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The EFA, Erosion Function Apparatus: An overview

Le EFA, Erosion Fonction Apperreie: Un résumé

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ABSTRACT
A new apparatus is described to measure the erosion function of a soil. The patented apparatus is called the EFA or Erosion Function Apparatus. The erosion function is the relationship between the hydraulic shear stress applied at the soil-water interface by the water flowing over the soil and the erosion rate of the soil. This erosion function can then be used to predict scour of soil by water.

RÉSUMÉ
On decrit un nouvel appareil pour mesurer la function d'erosion d'un sol. L'appareil s'appelle le EFA ou Erosion Fonction Appareil. La fonction d'erosion est la relation entre la contrainte au cisaillement appliquee par l'eau sur le sol a l'interface eau-sol d'une part et la vitesse d'erosion d'autre part. On peut se servir de cette fonction d'erosion pour faire des calculs d'erosion en general et d'affouillement des piles de ponts en particulier.

1 INTRODUCTION

The erosion rate of clean sands is very high and may be measured in meters per hour. For example a 5 meter deep hole can be created by a single flood around a bridge pier. On the other hand the erosion rate of rock is very slow and may be measured in millimeters per year. For example the Grand Canyon in the USA is about 1.6 km deep and took approximately 20 million years to develop; this leads to an average erosion rate of 0.08mm/yr. For a bridge pier built on clean sand, one needs only to consider the worst flood and calculate the scour depth for that flood because the erosion rate is so high that time is not a factor. For a bridge pier built in rock it is not economical to use the same calculations as for sand because the rate is so slow that even after say 100 years the scour depth in rock may be a very small fraction of the scour depth in sand.

The erosion rate of fine grained soils is intermediate between that of sand and that of rock. There is a need to predict that rate to estimate how large the scour depth will be at the end of the bridge design life. This prediction process starts by a measurement of the erosion function, which links the hydraulic shear stress τ applied at the water-soil interface to the erosion rate of the soil $\dot{z}$. The EFA (Erosion Function Apparatus) was developed to measure the $\dot{z}$ vs τ curve for a given soil.

2 THE EROSION FUNCTION APPARATUS

The EFA (Figs. 1 and 2) (Briaud et al. 1999 (a) and (b)) was conceived in 1991, designed in 1992, and built in 1993. The sample of soil, fine-grained or not, is taken in the field by pushing an ASTM standard Shelby tube with a 76.2 mm outside diameter(ASTMD1587).

One end of the Shelby tube full of soil is placed through a circular opening in the bottom of a rectangular cross section pipe. A snug fit and an O-ring establish a leak proof connection. The cross section of the rectangular pipe is 101.6 mm by 50.8 mm. The pipe is 1.22 m long and has a flow straightener at one end. The water is driven through the pipe by a pump. A valve regulates the flow and a flow meter is used to measure the flow rate. The range of mean flow velocities is 0.1 m/s to 6 m/s. The end of the Shelby tube is held flush with the bottom of the rectangular pipe. A piston at the bottom end of the sampling tube pushes the soil until it protrudes 1 mm into the rectangular pipe at the other end. This 1 mm protrusion of soil is eroded by the water flowing over it.

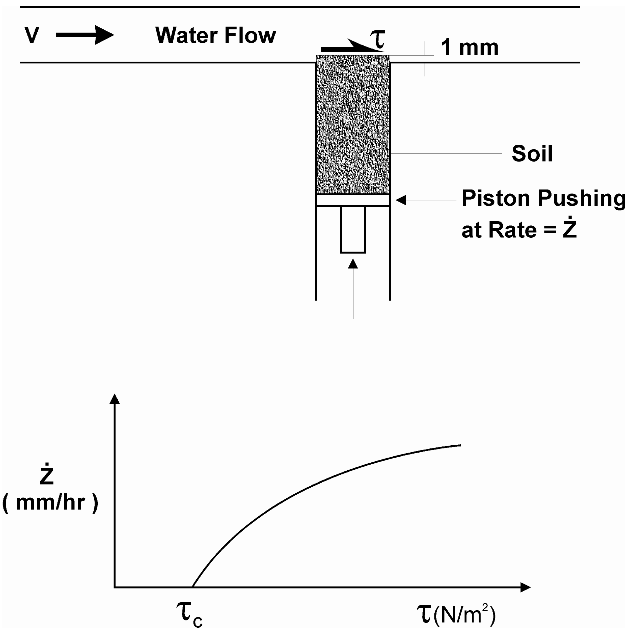

Figure 1. Schematic Diagram and Result of the EFA (Erosion Function Apparatus)

Figure 2. Photograph of the Erosion Function Apparatus

3 EFA TEST PROCEDURE

The procedure for the EFA test consists of

1. Place the sample in the EFA, fill the pipe with water, and wait one hour.
2. Set the velocity to 0.3 m/s.
3. Push the soil 1 mm into the flow.
4. Record how much time it takes for the 1 mm soil to erode (visual inspection through plexiglas window)
5. When the 1 mm of soil is eroded or after 30 minutes of flow whichever comes first, increase the velocity to 0.6 m/s and bring the soil back to a 1 mm protrusion.
6. Repeat step 4.
7. Then repeat steps 5 and 6 for velocities equal to 1.0 m/s, 1.5 m/s, 2 m/s , 3 m/s, 4.5 m/s, and 6 m/s.

The choice of velocity can be adjusted as needed to better the particular soil being studied.

