SUMMARY REPORT

THE SRICOS–EFA METHOD


TEXAS A&M UNIVERSITY

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INTRODUCTION

Most prediction equations to estimate bridge scour depths have been developed on the basis of laboratory flume test results using coarse grained soil. Unfortunately these same equations are also used for fine grained soil which have much lower erosion rate than coarse grained soil. It usually takes less than a day for coarse grained soil to reach the maximum scour depth around a bridge support under a constant flow rate but for a fine grained soil the scour depth developed in a day maybe a small percent of the maximum scour depth because of the slower erosion rate. Studies of bridge scour depths in fine grained soils with consideration of soil erodibility and time dependence have been performed at Texas A&M University since 1990.

The SRICOS-EFA (Scour Rate In COhesive Soil – Erosion Function Apparatus) method has been developed starting in early 1990s by Briaud and his coworkers for fine grained soils. This method allows the user to predict the scour depth as a function of time; it is based on two main parameters, the maximum scour depth and the maximum shear stress before scour begins. The equation to calculate the maximum scour depth was developed on the basis of flume test results and dimensional analysis, while the maximum shear stress was developed on the basis of three-dimensional (3D) numerical computation results.

The SRICOS-EFA program allows users to perform the complex pier scour, contraction scour and abutment scour alone, also it can handle the combined scour of the pier, contraction and abutment scour (integrated SRICOS-EFA method). It automates the calculations of all the parameters such as maximum initial shear stress, initial scour rate, maximum scour depth, and transformation of the discharge into velocity. It also automates the computations to handle multi-flood hydrograph and multi-layer soil systems.
BASIC CONCEPT OF SRICOS

The scour phenomenon in fine grained soils is much slower and more dependent on soil properties than that in coarse grained soils. Applying the equations developed to predict depth of scour in coarse grained soils to fine grained soils without the consideration of time yields overly conservative scour depths. Therefore, a scour analysis method for fine grained materials needs to consider the effect of time and soil properties as well as hydraulic parameters. Once the SRICOS (Scour Rate In COhesive Soils) method was developed to predict the scour depth versus time around a cylindrical bridge pier founded in fine grained soils, it has been expanded to contraction scour and abutment scour.

The SRICOS method is highly dependent on the maximum scour depth and the shear stress between the flow and soil interface. The procedure of SRICOS method is consisted with following steps.

1. Obtain standard 76.2 mm diameter Shelby tube samples as close to the pier as possible.

2. Test the sample in the EFA to get the erodibility curve ($\dot{z}$ vs. $\tau$).

3. Determine the maximum shear stress $\tau_{\text{max}}$.

4. Obtain the initial scour rate ($\dot{z}_i$) corresponding to $\tau_{\text{max}}$.

5. Develop the complete scour depth $y_s$ vs. $t$ curve.

6. Predict the depth of scour by reading the $y_s$ vs. $t$ at the time corresponding to the duration of the flood using

$$y_s(t) = \frac{t}{\frac{1}{\dot{z}_i} + \frac{1}{y_s}}$$

(1)

where $t$ is time (hour), $y_s$ is the maximum pier scour depth (mm), $\tau_{\text{max}}$ is the maximum shear stress on the channel bed.
EFA TEST

An apparatus measuring the erosion function was developed in the early 1990s, called the EFA (Erosion Function Apparatus), and it is shown in Figure 1 (Briaud et al., 2001; Briaud et al., 1999). The principle is to go to the site where erosion is being investigated, collect samples within the depth of concern, bring them back to the laboratory, and test them in the EFA. The 75 mm outside diameter sampling tube is placed through the bottom of the conduit where water flows at a constant velocity. The soil or rock is pushed out of the sampling tube only as fast as it is eroded by the water flowing over it.

For fine grained and coarse grained soils, ASTM standard thin wall steel tube samples are favored. If such samples cannot be obtained (e.g.: coarse grained soils), Split Spoon SPT samples are obtained and the coarse grained soil is reconstituted in the thin wall steel tube. Fortunately in the case of erosion of coarse grained soils, soil disturbance does not affect the results significantly. If it is representative of the rock erosion process to test a 75 mm diameter rock sample, the rock core is placed in the thin wall steel tube and tested in the EFA. The rate of erosion can be very different for different soils.

