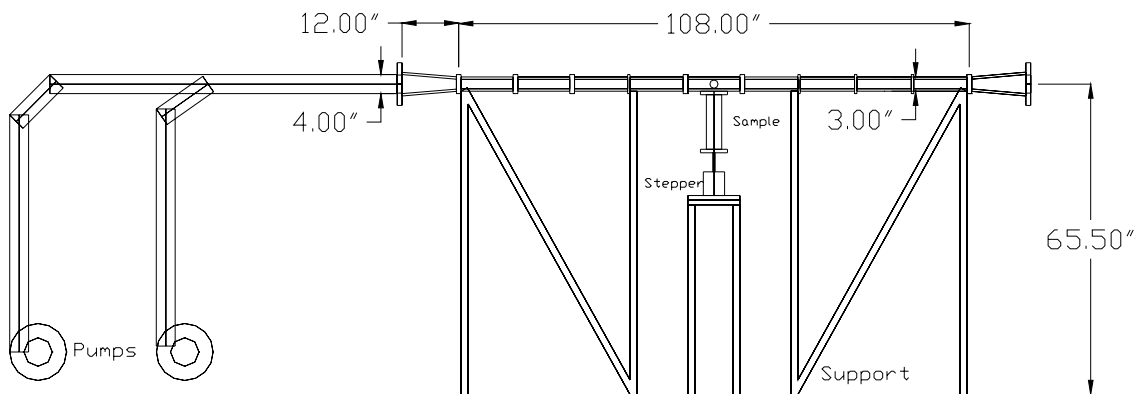


Figure IIC - 2. Schematic Drawing of the Profile View of the SERF.

Note: All unspecified measurements listed are in inches.

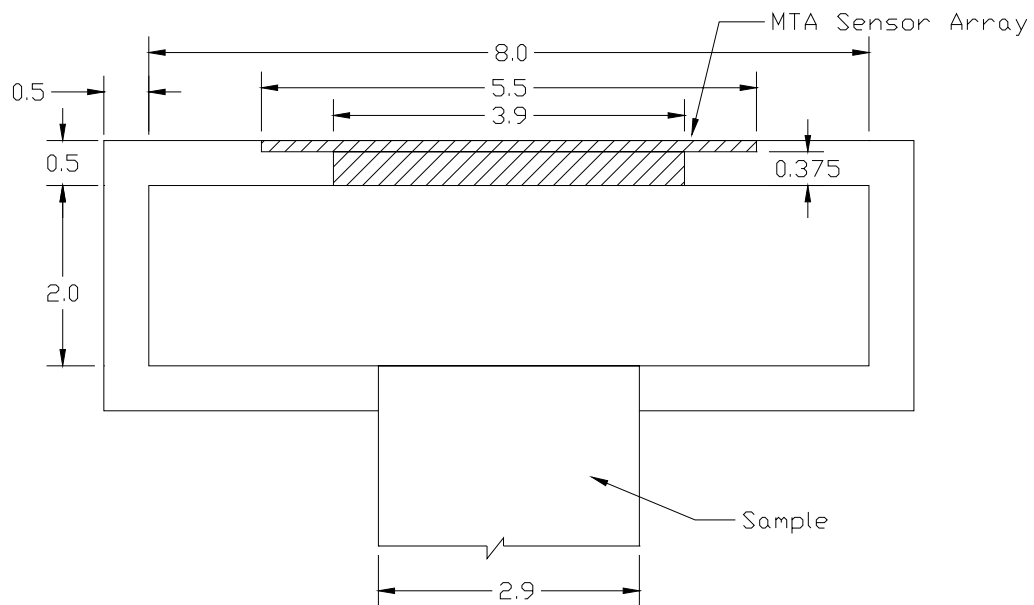


Figure IIC - 3. Schematic Drawing of Flume Cross Section Viewed at the Test Section.

