
Utilization of a New Erosive Shear Stress Technique

J. F. HARP, Department of Civil Engineering
and Environmental Sciences
University of Oklahoma, Norman

SYNOPSIS

The laboratory measurement of erosive shear stress has proven to be very difficult except in a few simple cases where it can be deduced from a known pressure drop. New methods of measuring erosive boundary shear stresses are in constant demand. There has been many rather unfruitful ideas and complicated gadgetry in the history of the problem. This paper presents the application of a very simple method of measuring the boundary shear stresses when the pressure gradient is zero. The boundary roughness is a factor which has caused many past failures of other techniques. This method accounts for roughness and other previously unsurmountable handicaps.

INTRODUCTION

Boundary shear techniques have been slow to develop because of the inabilities to determine small-magnitude pressure differentials. Recent advances in this field of endeavor have furnished the impetus to revaluate older problems and subsequent solutions.

In 1954, Preston utilized the simple technique of measuring the local surface resistance by means of a Pitot tube resting on the boundary of a smooth surface. The method is based on the assumption of an inner law relating the local shear to the velocity distribution near the wall. Using the pressure drop in a pipe to calibrate the instrument, Preston obtained equations relating the intensity of shear to the Pitot tube reading for the case of the laminar sublayer enveloping the tube and for the case of the tube in the turbulent boundary layer of a smooth surface. His calibrations give an empirical relationship which is apparently quite reliable. Hsu (1955) extended the Preston shear method to cases where an adverse pressure gradient exists. He made an analysis using the one-seventh power velocity distribution in the derivation of his turbulent flow equation at moderate values of Reynolds numbers. In the laminar sublayer he used a linear velocity distribution. Then Laursen and Hwang (1962) extended the method even further to be applicable to rough boundaries. Both Hsu, and Laursen and Hwang, have substantiated the Preston shear technique to the point where it is not only feasible, but have virtually opened the door to a whole new field of measurements that heretofore have not been possible.

METHOD OF APPLICATION

To apply this technique a small Pitot-static tube is placed on the boundary of the surface, smooth or rough, where the erosive shear stress is to be measured. The pressure differentials relate directly to the shear stress magnitude and one has but to refer to the calibration curves of Preston, Hsu, or Laursen and Hwang for the appropriate magnitude. According to Hsu (1955) the pressure gradient and tube configuration are of no consequence.

We shall take the smooth-and-rough boundary configuration conditions separately for the benefit of those readers who are not familiar with the new technique. Then we shall extend slightly the work of Laursen and Hwang whereby the application is made to open channels.

Case 1. The Smooth Boundary—It can be shown that the dynamic pressure acting on the end of a surface Pitot tube is related to the boundary shear stress by Equation (1): $(p - p_0)\, \pi a^2 = 1/2\, g \int_A v^2\, dA$.

Now, two conditions arise. First, the tube is totally submerged within the laminar sublayer, and second, the tube is totally outside the laminar sublayer. See Figure 1 for the configuratory details. For the condition of total submergence, the law of the wall is expressed $v/v_* = (v_* y)/\nu$ which when substituted into equation (1) gives Equation (2): $T_0\, d^2/4\, \rho\, \nu^2 = 8/(4 + t^2)^{1/2}\, [(p - p_0)d^2/\rho\, \nu^2]^{1/2}$

When the tube is outside the laminar sublayer the velocity distribution can be expressed in the form of a power function as $v/v_* = ky^{1/7}$ and when appropriately substituted into equation (1) yields Equation (3): $T_0\, d^2/5\, \rho\, \nu^2 = k\, [(p - p_0)\, d^2/4\, \rho\, \nu^2]^{7/8}$

Both of these equations are plotted in Figure 2. The experimental verification of these relationships is such that the data falls exactly on the analytically predicted curves. This is evidence that the basic assumptions are valid.

Case II. The Rough Boundary—The difficulty in rough channel configurations is that the zero point of origin is unknown. Fortunately, the location of exact datum is not required in this particular analysis. This is indicated in Figure 3. Equation (1) also applies here. When the tube is totally within the laminar sublayer, Equation (2) will apply since classical analysis reveals that shear stresses are constant where velocities are linear. Now, when the laminar sublayer is thin enough that the tube is positioned beyond it the position of the tube becomes important. If the rough-configuration velocity distribution is substituted into equation (1), the solution becomes Equation (4):

$$[(p - p_0)/T_0] = 16.531\, [\ln 30\, h/e]^2 - \ln\,(30\, h/e)\, [0.25\, (a/h)^2 + 0.0625\, (a/h)^4 + 0.0260\, (a/h)^6 + \ldots.] + [0.25\, (a/h)^2 + 0.1146\, (a/h)^4 + 0.0586\, (a/h)^6 + \ldots.]$$

When the solution for the rough-boundary case is plotted we have a vivid picture of the physical relationship between the appropriate parameters. This is shown in Figure 4.

When the experimental values are plotted as a ratio of the analytical values, a curve results as shown in Figure 5.

Now, to extend the presentation just made to open channels, we proceed as follows: from Figure 4, a family of curves can be derived for various roughnesses.

