TEXAS TRANSPORTATION INSTITUTE
THE TEXAS A&M UNIVERSITY SYSTEM

Project Summary Report 2937-S
Project 7-2937: Scour Rate of Cohesive Soils

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PROJECT SUMMARY REPORT

# SRICOS: Prediction of Scour Rate at Bridge Piers

Scour—erosion of the stream bed—causes serious damage to bridges every year

The scour depth created by a river around a bridge pier is currently calculated using the HEC-18 equation. This equation was developed for piers founded in sand, and there is a sense that in clay the depth of scour is not as large. The purpose of this study was to develop a method for clays, silts, and dirty sands.

## What We Did . . .

The SRICOS method was developed on the basis of flume tests, numerical simulations, and erosion testing of the soil. A new apparatus called the EFA (Erosion Function Apparatus, Figure 1) was built for departments of transportation (DOTs) to test the soil for erodibility. The following is a summary of the recommended method that is detailed in Briaud et al. (1999[a], 1999[b], 2001[a], 2001[b]).

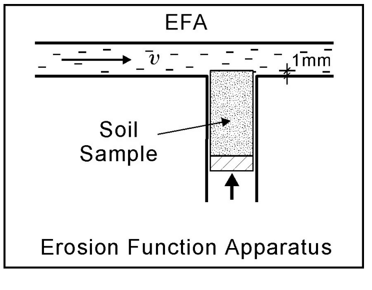



Figure 1: EFA built to test the soil for erodibility

## What We Found . . .

In the case of cohesive soils, the scour rate can be thousands of times slower than in the case of cohesionless soils. Cohesive soils include silts and clays.

According to the unified soil classification system, silts and clays are soils which have more than 50 percent by weight of particles passing the 0.075 mm sieve opening. Silt-size particles are between 0.075 mm and 0.002 mm, and clay-size particles are smaller than 0.002mm. Cohesive soils are not classified by grain size but instead by their degree of plasticity, which is measured by the Atterberg limits.

Because cohesive soils scour so much slower than cohesionless soils, it is necessary to include the scour rate in the calculations. Indeed, while one flood may be sufficient to create the maximum scour depth $z_{max}$ in cohesionless soils, the scour depth after many years of flood history at a bridge in cohesive soil may be only a fraction of $z_{max}$. The scour rate effect in cohesive soils is measured by the erosion rate versus shear stress curve (Figure 2) that can be used to calculate the reduction in scour depth in the case of cohesive soils. The erosion rate $\dot{z}$ is defined as the vertical distance scoured per unit of time and is conveniently quoted in mm/hr. The shear stress $\tau$ is the shear stress imposed at the water soil interface and is given in $N/m^2$.

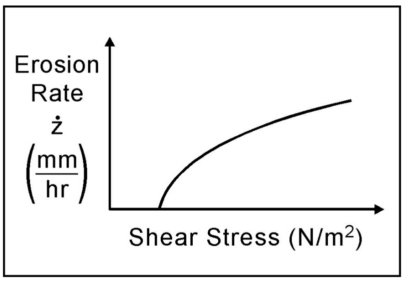



Figure 2: Erosion function

The $\dot{z}$ versus $\tau$ curve is a measure of the erodibility of the soil. Typically the erosion rate $\dot{z}$ is zero until the critical shear stress $\tau$ is reached and then $\dot{z}$ increases as $\tau$ increases. The $\dot{z}$ versus $\tau$ curve can be measured with the EFA (Briaud et al., 1999[a], Briaud et al., 2001[a]). In the EFA, a soil sample is eroded by water flowing over it. The sample is collected from the site in a standard thin-wall steel tube, placed through the bottom of a rectangular cross section pipe, and a 1 mm protrusion is eroded over time.

Once the $\dot{z}$ versus $\tau$ curve is obtained, the method to predict the pier scour depth as a function of time proceeds as follows. First, the maximum shear stress $\tau_{max}$ around the bridge pier is calculated (Briaud et al., 1999)[a], Briaud et al., 2001[b]):

**(1)**

$$\tau_{max} = 0.094\, \rho v^2 \left( \frac{1}{\log Re} - \frac{1}{10} \right)$$

where $\rho$ is the density of water, $v$ the mean approach velocity, and Re the pier Reynolds number. Second, the initial scour rate $\dot{z}_i$ corresponding to $\tau_{max}$ is read on the $\dot{z}$ versus $\tau$ curve.