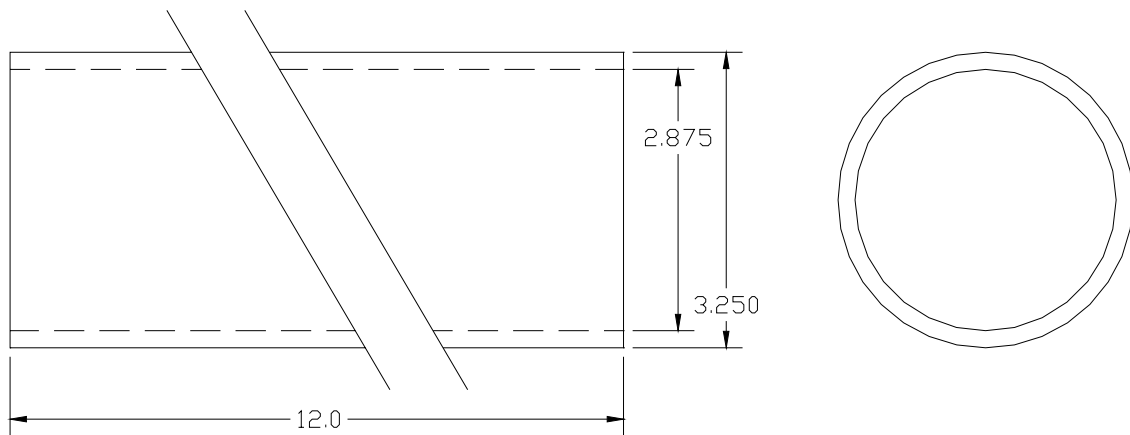


Figure IIC - 4. Schematic Drawing of the Acrylic Test Cylinder.

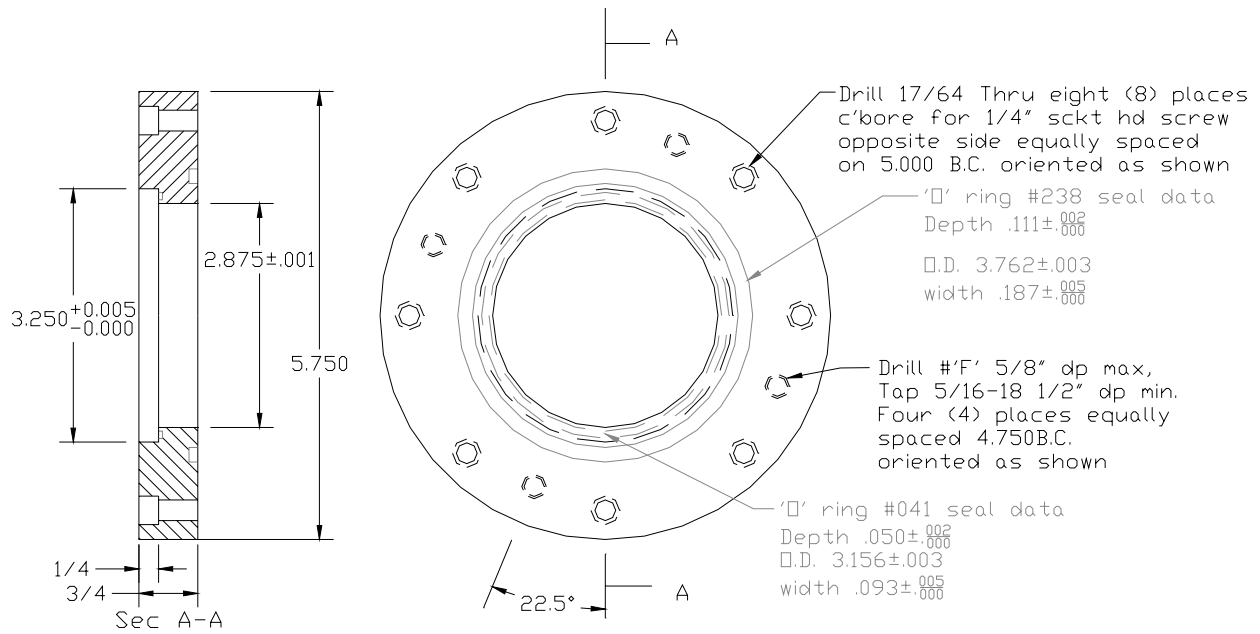


Figure IIC - 5. Schematic Drawing of Upper Compression Plate Used to Position Test Cylinder.