The test result consists of the erosion rate $\dot{z}$ versus shear stress $\tau$ curve (Figure 1). For each flow velocity $V$, the erosion rate $\dot{z}$ (mm/hr) is simply obtained by dividing the length of sample eroded by the time required to do so.

$$\dot{z} = \frac{h}{t}$$

where $h$ is the length of soil sample eroded in a time $t$. The length $h$ is 1 mm and the time $t$ is the time required for the sample to be eroded flush with the bottom of the pipe (visual inspection through a Plexiglas window).

After several attempts at measuring the shear stress $\tau$ in the apparatus it was found that the best way to obtain $\tau$ was by using the Moody Chart (Moody, 1944) for pipe flows.

$$\tau = \frac{1}{8} f \rho V^2$$
where \( \tau \) is the shear stress on the wall of the pipe; \( f \) is the friction factor obtained from the Moody Chart (Figure 2); \( \rho \) is the mass density of water (1,000 kg/m\(^3\)); and \( V \) is the mean flow velocity in the pipe. The friction factor \( f \) is a function of the pipe Reynolds Number \( Re \) and the pipe roughness \( \varepsilon / D \). The Reynolds Number is \( \nu / VD \) where \( D \) is the pipe diameter and \( \nu \) is the kinematic viscosity of water (10\(^{-6}\) m\(^2\)/s at 20°C). Since the pipe in the EFA has a rectangular cross section, \( D \) is taken as the hydraulic diameter \( D = 4A / P \) where \( A \) is the cross-sectional flow area, \( P \) is the wetted perimeter, and the factor 4 is used to ensure that the hydraulic diameter is equal to the diameter for a circular pipe. For a rectangular cross-section pipe:

\[
D = \frac{2ab}{(a+b)}
\]  

(4)

where \( a \) and \( b \) are the dimensions of the sides of the rectangle. The relative roughness \( \varepsilon / D \) is the ratio of the average height of the roughness elements on the pipe surface over the pipe diameter \( D \). The average height of the roughness elements \( \varepsilon \) is taken equal to \( 0.5D_{so} \) where \( D_{so} \) is the mean grain size for the soil. The factor 0.5 is used because it is assumed that the top half of the particle protrudes into the flow while the bottom half is buried in the soil mass.

Figure 1 – EFA (Erosion Function Apparatus) to measure erodibility (Briaud et al., 1999).
The critical shear stress, \( \tau_c \), is the property of channel bed material. No erosion occurs if the shear stress acting on the interface between water flow and channel material is below it, but erosion starts if the shear stress is above it. In cohesionless soils (sands and gravels), the critical shear stress has been empirically related to the mean grain size \( D_{50} \) (Briaud et al., 2001, Briaud, 2008).

\[
\tau_c (N/m^2) = D_{50} (mm)
\]  

(5)

For such soils, the erosion rate beyond the critical shear stress is very rapid and one flood is long enough to reach the maximum scour depth. Therefore there is a need to be able to predict the critical shear stress to know if there will be scour or no scour. Meanwhile, in cohesive soils (silts, clays) and rocks, eq. (5) is not applicable as shown in Figure 3.

**Figure 2 – Moody Chart** (reprinted with permission from (Munson et al., 1990)).
In a similar way, the critical velocity of channel bed material has been empirically related to the mean grain size $D_{50}$ in cohesionless soils (Briaud, 2008), and the critical velocity in cohesionless soil is:

$$V_c = 0.35(D_{50})^{0.45}$$  \hspace{1cm} (6)

However, the critical velocity in cohesive soil cannot be defined as function of the mean grain size $D_{50}$ as shown in Figure 4.

![Diagram](image)

**Figure 3 – Critical shear stress as a function of mean grain size.**
The categories of erosion rate for different soils are proposed on the basis of 15 years of erosion testing experience using EFA (Erosion Function Apparatus). In order to classify a soil or rock, the erosion function is plotted on the category chart and the erodibility category number for the material tested is the number for the zone in which the erosion function fits. Note that using the water velocity is less representative and leads to more uncertainties than using the shear stress; indeed the velocity and the shear stress are not linked by a constant. Nevertheless the velocity chart is presented because it is easier to gage a problem in terms of velocity.

Categories are used in many fields of engineering: soil classification categories, hurricane strength categories, earthquake magnitude categories. Such categories have the advantage of quoting one number to represent a more complex condition. Briaud (Briaud, 2008) proposed Erosion categories in order to bring erodibility down in complexity from an erosion rate vs shear stress function to a category number. Such a classification system can be presented in terms of velocity (Figure 5) or shear stress (Figure 6).
Figure 5 – Proposed erosion categories for soils and rocks based on velocity (Briaud, 2008).