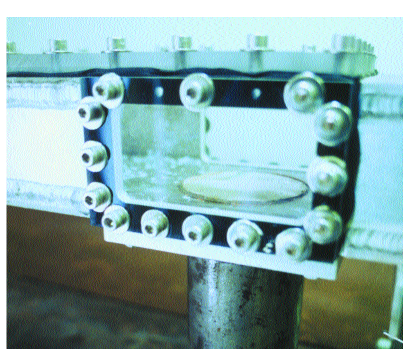
Third, the maximum depth of scour $z_{max}$ is calculated (Briaud et al., 1999)[a]):

**(2)**

$$z_{max}(mm) = 0.18\ Re^{0.635}$$

where Re is the pier Reynolds number. Note that equation (2) gives a value of $z_{max}$ that is very close to the one for cohesionless soils. Indeed, it was found that the maximum depths of scour in clays and in sands were approximately the same in flume experiments. In those same experiments, however, it was found that the scour hole in clay developed to the side and in the back of the pier and not in the front of the pier. This indicates that, for scour in clay, the front of the pier may not be the best place to install monitoring equipment.

Fourth, the equivalent time $t_{eq}$ is defined as the time over which the design velocity $v_{des}$ would have to be applied for the depth of scour z to be equal to the depth of scour reached after the hydrograph spanning the design life of the bridge $t_{life}$ has been applied. The time $t_{eq}$ is calculated as (Briaud et al., 1999[a]):



A 1 mm protrusion is eroded over time in the EFA

**(3)**

$$t_{eq}(hrs) = 73\,(t_{life}(years))^{0.126}(V_{des}(m/s))1.706(\dot{z}_i(mm/hr))^{-0.20}$$

Fifth, the scour depth z versus time $t$ curve is given by:

**(4)**

$$z = \frac{t}{\frac{1}{\dot{z}_i} + \frac{t}{z_{max}}}$$

and the depth of scour at the end of the design life of the bridge is calculated by using equation (4) with the $t_{eq}$, $\dot{z}_i$, and $z_{max}$ values obtained from equation (2) and (3) and from the erodibility curve. The following example (Figure 3) illustrates the procedure.

### Example Calculation

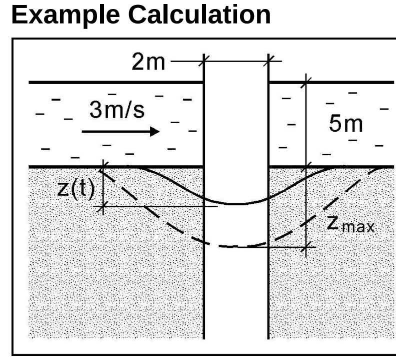



Figure 3: Example pier

A bridge is to be built in a cohesive soil. The bridge pier is 2 m in diameter, the water depth is 5 m deep, the design velocity is 3 m/s, and the design life of the bridge is 75 years.

The erodibility curve has been measured by testing a soil sample

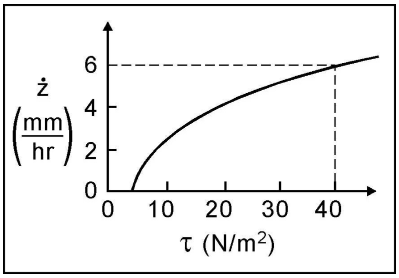



Figure 4: Example erosion function from EFA test

from the site in the EFA that gave the curve shown in Figure 4. The maximum shear stress around the pier before scour begins is calculated:

$$\tau_{max} = 0.094 \times 1000 \times 3^2 \left( \frac{1}{\log \frac{3x2}{10^{-6}}} - \frac{1}{10} \right)$$

$$\tau_{max} = 40.2\ N/m^2$$

The initial rate of scour $\dot{z}_i$ is read on the $\dot{z}$ versus $\tau$ curve for the $\tau_{max}$ value.

$$\dot{z}_i = 6\ mm/hr$$

Then the maximum depth of scour is calculated:

$$z_{max} = 0.18 \times \left(\frac{3x2}{10^{-6}}\right)^{0.635} = 3626\ mm$$

The equivalent time $t_{eq}$ is given by:

$$t_{eq} = 73 \times 75^{0.126} \times 3^{1.706} \times 6^{-0.20} = 572.7\ hrs$$
$$= 23.9\ days$$

The depth of scour after 75 years of flow around that bridge pier is estimated as:

$$z = \frac{23.9 \times 24}{\frac{1}{6} + \frac{23.9 \times 24}{3626}} = 1759\ mm$$

In this case, the scour depth after 75 years (1759 mm) is approximately 50 percent of the maximum scour depth (3626 mm).