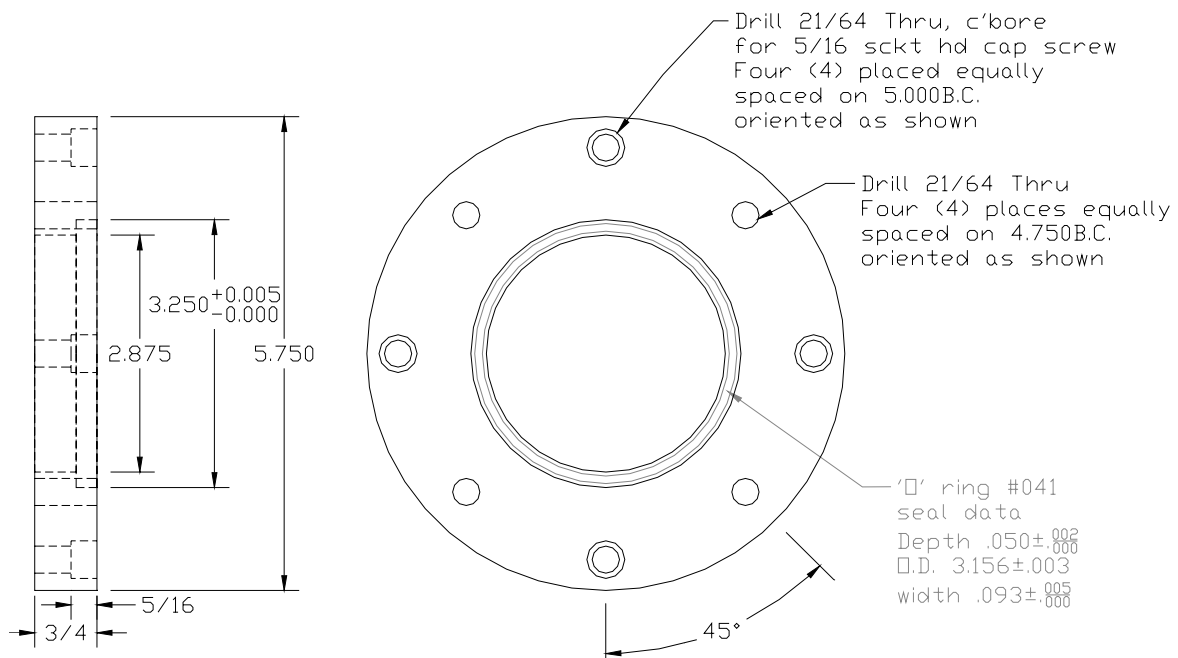


Figure IIC - 6. Schematic Drawing of Lower Compression Plate Used to Hold the Test Cylinder in Place.

APPENDIX II-D PHOTOGRAPHS OF THE SERF



Figure IID - 1. Photograph of the SERF at the University of Florida. The SERF Control Room is in the Background.



Figure IID - 2. The Pumps with Shut-Off Valves, Plumbing, and Pumps on the Inertial Bases.