Figure 6 – Proposed erosion categories for soils and rocks based on shear stress (Briaud, 2008).
PET (Pocket Erodometer Test)

Over the last 20 years, several tools have been developed in an effort to quantify the erodibility of a soil; however, they all require a significant amount of time for set up and sample preparation. The Pocket Erodometer Test (PET) is a simple test which can be performed in a few seconds with an inexpensive, compact, and very light instrument. The Pocket Erodometer is a regulated mini jet impulse generating device. The jet is aimed horizontally at the vertical face of the sample. The depth of the hole in the surface of the sample created by 20 impulses of water is recorded. The hole depth is compared to an erosion chart to determine the erodibility category of the soil. This erosion category allows the engineer to make preliminary decisions in erosion related work.

Many different options were considered during the development of the Pocket Erodometer including the most appropriate device, velocity range, direction of application, distance from the face of the sample, and repeatability from one person to another. The actual device chosen for the Pocket Erodometer measures 105 mm by 77 mm by 18 mm, has a nozzle velocity of approximately 8 m/s, and a nozzle hole diameter of approximately 0.5 mm. This velocity was selected because it showed measurable and varied erosion depths for a number of different soil samples, while keeping most of the sample intact for further testing.

It was important to obtain the nozzle exit velocity of each device tested during the development of the Pocket Erodometer. Figure 7 shows the calibration set up. The Pocket Erodometer is placed at a chosen height (around 1 m), aimed horizontally, and a water impulse is imparted. The particle motion equations are used:

\[ x = v_{0x} t \]  \hspace{1cm} (7)

\[ H = \frac{1}{2} gt^2 \]  \hspace{1cm} (8)

where \( x \) and \( H \) are defined on Figure 6, \( v_{0x} \) is the horizontal nozzle velocity, \( t \) is the time and \( g \) is the gravity acceleration. Eliminating \( t \) between Eq. (7) and (8) gives:
This procedure gives a reproducible determination of the nozzle velocity. The calibration can be run inside or outside, but variables such as wind which are neglected in the equations can affect the results. A table or other stable object can be used as a base for the Pocket Erodometer so that \( H \) is well known and constant throughout the calibration process. The Pocket Erodometer should be placed on the table and pointed in such a way that the water jet initially travels horizontally. The operator should squeeze the trigger 20 times at a rate of 1 squeeze per second. Because the water stream is not a single particle there will be some scatter in how far the water travels horizontally before hitting the ground (Figure 6). A mark should be made at the two ends of the majority of the water on the floor surface. The extreme outliers should be ignored. These end values of \( x \) should be averaged and used in Eq. (9).

\[
v_{0x} = \frac{x}{\sqrt{\frac{2H}{g}}}
\]  

To avoid having to plot the results from the PET in terms of erosion rate on the EFA erodibility chart while in the field, categories were developed based on the erosion depths for each PET. Figure 8 shows the PET depth ranges overlaid on the EFA erosion category chart. Each PET range corresponds to the category in which the EFA erosion function would lie.

The recommendations in Figure 8 are based on a limited number of PETs and should be used with caution until further tests are performed to corroborate these early results. It should be noted that, unlike the EFA erosion chart shown in Figure 7, the PET erosion chart (Figure 8) only contains five categories. The PET is not suitable for rock erosion testing. Soils exhibiting

**Figure 7 – Schematic of calibration dimensions.**
no noticeable erosion using the Pocket Erodometer should be further distinguished by testing them in the EFA or other appropriate erosion device.

Figure 8 – PET erosion depth ranges shown on EFA categories.

It is recommended that the calibration steps be taken before beginning each testing session to ensure a nozzle velocity of $8m/s \pm 0.5m/s$ for each test. The device should have a nozzle aperture of approximately $0.5 \text{ mm}$ and an impulse duration of $0.1s$ for each squeeze. If using a continuous device with the specified nozzle aperture and velocity, it should be run for $2 \text{ s}$ for each PET. The procedure of standard Pocket Erodometer (PE) is:

1. Place the sample horizontally either on a flat surface or by holding it in your hand. Note: The test cannot be run with the jet pointed vertically.
2. Smooth the surface to remove any uneven soil. You want to begin with a smooth and vertical surface, so that it is easy to measure the erosion depth.
3. Hold the Pocket Erodometer (PE) pointed at the smooth end of the sample, $50 \text{ mm}$ away from the face.
4. Keeping the jet of water from the PE aimed horizontally at a constant location, squeeze the trigger $20 \text{ times}$ at a rate of $1 \text{ squeeze per second}$, forming an indentation in the