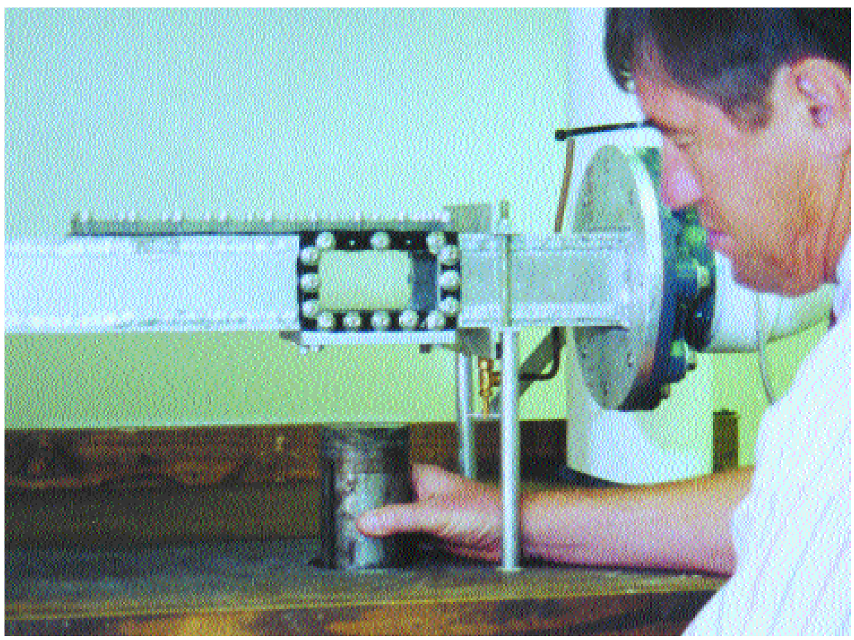
It is also possible to make predictions by applying a detailed velocity history over the design life of the bridge if one is available. This prediction requires the use of a computer program that can also consider the case of a layered soil system (Briaud et al., 1999[a], Briaud et al., 2001[b]). The limitation of this method is that it is for circular bridge piers and for water depth over pier diameter ratios larger than 2. Research is continuing to cover more complex cases.

## The Researchers Recommend . . .

DOTs which have bridges over water with piers founded in cohesive soils (clays, silts, dirty sands) can improve the accuracy of pier scour predictions by using this new method (SRICOS) instead of the HEC-18 equation. As shown for eight bridges in Texas, SRICOS generally leads to smaller calculated scour depths and compares much better to measured scour depths than HEC-18.

The following steps need to be taken in order to implement the results of this project:

- TxDOT purchases three EFAs at cost from the Texas Transportation Institute (TTI) and places them in selected district laboratories.
- TTI trains the district laboratory engineers on how to use the EFA, including data reduction.
- TTI transforms the SRICOS program into a user-friendly program (Windows® environment).
- TTI teaches the district laboratory engineers how to use the SRICOS program.



Erosion Function Apparatus in use

## For More Details . . .


- Briaud, J.-L., Ting, F. C. K., Chen, H. C., Gudavalli, R., Perugu, S., Wei, G., 1999 (a), "SRICOS: Prediction of Scour Rate in Cohesive Soils at Bridge Piers," *Journal of Geotechnical Engineering*, Vol. 125, No. 4, April 1999, pp. 237-246, American Society of Civil Engineers, Reston, Virginia, USA.
- Briaud, J.-L., Ting, F. C. K., Chen, H. C., Gudavalli, R., Kwak, K., Philogene, B., Han, S. W., Perugu, S., Wei, G., Nurtjahyo, P., Cao, Y., Li, Y., 1999 (b), "SRICOS: Prediction of Scour Rate at Bridge Piers," Report 2937-1. Texas Department of Transportation, Texas A&M University, Civil Engineering, College Station, Texas 77843-3136, USA.
- Briaud, J.-L., Ting, F. C. K., Chen, H.C., Cao, Y., Han, S. W., Kwak, K.W., 2001(a), "Erosion Function Apparatus for Scour Rate Predictions," *Journal of Geotechnical Engineering*, Vol. 127, No. 2, February 2001, pp. 105-113,American Society of Civil Engineers, Reston, Virginia, USA.
- Briaud, J.-L., Chen, H. C., Kwak, K. W., Han, S. W., Ting, F. C. K., 2001(b), "Multiflood and Multilayer Method for Scour Rate Prediction at Bridge Piers," *Journal of Geotechnical Engineering*, Vol. 127, No. 2, February 2001, pp. 114-125, American Society of Civil Engineers, Reston, Virginia, USA.



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## TxDOT Implementation Status January 2001

TxDOT believes the SRICOS Method which predicts the scour rate at bridge piers will be a useful hydraulic design tool for TxDOT engineers.

Scour techniques currently focus on cohesionless soils and ultimate scour depth. The research demonstrated that the ultimate scour depth of cohesive soils (clays) is the same as that for the scour rate of cohesionless soils (sands and silt). However, the research also clearly demonstrated that the scour rate of cohesive soils can be considerably longer than that of cohesionless material. Therefore, effective scour depth over the design life of a structure in cohesive soils can be considered "negligible" in many cases.

The researcher is pursuing a patent on a new apparatus called the Erosion Function Apparatus which was used in the research to test the erodibility of both cohesionless and cohesive soils.

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