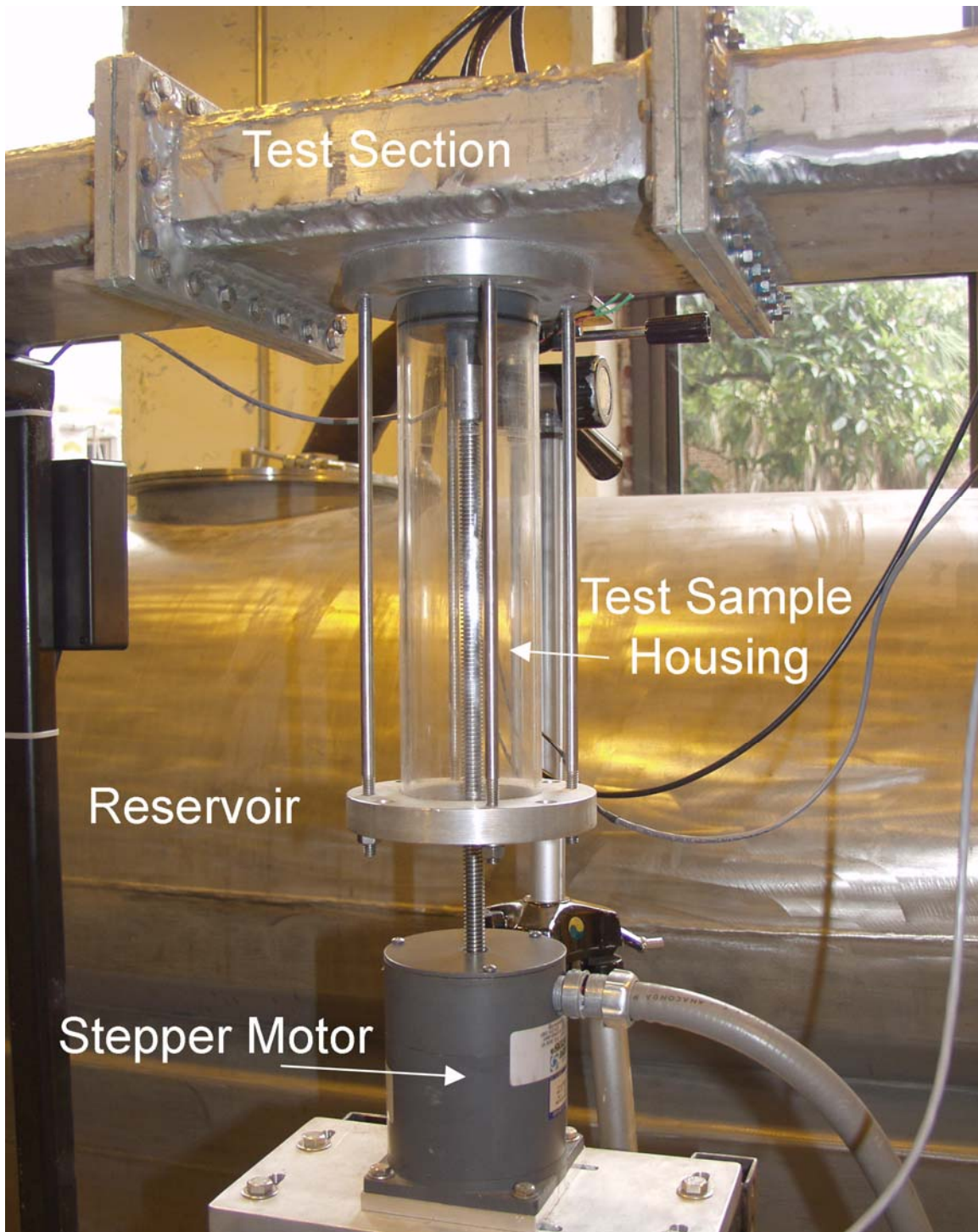


Figure IID - 3. Photograph of the Flume Test Section, Test Cylinder, the Reservoir, and the Stepper Motor.