4 EFA TEST DATA REDUCTION

The test result consists of the erosion rate $\dot{z}$ versus shear stress τ curve (Fig. 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.

$$\dot{z} = \frac{h}{t} \tag{1}$$

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 plexiglass window).

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

$$\tau = \frac{1}{8} f \rho v^2 \tag{2}$$

Where τ is the shear stress on the wall of the pipe, f is the friction factor obtained from Moody Chart (Fig. 3), ρ is the mass density of water (1000 kg/m3), and v is the mean flow velocity in the pipe. The friction factor f is a function of the pipe Reynold's number Re and the pipe roughness ε/D. The Reynold's number is v D/ν where D is the pipe diameter and ν is the kinematic viscocity of water $\left(10^{-6} m^2/s \; at \; 20^{\circ}C\right)$.

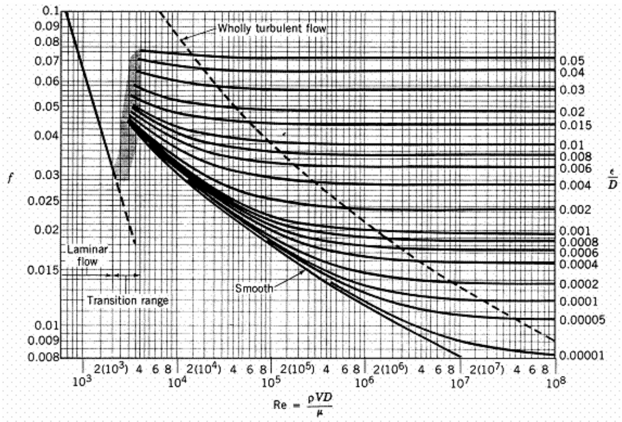

Fig. 3 - Moody Chart (reprinted with permission from Munson et al. 1990)

Since the pipe in the EFA has a rectangular cross section, D is taken as the hydraulic diameter D = 4A/P (Munson et al., 1990) 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:

$$D = 2ab/\left(a+b\right) \tag{3}$$

where a and b are the dimensions of the sides of the rectangle. The relative roughness ε/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 ε is taken equal to $0.5D_{50}$ where D_{50} 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 into the soil mass. During the test, it is possible for the soil surface to become rougher than just 0.5 D50; this occurs when the soil erodes block by block rather than particle by particle. In this case the roughness ε should be taken equal to the depth of the depression on the tested soil surface. Typical results are shown on Figure 4 for a sand and then a clay.

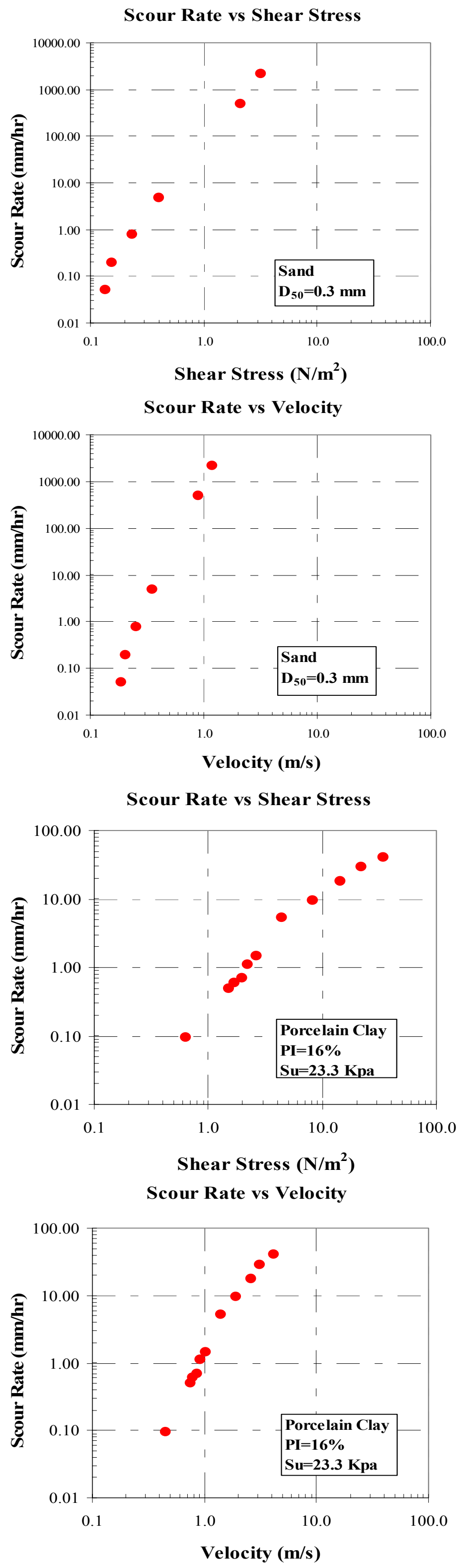

Figure 4. Example of Erodibility Functions

5 CONCLUSION

A patented apparatus called EFA is described to measure the erosion function ($\dot{z}$ vs τ curve) for a soil. It can be used for any soil or soft rock which can be cored or sampled in a 76.2 mm outside diameter tube. The EFA results can then be used to predict scour of soil by water. The SRICOS-EFA method is such a method (Briaud et al. 2001(a) and (b)); the details of that method and the free software automating the calculations can be found at http://ceprofs.tamu.edu/briaud/sricos-efa.htm

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