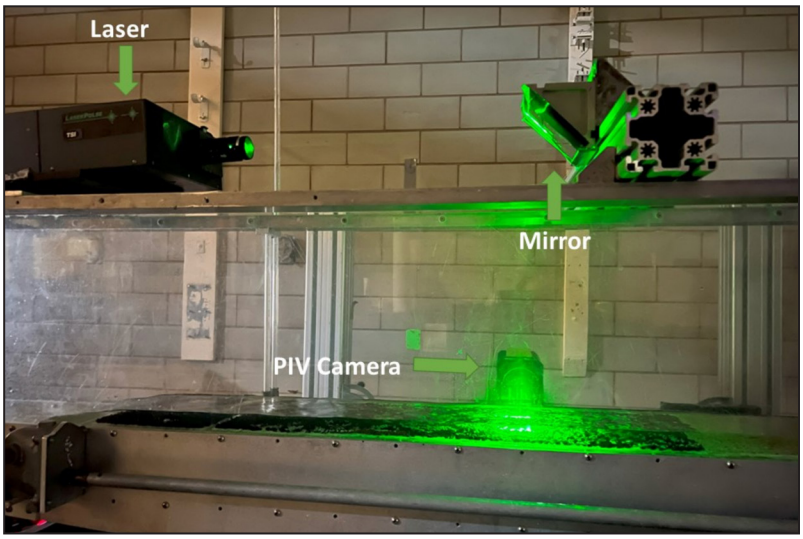
MOUNTAIN-PLAINS CONSORTIUM

RESEARCH BRIEF | MPC 24-567 (project 688) | October 2024

Response of Bed Shear Stress in Open-Channel Flow to a Sudden Change in Bed Roughness



the ISSUE

Sudden changes in bed roughness can occur in many situations in open-channel flows. These changes can occur naturally in a river or stream due to sediment sorting or near a river crossing from that of the original riverbed to that of the riprap protection and vice versa. In the laboratory, a flume with a smooth bottom can abruptly change to a sediment bed in the test section where sediment erosion is being studied. In these situations, the response of flow characteristics, such as turbulence intensity and bed shear stress, to the roughness transition has an engineering interest and needs to be understood. An improved understanding of these factors will lead to enhanced designs for highway infrastructure components such as culverts and bridge abutments and piers that are better able to withstand stresses and erosion.

the RESEARCH

Laboratory experiments were conducted in a 0.15-meter-wide, 0.3-meter-deep, and 1.825-meter-long tilting flume with a flow capacity of 4.5 liters per second. The channel was divided into an upstream and a downstream section with a smooth bed made of acrylic and a rough bed made of glass beads, sand, or gravel. Five different flow conditions were created by adjusting the flow discharge and channel slope, and included both subcritical and subcritical flows on rough-to-smooth and smooth-to-rough transitions. For each flow condition, water depth was measured using a point gage mounted on an instrument carriage to determine the water surface profile, and the two-dimensional velocity field was measured on a vertical plane along the centerline of the flume at several locations from upstream to downstream using a particle image velocimetry system. The bed shear stress was obtained from the measured velocity distributions using four different methods: depth-slope, wall function, logarithmic law, and Reynolds stress extrapolation. The results were used to compare the different methods for measuring bed shear stress in open-channel flows and to understand the effects of water surface profile and bed roughness on the development of the bottom boundary layer and bed shear stress through channel transitions.

MOUNTAIN-PLAINS CONSORTIUM REGION 8

A University Transportation Center sponsored by the U.S. Department of Transportation serving the Mountain-Plains Region. Consortium members:

Colorado State University
North Dakota State University
South Dakota State University
University of Colorado Denver
University of Denver
University of Utah
Utah State University
University of Wyoming

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Project Title

Response of Bed Shear Stress in Open-Channel Flow to a Sudden Change in Bed Roughness

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the FINDINGS

This study found that the water surface profile played an important role in the development of bed shear stress through roughness transitions in open-channel flows. When the flow depth was uniform downstream of the transition, the bed shear stress response was not very different from flows without a free surface. In both rough-to-smooth and smooth-to-rough transitions, the bed shear stress adjusted promptly to the new bed condition. In cases where the flow depth was either increasing or decreasing after the transition, the bed shear stress continued to evolve until the flow depth became uniform. This study also found that the evolution of bed shear stress in the developing boundary layer downstream of a smooth-to-rough transition may be determined from the measured velocity profile using the logarithmic law, provided that a logarithmic region exists near the bed and the equivalent roughness height is determined experimentally.

the IMPACT

This study will lead to a better understanding of the flow characteristics and bed shear stress developed when free-surface flow in an open channel suddenly encounters a different type of bed surface. This situation can occur in laboratory studies of sediment erosion and scour in a flume, and in rivers and streams where changes in bottom roughness are caused by sediment deposition or erosion or by the installation of scour countermeasures. In both cases, accurate determination of bed shear stress exerted by the flowing water is critical for reliable estimation of soil erosion and scour, which is important for the design and protection of highway infrastructure such as bridges and culverts.

For more information on this project, download the Main report at https://www.ugpti.org/resources/reports/details.php?id=1241

For more information or additional copies, visit the Web site at www.mountain-plains.org, call (701) 231-7767 or write to Mountain-Plains Consortium, Upper Great Plains Transportation Institute, North Dakota State University, Dept. 2880, PO Box 6050, Fargo, ND 58108-6050.