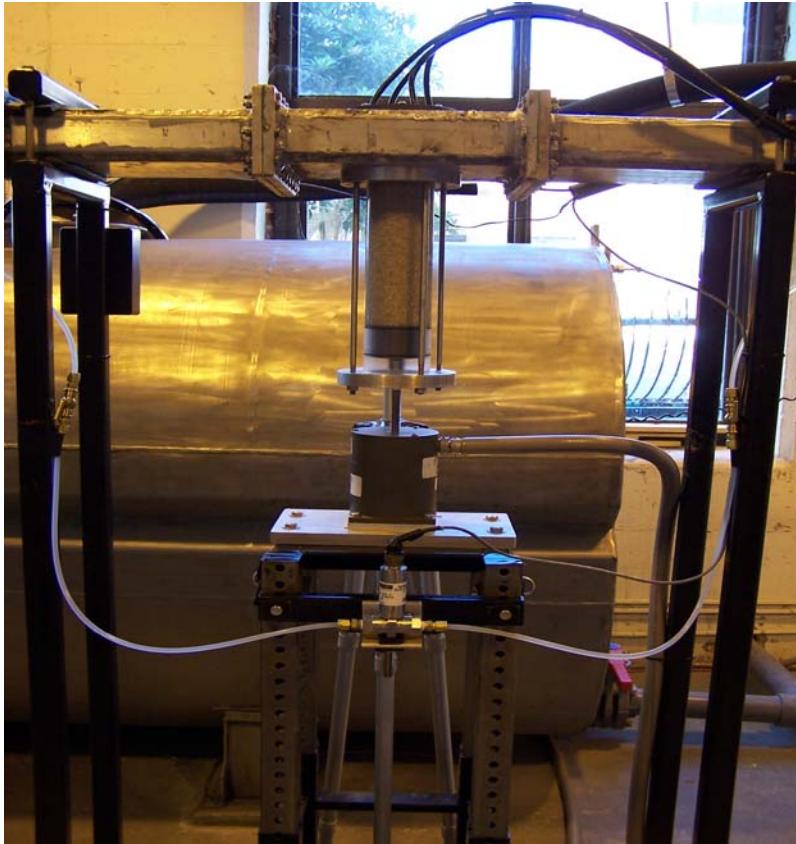


Figure IID - 4. Front View of the Test Section Showing the Stepper Motor, Test Cylinder, SeaTek Transducer, and the Differential Pressure Transducer.

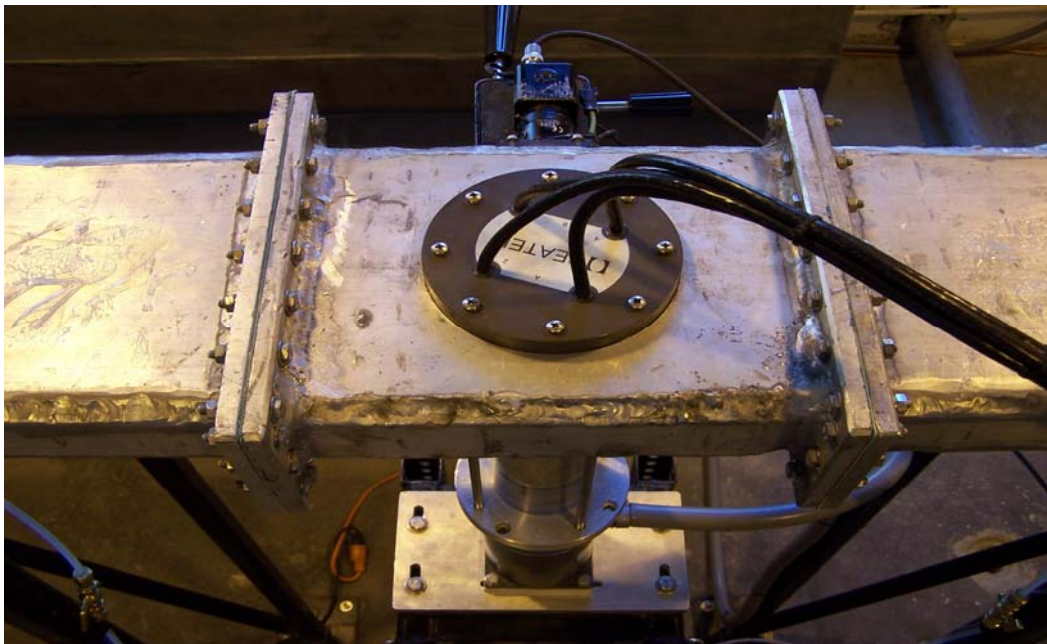


Figure IID - 5. Top View of the Test Section Showing the SeaTek Transducer Along With the Camera and Test Cylinder.

