VELOCITY AND STAGE DATA COLLECTED IN A LABORATORY FLUME FOR WATER-SURFACE SLOPE DETERMINATION USING A PIPE MANOMETER

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U.S. Geological Survey (USGS) hydrologists and ecologists are conducting studies to quantify vegetative flow resistance in order to improve numerical models of surface-water flow in the Everglades. For use in the models, vegetative flow resistance must be expressed in terms of measurable parameters that describe the flow and the vegetation. These parameters include the flow velocity through the vegetation, the water depth, the slope of the water surface, and the type, physical characteristics, and density of the vegetation.

A unique pipe manometer (Fig.1) was developed for the local measurement of water-surface slopes on the order of 1 cm/km, as water-surface slopes in the Everglades are perhaps the most difficult flow-resistance parameters to measure. Conventional surveying techniques do not have the accuracy to resolve such small slopes.

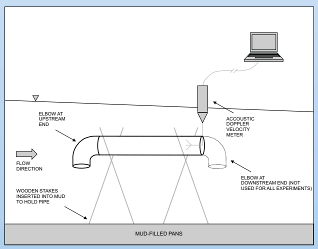

Figure 1. Laboratory configuration of pipe manometer. Not drawn to scale.

According to laminar flow theory, the centerline velocity of water flowing in a pipe is a function only of the pipe geometry, the water viscosity, and the difference in water surface elevation over the length of the pipe. Therefore, a very precise measurement of centerline velocity obtained inside the pipe manometer should serve as a unique proxy for water surface slope in the direction of the pipe axis.

In order to investigate the potential applicability of this theoretical relationship and to empirically calibrate the pipe manometer, water-surface elevation and pipe centerline velocity data were measured simultaneously in a set of experiments carried out at the USGS Hydraulic Laboratory Facility at Stennis Space Center, Mississippi. Experiments were conducted in a 60-m-long, 2-m-wide, 1.2-m-deep tilting flume. Mud-filled pans were fit tightly into the bottom of the flume and 17,000 sticks (1 cm x 2 cm x 120 cm) were inserted into the mud in a regular pattern to simulate vegetated conditions. A constant head tank controlled discharge at the upstream end and metal plates were added or removed at the downstream end to control the water depth. Before each set of experiments, the head was adjusted at the upstream end of the flume to create the desired discharge and the flow was allowed to reach steady state.

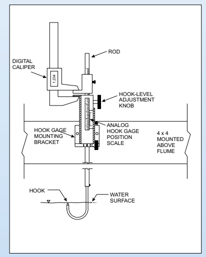

Figure 2. Laboratory configuration of hook gage

Eleven sets of concurrently measured water-surface slope and pipe centerline velocity data were collected. Each set of experiments consisted of two independent water-surface slope measurements and approximately twenty pipe centerline velocity measurements.

In order to accurately measure the very low-gradient water-surface slopes, hook gages (Fig.2) equipped with digital calipers precise to 0.01 mm were installed at five locations along the east and west sides of the flume (Fig. 3). Each slope calculation was based on sixty independent stage measurements (six readings at each gage location)and was referenced to an established level-water datum.

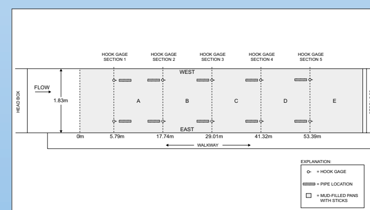

Figure 3. Flume layout in plan view. Not drawn to scale.

For each set of experiments, pipe centerline velocity measurements were collected at five locations along the east and west sides of the flume (Fig. 3) using two pipe manometers. Both pipe manometers were constructed from a 2.4-m-long, 7.6-cm.diameter piece of PVC pipe with a short elbow of the same diameter at the upstream end. One of the pipe manometers had an additional elbow at the downstream end. For each velocity measurement, the manometer was located approximately 0.46m from the wall of the flume, aligned parallel to the directions of flow, and positioned horizontally just below the water surface with the elbow(s) pointing down. Each manometer was supported by wooden stakes inserted into the mud in the bottom of the flume in an "X" configuration with the manometer resting in the top vertex of the "X" (Fig.1).

Pipe centerline velocity was measured by inserting an acoustic Doppler velocity (ADV) meter equipped with a sideward-looking probe into the downstream end of the pipe (Fig.1). The ADV meter has a rated precision of 0.1 mm/s in a range of 0 to 10 cm/s. Velocity components in three dimensions were collected at 10 Hz in bursts of two-minute duration producing a 1200-point time series for each sample.

Along with velocity, two 3-component signal quality statistics, correlation and signal-to-noise ratio, were measured for each data point. These signal quality statistics were used to remove suspect data points from the pipe centerline velocity calculations. In total, 316 our of 332 velocity measurements (95%) passed the signal quality test.

Figure 4 shows that pipe centerline velocity and the square root of water-surface slope show a distinct linear relationship for the pipe manometers used in these experiments. This is not what laminar pipe-flow theory predicts, but is a robust relationship that can be exploited to determine water-surface slope in the Everglades. Thereby, allowing one of the most difficult parameters in the vegetative-resistance-to-flow formulations to be measured.

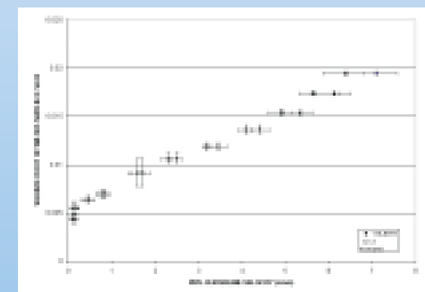

Figure 4. Relation of pipe centerline velocity to the square root of the water-surface slope for one- and two-elbow pipe manometer configurations. (Error bars indicate the spread of the velocity and slope data

Future work will focus on determination of pipe-geometry-characteristic ranges for which pipe manometer measurements will agree with laminar pipe-flow theory. Once these ranges are identified, pipe manometers other than those identical to the pipes used in this experiment can be used in the field.

Additional information regarding the measurement and processing of data in this experiment can be obtained from Dr. Harry Jenter (hjenter@usgs.gov). A full reporting of the experiment can be found in:

Lee, J.K.; H.M.Visser; H.L.Jenter and M.P. Duff. 2000. Velocity and Stage Data Collected in a Laboratory Flume for Water-Surface Slope Determination Using A Pipe Manometer. U.S. Geological Survey Open-File Report 00-393. 28 pages.