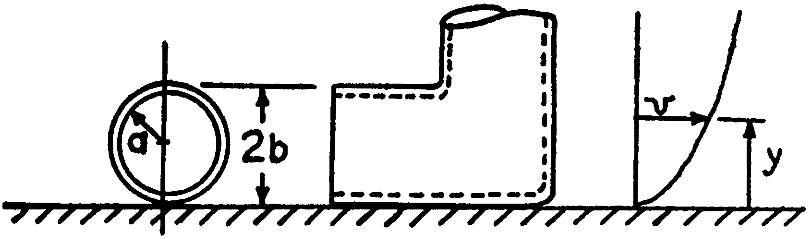

Figure 1

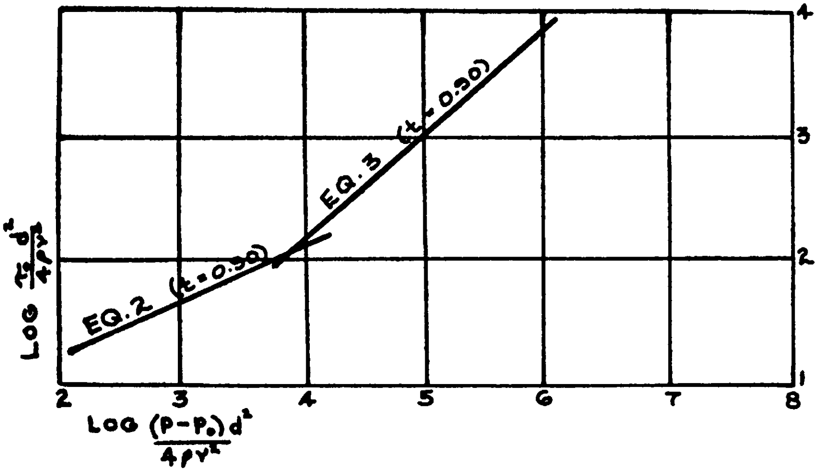

Figure 2

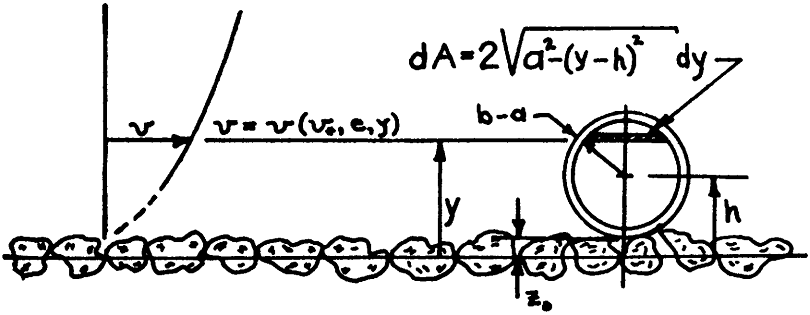

Figure 3

It should be pointed out that this technique is applicable only to fixed boundaries. The critical erosive shear stress can be measured only at the instant just before the incipient motion occurs. The method should be well suited for field studies since a number of battery-powered electronic indicators are commercially available.

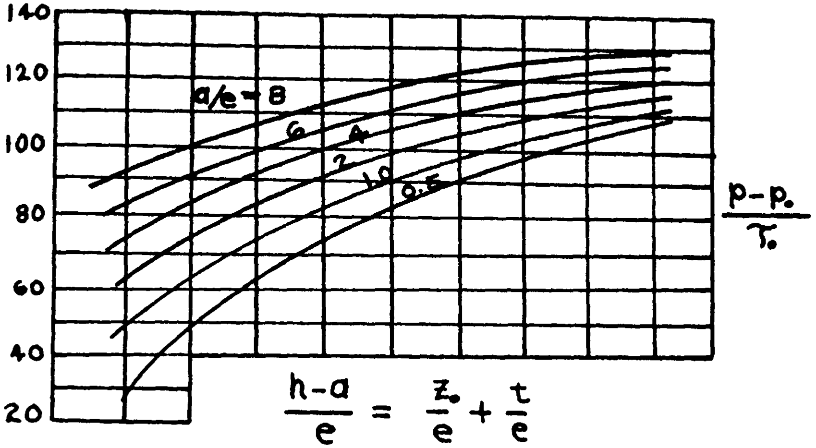

Figure 4

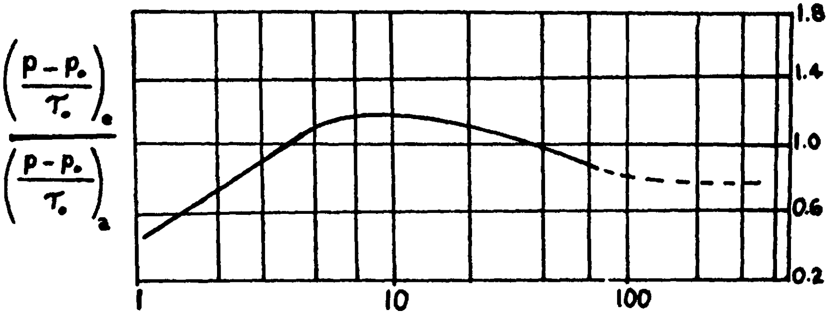

Figure 5

NOTATIONS

A	Area of stagnation tube opening
a	Inner radius of stagnation tube
b	Outer radius of stagnation tube
h	Height of center of stagnation tube from zero datum
e	Sand roughness
p	Stagnation pressure
p_0	Wall static pressure
ρ	Fluid density
T_0	Shear stress
t	Thickness of the pitot tube
v	Velocity at distance y from wall

v_*	Shear velocity = $\tau_0/\rho)^{1/2}$
y	Distance from zero datum
z_0	Height of bottom of stagnation tube from zero datum

LITERATURE CITED

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