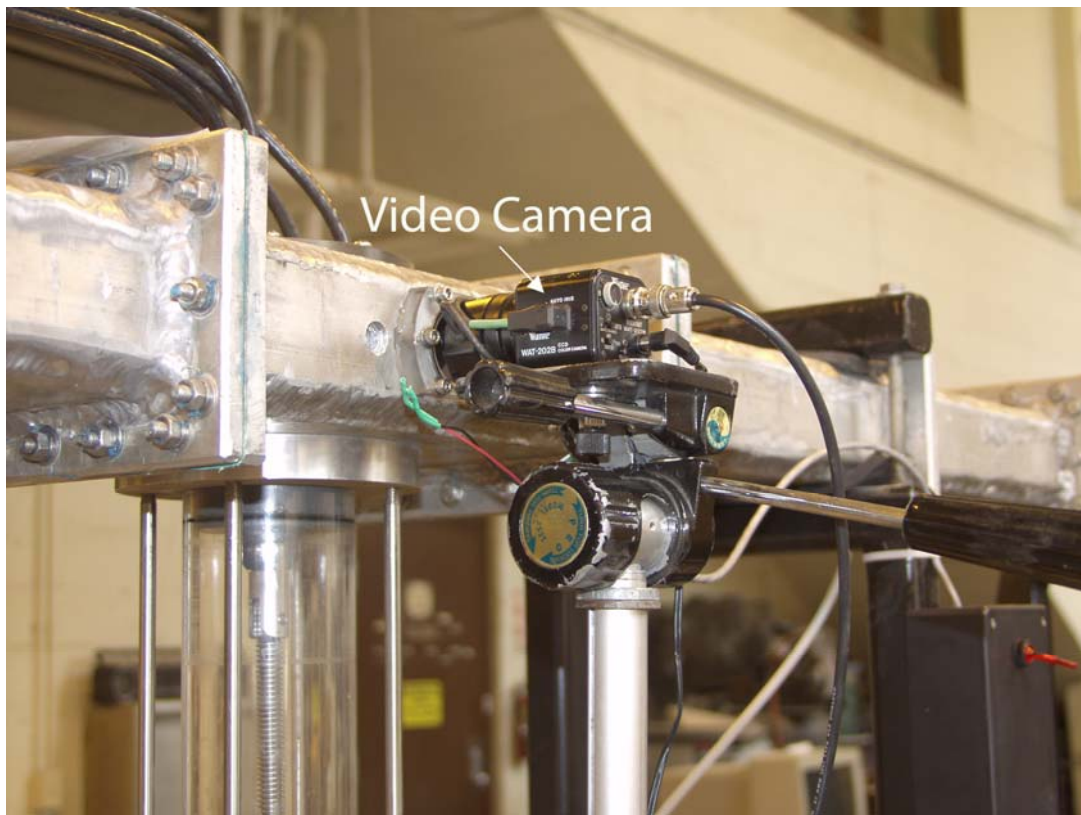


Figure IID - 6. Rear View of the Test Section, Showing the Camera and the Light Switch.

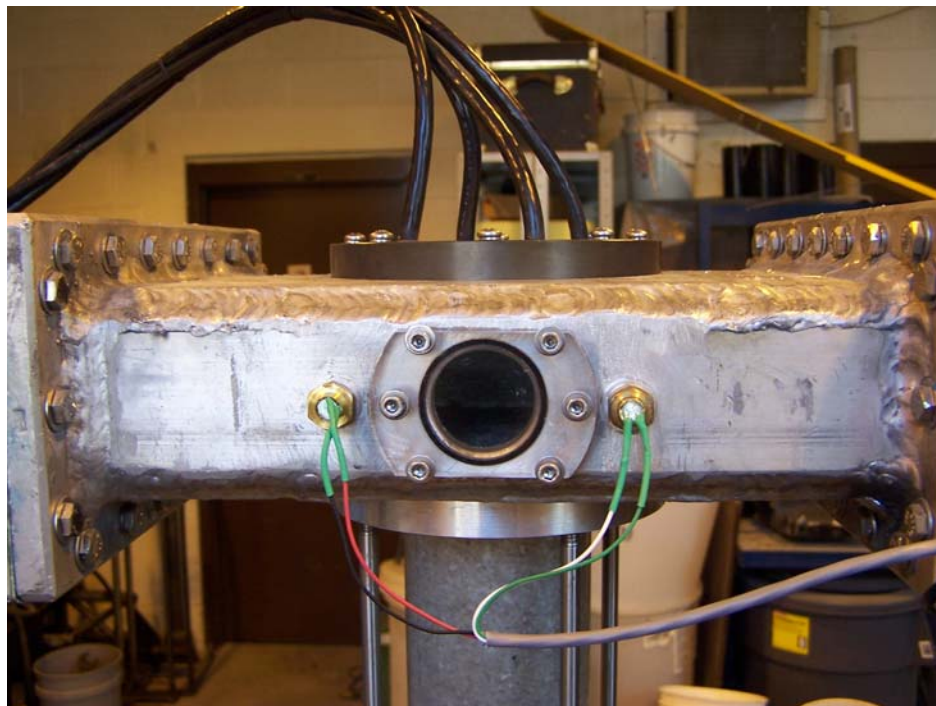


Figure IID - 7. Rear View of Test Section with Window, SeaTek Transducer, LED Lights and the Test Cylinder.



Figure IID - 8. Rock Core Test Cylinder with Separate Components, Cylinder, Rock Core Seat, Plunger, and Rock Sample.



Figure IID - 9. Assembled Rock Core Test Cylinder Containing a Rock Sample.

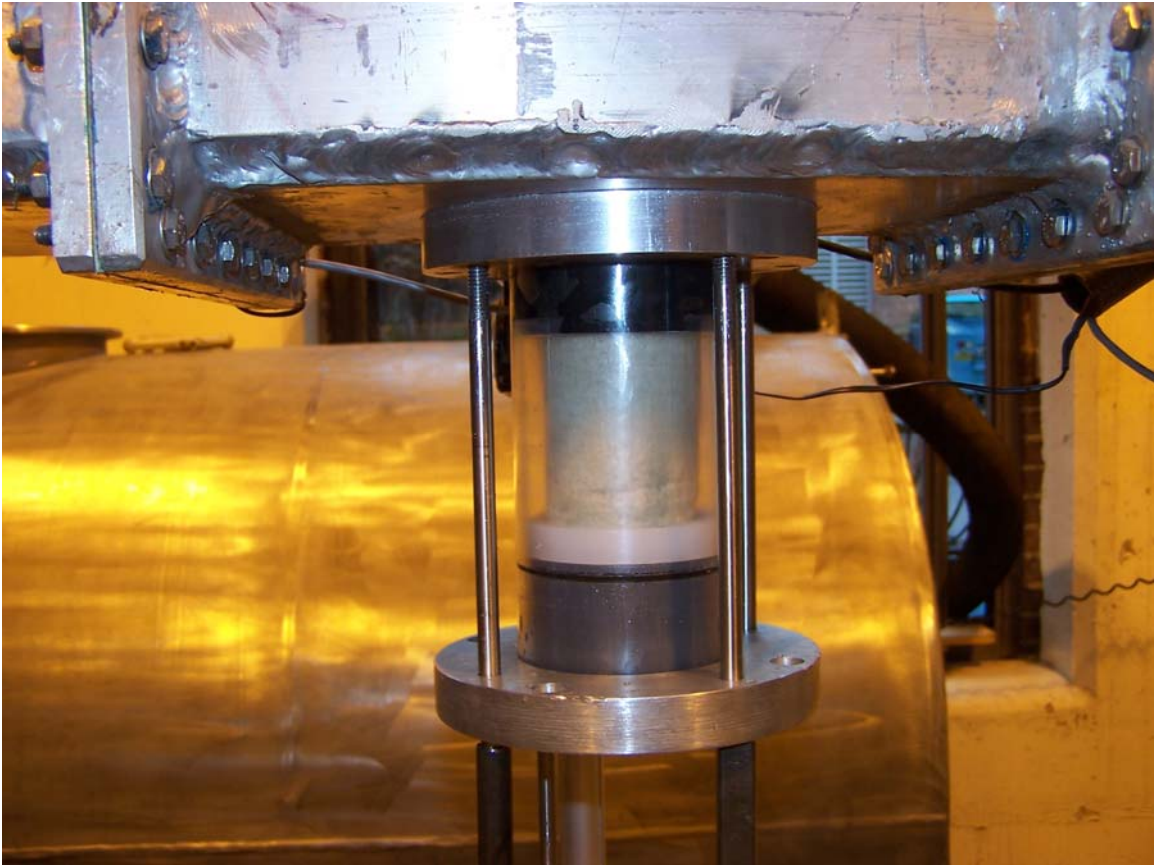


Figure IID - 10. Rock Core Test Cylinder in Flume, Containing a Rock Sample.



Figure IID - 11. Video Monitor Image of a Rock Sample.